Eighth EARSAM Regional Workshop on Sorghum and Millets

Citation: Mukuru, S.Z., and King, S.B. 1995. Eighth EARSAM Regional Workshop on Sorghum and Millets, 30 Oct–5 Nov 1992, Wad Medani, Sudan. (In En. Abstracts in En, Fr, Es.) Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 228 pp. (An ICRISAT semi-formal publication issued for limited distribution)

Abstract

The Eighth Eastern Africa Regional Workshop on Sorghum and Millets brought together scientists working on all aspects of sorghum and millets research in eastern Africa. A total of 42 papers were presented on: improvement and production of sorghum and millets, agronomy and resource management, crop protection, and utilization and socio-economics. In addition, the proceedings include reports of discussions and workshop recommendations.

Résumé

Le huitième atelier EARSAM sur le sorgho et les mils, 30 octobre–5 novembre 1992, Wad Medani, Soudan. L'atelier a réuni des chercheurs oeuvrant sur tous les aspects de recherche sur le sorgho et les mils en Afrique orientale. Quarante-deux communications ont été présentées sur: l'amélioration et la production du sorgho et des mils, l'agronomie et l'exploitation des ressources, la défense des cultures, ainsi que l'utilisation et la socio-économie. Ces comptes rendus comprennent également des procès verbaux des discussions et les recommandations de l'atelier.

Resumen

Octavo Taller EARSAM sobre Sorgo y Mijo, 30 Oct-5 Nov de 1992, Wad Medani, Sudán. El Octavo Taller de la Africa del Este sobre Sorgo y Mijo reunió a los científicos que están trabajando en los diversos aspectos de la investigación sobre sorgho y mijo en la Africa del este. Se presentaron un total de 42 ponencias sobre: la mejora y la producción de sorgo y mijo, la agronomía y el manejo de recursos, la protección de la cosecha, y la utilización y la socioeconomía. Además, las actas incluyen informes de las discusiones así como las recomendaciones del taller.

Eighth EARSAM Regional Workshop on Sorghum and Millets

30 Oct–5 Nov 1992
Wad Medani, Sudan

Edited by

S Z Mukuru
and
S B King

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India

1995

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Opening Address

His Excellency Mr Abd Elaziz Abd Elmoniem
Ministry of Agricultural, Natural Resources and
Animal Wealth, Central State, the Sudan

Distinguished ladies and gentlemen,

It gives me great pleasure to address this honorable gathering in this conference hall of the Agricultural Research Corporation (ARC) which has remained, through time, a minaret for the exchange of ideas and scientific findings. I am greatly pleased that the subject of your workshop will be on major crops not only in the Sudan, but also in our whole region. Indeed, sorghum and millets are major staple food crops for the majority of our people in eastern Africa.

Mr Chairman, may I take this opportunity to welcome our honorable guests from neighboring countries and the International and Regional Organizations working in our country. We, in Africa, have common goals and share similar problems. Our continent has been facing widespread recurrent drought, which resulted in food shortages in many areas. *Striga* is devastating many areas of otherwise productive land. Your meeting comes at a most opportune time to look into these problems, to find ways and means to mitigate the harmful effects of these constraints, and attain more sustainable yields. Ladies and gentlemen, in your deliberations it is pertinent, not only to discuss results and register findings, but also to evaluate the impact of your findings on crop production.

In the Sudan we give research all support and backing because it is the only way for crop improvement and development. Several improved sorghum varieties and hybrids have been generated and rendered available to the farmer through research. To maximize yields, ARC has developed recommended packages for all crops.

Mr Chairman, the Sudan Government welcomes with appreciation, the existing and continuing collaboration between our national research organization and the International Organizations for the improvement of grain production in the country. Previous collaboration between ICRISAT and ARC yielded the first Sudanese sorghum hybrid, which revolutionized crop production in the Sudan.

The establishment of interlinks greatly enhances technology development, exchange of knowledge and genetic resources. Sudan has a great wealth of sorghum germplasm available to neighboring and interlinked scientists. your distinguished gathering will pin down the most pressing priorities for future research. The rainy season has been

Ladies and gentlemen, I know that you have a lengthy and busy program to discuss and evaluate. I am sure that your distinguished gathering will pin down the most pressing priorities for future research. The rainy season has been very good, resulting in good sorghum crop. I hope that our guests will be given a chance to visit production areas, exchange ideas with our field people and interact with farmers to acquaint themselves with production patterns in the country.

Before I conclude, I would like to thank EARSAM for choosing the Sudan to hold this workshop and for the financial contribution offered by the organization. I wish you all a happy stay in the Sudan and a safe journey back home.

Objectives of the Workshop

S.Z. Mukuru[1]

On behalf of the Organization of African Unity (OAU)/Semi-Arid Food Grain Research and Development (SAF-GRAD)/International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and Eastern Africa Regional Sorghum and Millets (EARSAM) Network, I wish to welcome you all to this 8th EARSAM Network Regional Workshop, which is being held for the first time in the Sudan. I also wish to thank you all for having accepted to attend and participate in this Workshop.

The EARSAM Network brings together National Agricultural Research Systems (NARS) of eight countries in eastern Africa—Ethiopia, Burundi, Kenya, Rwanda, Somalia, Sudan, Tanzania, and Uganda. All these NARS in the eastern Africa region realize and appreciate the comparative advantage of working together to find solutions to various constraints limiting sorghum and millet production in the region. The network uses the available scientific manpower, skills, and research facilities in the NARS, by developing collaborative research with the strong NARS taking the lead. The Network also promotes and facilitates easy exchange of germplasm, technologies, and research information among the NARS in the region.

The EARSAM Network held a series of workshops for sorghum and millet research in eastern Africa. These were started in 1982 and have continued until today. The last seven workshops were held in Ethiopia (1982), Rwanda (1985), Tanzania (1984), Uganda (1985), Burundi (1986), Somalia (1988), and Kenya (1990). All these Workshops were well attended by sorghum and millet researchers from the NARS in eastern Africa as well as sorghum and millet researchers from international and regional organizations. These Workshops provided an excellent opportunity for scientific interaction and exchange of research information, and fostered a source of fraternity among the sorghum and millet researchers in the region.

This Eighth EARSAM Network Regional Workshop is being attended by 34 sorghum and millet researchers from the Sudan, Ethiopia, Kenya, Tanzania, Uganda, and Burundi. Unfortunately, participants from Somalia and Rwanda are unable to be with us today due to circumstances beyond their control. In addition, this Workshop is also being attended by scientists from regional and international organisations and from nongovernmental organisations in the region and outside.

During this Workshop, a total of about 40 scientific papers will be presented, covering a wide range of disciplines: Breeding, Agronomy and Resource Management, Plant Protection and Utilization, and Socioeconomics. I hope that these papers will stimulate maximum scientific interaction and discussions.

There will also be opportunities for you to visit Agricultural Research Corporation research projects and sorghum production in the Gaderef areas. The Sudanese National Sorghum Program is one of the strongest in the region and has carried out effective research and generated relevant and affordable technologies to farmers. It has also played a leading role in the activities of the EARSAM Networks. I therefore urge you to interact with the Sudanese scientists and observe and discuss the research technologies that they have developed for the farmers especially in *Striga* and drought research, and if possible, to transfer it to farmers in your countries.

The objectives of the Eighth EARSAM Regional Workshop on Sorghum and Millet Improvement in eastern Africa are to:

1. Provide an opportunity for sorghum and millet researchers in the region to interact and share their knowledge, expertise, and experience among themselves and with other scientists from the regional and international organizations.
2. Foster a source of fraternity and regional responsibility among the NARS scientists in the region, thereby strengthening even further, the existing linkages among the NARS scientists in the region, so that the flow of research information and germplasm in the region is accelerated.
3. Provide an opportunity for the NARS scientists in the region to participate in peer review and become more acquainted with the type and quality of sorghum and millet research in the region.

I would like to take this opportunity to express my sincere thanks to the ARC for accepting to host the Eighth EARSAM Workshop and to the Director General of ARC and his staff for making all the necessary arrangements locally for the Workshop.

1. EARCAL, ICRISAT, P.O. Box 39063, Nairobi, Kenya.

Presently ICRISAT Southern and Eastern Africa Region, P.O. Box 39063, Nairobi, Kenya.

Session 1

Improvement and Production of Sorghum

Sorghum Breeding at ICRISAT Asia Center

Belum V S Reddy, J W Stenhouse, K David Nicodemus, and B Ramaiah[1]

Abstract

World sorghum acreage decreased by about 5% during 1981–91, but increased by about 20% in Africa. Productivity was stagnant in Africa as a whole at 0.75 t ha⁻¹ during the same period, but declined by 29% in the eastern African region to 0.67 t ha⁻¹, which was 11% below the African average in 1991.

The breeding approach at ICRISAT Asia Center (IAC) is based on maturity-linked specific adaptation (early and medium maturities). Introducing genetic and cytoplasmic diversity and stress resistances into cultivars is important in achieving stable and sustainable yields, and most of our breeding activities target these objectives. Methods and progress made in breeding high-yielding restorers and seed parents with resistance to one or more stresses for each maturity class in a range of heights, and with diversity for other agronomic traits and cytoplasms are briefly described. Progress made in breeding seed parents for the less-heritable resistance traits, such as those for shoot fly, stem borer, and Striga, *is analyzed using a resistance index to account for variability in stress severity within and between seasons and nurseries. We also describe briefly, areas of interaction with scientists in the region, and the sorghum-related themes of ICRISAT's medium-term plan, which will become operational from 1994.*

Introduction

Sorghum is a staple food crop in semi-arid tropical areas in Africa and India. It is also an important feed and forage crop in other parts of the world which do not lie in the semi-arid tropics (SAT) (Reddy et al. 1990).

World sorghum acreage decreased by about 5% during 1981–91. On the other hand, during the same period, the area under sorghum in Africa increased by nearly 20%. The productivity of sorghum remained constant at 0.75 t ha^{-1} in Africa, while it rose by nearly 8% in the other less-developed parts of the world. In north and central America, in contrast, average productivity was 3.5 t ha^{-1}, nearly five times higher than in Africa in 1991 (Table 1).

Sorghum areas in eastern Africa accounted for nearly 36% of the sorghum-growing area in Africa in 1981, and 38% in 1991. Sorghum productivity in this region reduced by nearly 29% from 1981 to 1991, to end 11% below Africa average (Table 2). These figures should, however, be treated with caution as they mask very large season-to-season variation.

Table 1. Sorghum area, production, and productivity in various regions of the world in 1981 and 1991.

Region	Area ('000 ha)		Production ('000 t)		Productivity (t ha^{-1})	
	1981	1991	1981	1991	1981	1991
Africa	15 925	20 027	11 960	15 034	0.75	0.75
Asia	20 967	17 690	20 168	18 372	0.96	1.03
North and Central America	7 780	5 986	29 171	20 732	3.70	3.50
World	48 384	45 935	72 228	59 895	1.50	1.30

Source: FAO Year Book Vol. 37 (1983), and Vol.46(7) (1992).

1. ICRISAT Asia Center, Patancheru 502 324, Andhra Pradesh, India
ICRISAT Conference Paper no. CP 1027.

Table 2. Sorghum area, production, and productivity in the eastern African region and Africa continent in 1981 and 1991.

	Area ('000 ha)		Production ('000 t)		Yield (t ha^{-1})	
Country/Region	1981	1991	1981	1991	1981	1991
Egypt	–[1]	139	–	655[2]	–	4.7
Ethiopia	844	800[3]	1207	805[3]	1.42	1.01
Kenya	210[3]	–	200[3]	–	1.00	–
Mozambique	250[3]	462	160[3]	155	0.64	0.34
Somalia	413[3]	350[3]	207	145[2]	0.50	0.41
Sudan	3901	5585[3]	3345	2915[2]	0.86	0.52
Uganda	170	245[3]	320	380[3]	1.88	1.55
Eastern Africa total	5788	7581	5439	5055	0.94	0.67
Africa	15 925	20 027	11 960	15 034	0.75	0.75

1. Data not available.
2. Unofficial figure.
3. FAO estimate.
Source: FAO Year Book Vol. 37 (1983), and Vol.46(7) (1992).

Several abiotic and biotic factors account for low productivity in SAT areas. The most important among these are: use of low-yielding landraces, drought and crop establishment problems, bird predation (mainly in Africa), shoot fly (mainly in India), stem borer, midge, head bugs, *Striga*, anthracnose, head smuts (most important in West Africa), and infertile soils (Mukuru 1981).

In this paper, we give an account of the progress made in breeding for resistances to various factors in sorghum at ICRISAT Asia Center.

ICRISAT Asia Center Sorghum Breeding Program

A Global In-House Review of ICRISAT Cereals Program in 1989 concluded that (1) selecting for one or two traits was more effective than selecting simultaneously for several traits, (2) most IAC-bred improved sorghum hybrids and varieties tended to flower after 64 days at IAC (indicating that early lines had been lost in selection), and (3) most improved hybrids and varieties have zera-zera landraces in their parentage (leading to a narrow genetic base). Since then, we have followed an approach of breeding for specific season lengths (<100 days or >100 days) and have deliberately set out to increase diversity in our breeding materials at IAC. At the same time, we have attempted to breed for resistance to only one or two of the most important yield-reducing factors, in addition to high grain yield in each duration category (ICRISAT 1989). Progress made in these areas—breeding early-maturing lines, medium-maturing lines, grain mold-resistant lines, and improved male-sterile lines—are briefly reported here. Also, breeding of restorer lines for nonmilo cytoplasmic male-sterility systems is described.

Breeding early-maturing lines

Until the late 1980s, the main selection criterion in our breeding program was grain yield. This led to the elimination of early genotypes, which are generally lower yielding, from among our elite lines and varieties. There is, however, strong demand for early-maturing sorghums from tropical areas with extremely short rainy seasons, and from areas at high latitude and high altitude, where the growing season is restricted by low temperatures, and to open up new cropping system alternatives. For these areas and uses, the duration of our presently available elite hybrids and varieties is too long and their performance is poor. We have therefore initiated efforts to develop early-maturing sorghums (flowering in <60 and maturing in <100 days). In addition to earliness, seedling vigor, total biomass production, and grain yield are the main selection criteria.

During 1991, 568 S_1 progenies from early-maturing populations (142 from each of US/R C1, US/R C2, RS/R C1, and RS/R C2) and 146 germplasm lines selected for earliness and good agronomic type were evaluated in multilocational trials. Significant positive correlations were observed between seedling vigor and grain and stover yields (Table 3). Seedling vigor was significantly but negatively correlated with maturity. However, vegetative growth rate was

Table 3. Genetic correlations of seedling vigor and vegetative growth rate with agronomic traits in early-maturing sorghum.

Material	Grain	Stover	Maturity	Height
Seedling vigor				
US/R	0.43±0.07	0.31±0.07	–0.30±0.06	0.33±0.06
Tall-GL	0.32±0.13	0.59±0.11	–0.28±0.13	0.60±0.10
Short-GL	0.23±0.15	–	–0.32±0.13	0.10±0.14
Vegetative growth rate				
US/R	0.55±0.07	0.97±0.01	0.20±0.08	0.84±0.04
Tall-GL	0.35±0.14	0.97±0.01	0.25±0.15	0.78±0.09

positively correlated with grain and stover yields and maturity (Rattunde 1992). Several early-maturing lines with high yields of both grain and stover were identified and are forming the basis for a new dual-purpose population. The selected lines were intercrossed in the 1991–92 postrainy season, the F_1 generations raised during the 1992 rainy season, and the first random mating of the new population will take place in the 1992 postrainy season. At the same time, selections from the US/R population (3/4 from C1 and 1/4 from C2), chosen for earliness and high grain and stover yields, have been recombined and this population is being subjected to recurrent selection for these traits. Also, mass selection for earliness, grain yield, and grain traits has been carried out in US/R C1 to develop an early grain-yield orientated population.

Breeding medium-maturing lines

The mainstream breeding materials from earlier breeding for high grain yield and food-grain quality at IAC have, in general, been of medium duration—flowering in 65–75 days and maturing in about 110 days. Many high-yielding grain sorghum lines and hybrids are available in this duration category. But most have lacked resistance to important yield-limiting stresses.

In breeding for insect resistance, considerable success has already been achieved in the transfer of high levels of midge resistance from a landrace source into high-yielding lines and varieties. For shoot fly and stem borer, intermediate levels of resistance have been transferred into partially improved backgrounds that might have potential as dual-purpose varieties. These improved and partially improved resistant lines are now being used as the basis for further breeding, to produce medium-maturing lines with improved insect resistance.

Until recently, pedigree selection within crosses of resistant source lines × high-yielding lines was the main approach to breeding for insect resistance at IAC. This approach offered little opportunity for recombination of resistance genes from different sources. Population breeding was also carried out with mass selection within shoot pest and head pest populations. In the shoot pest population, plants with deadhearts due to shoot fly were removed and those which were undamaged were artificially infested with stem borer. Any plants showing deadhearts were again removed before flowering. At harvest time, selection for good agronomic and grain types was done. In the head pest population, selection was for less damage by head pests and good head and grain traits. In both populations, selection for agronomic, grain and head traits appears to have been intense to the point where little variability remains for these traits.

During 1991 and 1992, a series of multilocational trials to determine basic genetic parameters and to evaluate different selection methodologies for shoot fly, stem borer, and midge resistance were carried out on genetically diverse material. These trials suggested that screening for shoot fly resistance in F_3 should be a two-stage process, with selection for agronomic type during the rainy season followed by evaluation for shoot fly damage during the postrainy season in a single environment with two replications in two-row plots. The selected F_4 lines should then be tested for shoot fly resistance the following rainy season, in two environments with three replications of one-row plots. The selected F_5 lines should be tested in three environments, again with three replications and one-row plots. Heritabilities for primary resistance to shoot fly (low deadheart percentages) were moderate. For midge damage scores, highly significant genotype × environment interactions and moderate heritabilities were recorded, suggesting that testing should be done in as many environments as possible. Single-row plots with three replications in each environment seemed appropriate. For stem borer resistance, high error variances and low heritabilities were obtained, although the mean stem borer damage levels in materials that had undergone different amounts of selection for resistance confirmed that progress had been made in breeding. The high error variances in these trials appeared to originate from uneven field emergence, frequent shoot fly attack, and lack of uniformity of stem borer infestation. These problems need to be addressed before breeding for stem borer resistance can be effective.

These trials also confirmed that the variability for resistance in the shoot and head pest populations was limited. Current efforts, therefore, center on diversifying these populations by introgressing source lines from different origins or with different mechanisms of resistance. Crosses of resistant source lines with genetic male-sterile plants from the populations were made in the 1991–92 postrainy season and first random matings of the newly diversified populations are being made in the 1992–93 postrainy season. Two further random matings will be made before beginning selection for resistance, with the aim of increasing levels of resistance by combining genes for different resistance mechanisms. At the same time, the same general objective of combining genes for different resistance mechanisms is being pursued through pedigree selection in crosses between partially improved lines derived from different resistance sources.

Breeding grain mold-resistant pollinator lines and cultivars

Traditional rainy-season sorghum varieties generally flower at the end of the rains and mature in dry weather. As a result, they are often subject to terminal drought stress which severely reduces their yield levels. An early objective of sorghum improvement was therefore to shorten duration to avoid terminal drought stress and thereby increase potential yield. But shortening of the growth cycle resulted in cultivars which flower and mature in humid, wet conditions and are subject to attack by a complex of fungal pathogens collectively referred to as grain mold. The problem is particularly acute for the white-grained sorghums, which are favored in India and which are the most-used IAC breeding materials.

Attempts to introduce resistance to grain molds into white-grained sorghums have been under way at IAC for several years and a number of highly resistant lines have been produced. However, these lines derive their resistance from guinea sorghums and resemble their resistant parent in being of poor agronomic type and having a low yield potential (ICRISAT 1984).

The mechanisms of resistance to grain mold have also been described and shown to involve tannins, flavan-4-ols, and grain hardness. Tannins and flavan-4-ols are found only in colored grain sorghums. These appeared to afford some form of chemical protection against grain mold. Grain hardness appears to provide a lower level of physical resistance to attack (Mukuru 1992) and appears to be the only mechanism that can be deployed in breeding mold-resistant white-grained sorghums.

Limited and slow success in breeding white-grained mold-resistant sorghum has led to a change in direction in grain mold resistance breeding at IAC. We now aim to breed high-yielding colored-grained sorghums, particularly those with hard red grain (the red pigmentation results from the presence of flavan-4-ols), as a short-term answer to grain mold. The most advanced red grain derivatives are now in F_6 but appear to be later than desirable and require further improvement.

For white-grained sorghums, we continue to investigate the roles of glume cover and panicle density in grain mold resistance as well as the genetic control of grain hardness to determine the extent to which we can compromise between grain hardness, grain size, and yield potential, to minimize the dangers of grain mold and maximize productivity. We also have a grain mold-resistant population derived from resistant source lines, resistant guinea sorghums breeding lines, and elite lines. This has been extensively random-mated and is now being selected for white grain with further random mating. The proportion of white grain in the population is still low and further rounds of selection for white grain are envisaged before beginning selection for grain mold resistance and yield potential. In this way, we hope to break the linkage that appears to exist between guinea grain, plant type, and panicle traits and grain mold resistance in white-grained sorghums.

Recently, we produced, tested, and identified high-yielding grain mold-resistant hybrids with red grain (Reddy, et al. 1992a). These were produced by crossing hard white grain restorers onto red grain male-sterile lines. Both parents were susceptible to grain mold. Both the hard grain trait from the restorer and flavan-4-ol content of the male-sterile parent were dominant and complemented each other in the hybrid to make it resistant (Table 4).

Table 4. Performance of selected red-grained sorghum hybrids and their parents at ICRISAT Asia Center and Bhavanisagar, India, rainy season 1991.

Pedigree	Grain yield (t ha^{-1}) IAC[1]	Grain yield (t ha^{-1}) Bhavanisagar[2]	Time to 50% flowering (days)	Plant height (m)	Agronomic score[3]	Grain mold resistance[4]	Grain hardness (kg)[5]	Flavan 4-ols
Hybrids								
ICSH 91200	3.5	5.0	67	1.8	1.6	2.0	5.2	4.7
ICSH 91201	3.7	5.6	67	1.7	1.7	2.0	5.2	3.3
ICSH 91202	3.5	4.8	65	1.8	1.8	2.0	4.6	7.5
Parents								
BTx6754	2.2	3.2	69	0.9	3.4	3.0	2.8	6.2
BTx2755	2.2	3.0	68	1.0	3.3	4.0	2.7	5.2
ICSR 3	2.4	3.3	70	1.5	2.9	4.0	6.2	0.1
ICSR 41	2.6	3.2	72	1.6	2.3	3.0	4.8	0.2
ICSR 111	3.0	5.0	70	1.5	2.1	4.0	5.1	0.1
Control								
ICSH 153 (CSH 11)	4.0	5.3	66	1.9	1.3	4.0	3.4	0.2
SE	±0.4	±0.5	±0.6	±0.03	±0.002	±0.002	±0.28	±0.46
Mean	2.9	3.6	67	1.6	2.7	3.3	4.1	3.5
CV (%)	20	23	3	6	21	12	12	13

1. BP 8 = High fertility (80N:40P:0K) and RCW 18B = Low fertility (40N:20P:0K), without sprinkler irrigation, and BS7 = high fertility (80N:40P:0K), without sprinkler irrigation.
2. Bhavanisagar:High fertility (80N:40P:20K), without sprinkler irrigation.
3. Scored on a scale of 1–5, where 1 = most desirable, and 5 = least desirable.
4. Based on Threshed Grain Mold Rating (TGMR) on a scale of 1–5, where 1 = no mold, 5 = over 50% of the surface of the grain molded.
5. Pressure (kg) required to break the grain.

Breeding improved female lines

In sorghum, the female lines or seed parents used in commercial production of hybrids are cytoplasmic genetic male-sterile lines of the system first reported by Stephens and Holland (1954) in crosses between Dwarf Yellow Sooner Milo with Texas Black Hull Kafir. This cytoplasmic male sterility (cms) system is referred to here as the milo cms system or the A_1 cms system.

Breeding improved milo cms lines

Before 1990, we developed, at IAC, nearly 100 milo cms lines. These were screened for resistance to various stresses and found, in general, to be susceptible (Reddy 1992a). The exceptions were: ICSB 4, -25, -54, -82, -88013, and ICSB 90004 were resistant to midge; ICSB 4, -5, -25, -49, -53, -73, -84 and ICSB 90 were resistant to rust; and ICSB 26, -28, -49, -53, -54, and ICSB 55 were resistant to leaf blight. Analyses of the parents involved in their pedigrees and their grain masses showed that the male-sterile lines were mostly caudatum or caudatum-kafir based, and that their 100-grain mass was below 3 g (Reddy and Rao 1991a). We therefore felt the need to (a) introduce resistances into milo cms lines, and (b) diversify them by introducing new traits such as improved grain size, earliness, tillering habit, and durra germplasm.

Introducing resistance into milo cms lines. We considered that introducing favorable genes for resistance to any one or more of the major yield-reducing factors into high-yielding male-sterile lines was a step forward. To do this, we crossed elite milo cytoplasm maintainer lines with various improved resistant sources and screened the progenies in segregating generations as shown in Figure 1. From F_3 onwards, we used family mean resistance as the main selection criterion, and then selected for agronomic desirability, grain type, and grain yield within the selected families.

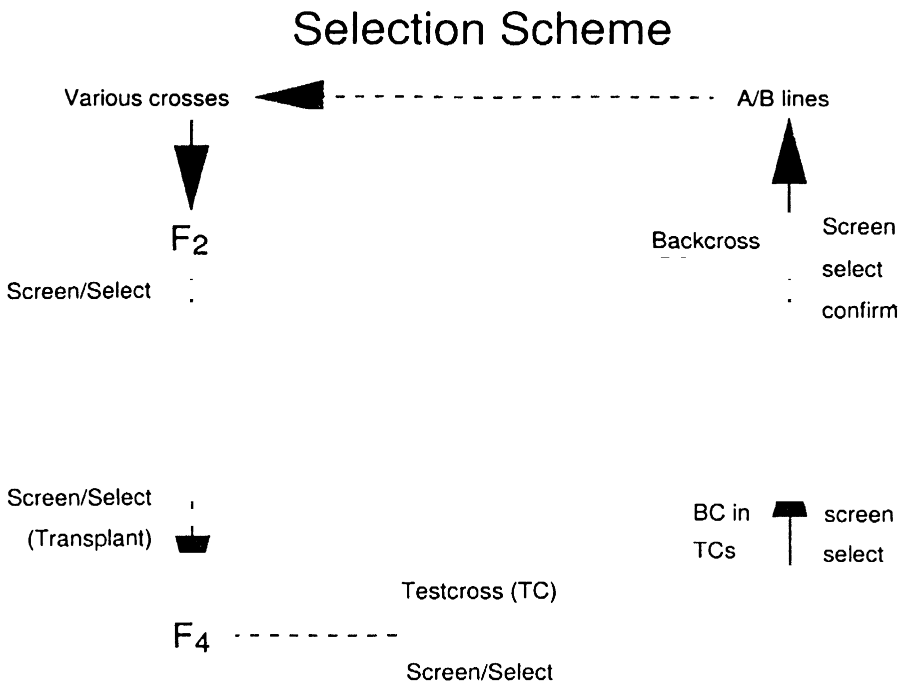

Figure 1. Breeding program for developing resistant male-sterile lines.

Testcrossing to identify sterility maintainers was attempted from F_4 onwards. Using this approach, we are attempting to improve resistance to shoot fly, stem borer, midge, and head bug (Reddy and Taneja 1991a,b; 1992 a,b; Reddy and Sharma 1991, 1992) and to grain mold, downy mildew, anthracnose, rust, and leaf blight (Reddy et al. 1992a,b,c; Singh et al. 1992). We are also working on developing male-sterile lines resistant to *Striga asiatica* (Reddy and Rao 1991a, 1992a). Details of the numbers of lines in each stage of breeding and conversion are given in Table 5.

Table 5. Progenies in different stages of conversion, rainy season 1992.

Trait	Advanced generations[1]	TC[1]	BC_1	BC_2	BC_3
Shootfly	360	226	29	24	0
Stem borer	337	106	160	121	60
Midge	385	51	126	162	20
Head bug	65	0	0	0	0
Grain mold	350	316	22	87	0
DM	299	367	42	24	26
Anthracnose	486	146	0	0	22
Rust	166	0	0	4	22
Striga	190	120	9	16	67
Durra	132	96	23	20	45
Tillering	6	0	0	0	8
Early maturity	0	0	0	0	10

1. Testcrosses.

Diversification of milo cms lines. We crossed agronomically desirable maintainer lines with selected durra lines (IS 1054, IS 18417, IS 18425, IS 18432, and IS 19016); and made backcrosses or three-way crosses by crossing with the same or other maintainer or durra lines. We selected several high-yielding dwarf durra-type progenies with 100-grain mass >3g (Reddy and Rao, 1991c and 1992c). We also began to introduce bold, globular, and lustrous grain characters into milo cms lines. For this purpose, we selected 13 lines (IS 19013, 20160, 20163, 20164, 20167, 20175, 20300, and 20235; and E 11834, 11848, 11850, 18530, and 11856)—mostly belonging to the race durra—and crossed them with elite milo maintainer lines to produce 17 single crosses (Reddy and Rao 1991c). From these, we selected dwarf single plants with bold and lustrous grain. From both these groups of crosses, we now have 132 progenies in advanced generations (F_5–F_7), 96 in test crosses to identify sterility maintainers and 92 lines under conversion (BC_2–BC_4) to male sterility. The 100-grain masses in these lines are significantly higher than that of the control male-sterile line, 296A. Also, there is considerable variability among the progenies for days to 50% flowering and plant height (Table 6).

Table 6. Characters of bold grain and durra type progenies.

Material	Seed mass		Time to 50% flowering (days)		Plant height (m)	
	Mean	Range	Mean	Range	Mean	Range
Advanced lines	3.7	2.6–4.9	85	75–85	1.2	1.0–1.6
Testcross	3.5	2.7–4.1	87	78–84	1.2	1.0–1.5
Lines/conversion	3.3	2.4–4.3	87	80–82	1.3	0.9–1.9
296B (control)	2.9		89		0.9	

Some lines tiller in response to adverse environmental conditions (such as *Striga*, shoot fly, or stem borer infestation, or severe early-season drought). Several such lines were identified by physiologists and were further evaluated in three situations (Reddy and Rao 1991d). Three lines (IS 1347, IS 3075, and IS 3479) with confirmed 'tillering ability' were crossed with elite milo maintainer lines and selection for tillering ability was carried out (Reddy and Rao 1992b). We now have six tillering lines in advanced generations (F_5–F_7) and 8 lines under conversion (BC_2–BC_4) to male sterility.

Available milo cms lines flower in more than 60 days. We do not have lines that flower earlier than this. We identified 12 milo maintainer lines that flower in 51–56 days at IAC (Reddy and Rao 1992b), and have now completed four backcrosses in converting them to male sterility.

Effectiveness of selection in introducing resistance into milo cms lines. It becomes difficult to demonstrate progress in breeding because of variability of infestation pressure for certain stress resistances from season to season, from block to block, and within blocks in screening nurseries. To overcome this problem, we developed a resistance index to relate the performance of breeding lines within a nursery to resistant control varieties.

We followed a systematic design for sowing shoot fly and stem borer nurseries, with the 10th and 30th plot in a block of 40 plots sown with resistant controls (IS 18551 for shoot fly and IS 2205 for stem borer) and the rest with test materials. In the case of *Striga*, the susceptible control (CSH 1) was sown after every second test plot so that each test plot was adjacent to a control plot.

We calculated the resistance index (RI%) as:

$$\frac{X - [(C_1 + C_2)/2]}{(C_1 + C_2)/2} \times 100$$

where X is the rating of the character in the test entry, C_1 and C_2 are the ratings of the nearest resistant control plots. For shoot fly and stem borer, we used percentage of healthy plants (after removal of plants with deadhearts) to rate resistance, and for *Striga*, we used the number of *Striga* plants in the plots.

Table 7. Resistance to shoot fly in relation to resistance index (RI)[1] in single-cross derived families.

Generation	Mean RI (%)	Families in each class of RI (%)			
		<–51	–50 to –26	–25 to –1	>0
SC F_3	–82	97	1	2	0
SC F_4	–72	85	10	3	2
SC F_5	–25	25	27	25	22
SC F_6	–25	17	32	38	15

1. RI = Resistance Index, SC = Single cross.

Table 8. Resistance to shoot fly in relation to resistance index (RI)[1] in three way-cross derived families.

Generation	Mean RI (%)	Families in each class of RI (%)			
		<–51	–50 to –26	–25 to –1	>0
TC F_2	–88	88	22	7	3
TC F_3	–64	75	15	7	3
TC F_4	–27	28	24	27	21
TC F_5	–37	31	38	26	8

1. RI = Resistance Index; TC = Three way cross.

Table 9. Resistance to stem borer in relation to resistance index (RI)[1].

Generation	Mean RI (%)	Families in each class of RI (%)			
		<0	0–50	51–100	>100
SC F_3	–30	87	13	0	0
SC F_4	–22	92	8	0	0
SC F_5	–14	75	12	4	9
SC F_6	–20	79	21	0	0

1. RI = Resistance Index, SC = Single cross.

We calculated means and distributions of RI% values for shoot fly (Tables 7 and 8), stem borer (Table 9), and *Striga* (Table 10). It is clear from the tables that RIs and the number of progenies in the more-resistant classes increased progressively through selection cycles for all the traits.

Table 10. Resistance to *Striga* in relation to susceptible CSH 1 (RI)[1].

Generation	Mean RI (%)	Families in each class of RI (%)		
		-100 to -96	-95 to -91	>-90
Adv. F_6	-81	66	12	33
Adv. F_5	-94	64	16	21
SC F_4	-91	71	7	22
SC F_6	-93	66	20	24
TW F_3	-66	11	10	79
TW F_6	-81	26	17	67
FW F_4	-91	22	44	33

1. RI = Resistance Index, SC = Single cross, TW = Threeway cross, and FW = Fourway cross.

Grain yield levels in the resistant progenies. It is important that improved male-sterile lines have acceptable grain yield resistance. Table 11 gives information on grain yield and resistance in lines selected for shoot fly resistance, Table 12 for stem borer resistance, and Table 13 for downy mildew resistance. It is clear that the lines bred under these programs showed reasonably high levels of grain yield, comparable with the control 296B, and had resistance levels higher than 296B.

Breeding improved alternative cms lines

There are other cytoplasms which are known to interact with nuclear genes and result in male sterility in sorghum. These are the A_2 cytoplasm identified from IS 12662C (Schertz and Ritchey 1978); the A_3 cytoplasm from IS 1112C, or converted Nilwa (Quinby 1980); and the A_4 cytoplasm derived variously from IS 84 and M 35-1, or Maldandi (Rao et al. 1971). The VZM 1, VZM 2, and G_1 cytoplasms from durra landraces (Nagur 1971) have also been designated A_4 (Reddy and Rao 1991a).

The A_1 cms system is conventionally considered the most stable for sterility (Murty and Vidyabhushanam 1990). The anthers of sterile plants with the other cms systems (A_2, A_3, and A_4) are also thought to be less readily distinguishable from fertile anthers in seed production plots. We found that the decreasing order of stability was A_1, A_3, A_4, and A_2 (Table 14). However, we anticipate that enhanced technical expertise in the private sector of the seed industry and increased numbers of private sector entrepreneurs may soon lead to the use of male-sterile lines with these alternative cytoplasms in hybrid programs.

Dependence on a single cms system in hybrid production may be disastrous, as happened with Texas cytoplasm (T cytoplasm) of maize in 1970, when hybrids carrying this cytoplasm became highly susceptible to the T race of southern leaf blight, *Helminthosporium maydis*. As a result, the U.S. incurred an estimated loss of US$ 1 billion in a single year (Ullstrup 1972). Therefore, we believe that diversification of cms systems in sorghum is timely, and that the new male-sterile lines can be readily used now with improved non-milo cytoplasm restorers which are available (see section on non-milo cytoplasm restorers).

Converting resistant source lines to sterility on alternative cytoplasms. We have used the fact that almost all lines act as sterility maintainers on one or more of the alternate cytoplasms (Reddy and Rao 1992a) to convert improved resistant source lines and sources of traits of interest to male sterility on various cytoplasms. These include: 4 grain mold, 2 downy mildew, 2 anthracnose, 2 rust, 2 leaf blight, 1 charcoal rot, 8 stem borer, 3 shoot fly, 6 midge,

Table 11. Performance of shoot fly resistant breeding lines, ICRISAT Asia Center, postrainy season 1991.

Genotype	Grain yield (t ha^{-1})		Deadhearts (%)	Time to 50% flowering (days)	Plant height (m)
	Noninfested	Infested			
SPSF 1017	2.1	2.2	34	80	1.4
SPSF 1169	3.2	2.8	32	78	1.5
SPSF 1101	3.5	2.9	14	81	1.3
IS 18551 (control)	2.7	2.4	17	77	2.3
ICSV 112 (control)	3.7	2.9	92	75	1.3
SPSF 1014	3.4	2.9	22	80	1.1
SPSF 1028	2.8	2.4	30	88	1.0
SPSF 1094	2.5	2.4	17	72	0.9
ICSV 705 (control)	2.9	2.1	18	88	0.8
296 B (control)	0.9	0.6	82	85	1.0
SE	±0.52	±0.36	±6.1	±1.9	±0.01
CV (%)	18	15	16	2	10

1 head bug, and 4 *Striga*-resistant lines; and 2 lines with tillering ability (Reddy and Rao 1992a). All these lines have now reached BC_4/BC_5 stage.

Conversion of common maintainers. In addition, we found nine agronomically desirable and high-yielding milo maintainer lines which also maintain sterility on the alternative cms systems and have been backcrossing them to develop male-sterile lines on those cytoplasms. We have now completed six/seven backcrosses (Reddy 1992b).

Differential testers. In order to clarify the classification of male-sterile lines and to identify a minimum set of testers to differentiate between them, we crossed 11 male-sterile lines with known or questionable cytoplasms with their maintainer lines in all possible combinations; we also crossed 8 male-sterile lines with 9 newly developed maintainer lines, and 10 A_1, 3 A_2, 2 A_3, and 4 A_4 restorer lines in all possible combinations. The fertility status of the testcrosses was evaluated in rainy and postrainy seasons at IAC and in summer at Bhavanisagar. On the basis of stable restoration reaction, we identified 4 testers: TAM 428B (A_2), which gave fertile F_1s only on A_1 cytoplasm; IS 84B (A_4), which gave fertile F_1s on A_1 and A_2; IS 5767 (A_4 restorer), which gave fertile F_1s on all except A_3; and CK 60B (A_1) which gave sterile F_1s on all cytoplasms (Reddy and Rao 1991b).

Breeding restorer lines for alternative cms systems

In sorghum, improved restorer lines are available for milo cms system but are not available for alternative cms systems. This is one of the main reasons why alternative cms systems have not been used in commercial production of hybrids (Reddy and Rao 1991b). We identified several germplasm lines as restorers on alternative cytoplasms (ICRISAT 1987). However, most of them were tall, sensitive to photoperiod and had undesirable grain characteristics. We used A_2 restorer (IS 84, IS 2914, and IS 3567), A_3 restorers (IS 3502, IS 8013, and IS 10036), and A_4 (maldandi) restorers (IS 5767 and IS 23183) in crosses with elite maintainer lines for the milo (A_1) cms system and selected high-yielding, agronomically desirable lines (Reddy and Rao 1991b). These were testcrossed onto male-sterile lines with the relevant cytoplasms, and several lines were identified, which restored fertility in the F_1s (Reddy and Rao 1992b). We have the following lines at hand now:

A 198 advanced lines, 333 testcrosses, 19 identified restorers.
A_3 182 advanced lines, 551 testcrosses, 38 identified restorers.
A_4 109 advanced lines, 202 testcrosses, 11 identified restorers.

Table 12. Performance of stem borer resistant breeding lines, ICRISAT Asia Center, postrainy season 1991.

Genotype	Grain yield (t ha⁻¹)	Dead-hearts (%)	Time to 50% flowering (days)	Plant height (m)
SPSB 978	4.5	40	81	1.0
SPSB 1114	3.7	47	79	0.9
296B (susceptible)	3.4	70	96	0.9
IS 12308 (resistant)	1.9	34	71	1.2
SPSB 1229	3.8	26	80	1.8
SPSB 1475	3.8	16	77	1.6
ICSV 1 (susceptible)	3.0	48	78	1.3
IS 2205 (resistant)	3.3	22	86	1.9
SE	±0.6	±5.7	±2.8	±0.1
CV %	19	26	3	9

Table 13. Performance of downy mildew resistant B-lines, ICRISAT Asia Center, postrainy season 1991.

Entry	Grain yield (t ha⁻¹)	Time to 50% flowering (days)	100-grain mass (g)	Plant height (m)
SP 86013	2.5	90	2.0	0.9
SP 86019	2.0	92	2.3	1.0
SP 86023	3.0	92	2.0	0.8
SP 86038	2.6	88	2.3	0.9
SP 86047	2.0	93	2.3	1.0
296B (control)	1.6	102	2.0	0.9
QL 3 (control)	2.7	87	2.0	1.1
SE	±0.6	±2.3	±0.4	±0.06
CV (%)	24	3	20	6

Table 14. Stability in maintaining male sterility by various cytoplasms at ICRISAT Asia Center (rainy and postrainy seasons) and at Bhavanisagar (summer).

	Single-cross male steriles with variable reaction (%)		
	ICRISAT Asia Center		Bhavanisagar
Cytoplasms	Rainy	Postrainy	Summer
A_1 (milo)	1	0	9
A_2	2	0	42
A_3	1	0	25
A_4 (Maldandi)	2	0	32
Mean	1.4	0	27

Cooperation with ICRISAT regional program and NARS

We endeavor to share our experiences and the materials developed at IAC with ICRISAT regional programs and the National Agricultural Research Systems (NARS). In the process, we learn from the information readily supplied by the scientists in the region and, hopefully, improve the focus of our breeding goals. We briefly describe below two areas of cooperation involving the scientists in the region.

1. We evaluated 149 IAC-bred hybrids at Kiboko and Katumani, Kenya, during a short rainy season (Nov 1990–Feb 1991) for seed-setting efficiency under low temperatures. The minimum temperatures during the flowering period (29 Dec 1990 – 8 Jan 1991) ranged from 13.8–15.5°C. Nearly 43% of the hybrids tested had more than 75% seed-setting efficiency, while 3% of them had more than 96% efficiency. The hybrids with good seed setting efficiency (>90%) were ICSH 89004, ICSH 228, ICSH 89122, ICSH 90038, ICSH 90117, ICSH 90078, and ICSH 90091 (Mukuru and Belum Reddy, ICRISAT, personal communication). This information is useful to the scientists in the region, and also to us at IAC.
2. Another area of interaction is supply of the germplasm to scientists in the region. We supplied several types of materials including A-lines, B-lines, and R-lines to the scientists in NARS of the region. In addition, we also supplied hybrids (along with their parents), upon specific requests from scientists in Egypt and the Sudan (Table 15). We attach great importance to these requests and we can now make specific hybrids, if requests are received in advance.

Table 15. Sorghum breeding lines dispatched from ICRISAT Asia Center to eastern African region during 1990–92.

			Lines					
Country/Year	Varieties	Hybrids	A	B	R	Resistant lines	Others	Total
1990								
Egypt	23	–[1]	24	24	42	–	–	113
Ethiopia	–	28	–	–	–	–	–	28
Somalia	–	–	23	23	3	–	–	49
Sudan	25	–	20	77	8	19	75	224
1991								
Ethiopia	20	–	104	104	244	–	4	476
Sudan	4	1	1	1	1	–	–	8
1992 (up to 10 Sep)								
Egypt	5	272	142	142	263	1	11	836
Kenya	–	–	–	–	–	–	47	47
Sudan	6	264	67	67	112	15	34	565
Grand total	83	565	381	438	673	35	171	2346

1. – = Not sent.

Future outlook in relation to ICRISAT's Medium-Term Plan

So far, we have presented the progress made in work that is currently under way at ICRISAT Asia Center. However, we are now working on a Medium-Term Plan which will determine work from 1994. A detailed analysis of production constraints was undertaken to decide on the priority areas. The research themes center around strategic research on the improvement of grain yield and resistance to various stress factors. Thus, improvement for grain and stover yield, and resistance to *Striga*, stem borer, grain mold, head bugs, anthracnose, midge, drought, leaf blight, and shoot fly, and improving forage sorghums (in order of priority) will form the themes of the new program, depending on funding availability.

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Breeding Sorghum for Irrigated High and Low Rainlands of the Sudan

Osman El Obeid Ibrahim[1]

Abstract

Locally developed and introduced varieties and F_1 hybrids were evaluated at various levels of testing at irrigated and rainfed locations. Data obtained supported the release of the variety CR 35:18 for farmers use under irrigation and medium-to-high rainfall situations. The variety M90393 and the F_1 hybrid YSW164 were also released for commercial use only under irrigation. Data were also obtained from on-farm and advanced varietal/hybrid yield trials. The experimental hybrid 87/OSH:5283 consistently outyielded the most popular and commercially used open-pollinated varieties and hybrids. Two open-pollinated varieties, namely 89/OSF:5021 and 2451, outyielded the commercial varieties Gadam Hamam and Dabar-1. Three drought-tolerant lines performed better than farmer's variety Korakollo. Three experimental hybrids namely, 87/OSH:5283, 87/OSH:5204, and 89/OSH:124 showed superiority over HD-1 and Pioneer hybrids P8319 and P8320.

Introduction

Grain sorghum (*Sorghum bicolor* (L.) Moench) is the most widely adapted and grown crop in the Sudan. It is also the most important crop in terms of total production, acreage, and as human food and animal feed (Table 1).

Table 1. Major crops, acreage, and production in the Sudan, 1987–89.

	1987/88			1988/89		
Crop	Area (ha)	Yield (t ha^{-1})	Production (t)	Area (ha)	Yield (t ha^{-1})	Production (t)
Cotton	312	1.4	438	321	1.7	530
Sorghum	3390	0.4	1360	5881	0.8	4640
Millet	1096	0.2	140	2300	0.2	600
Groundnut	685	0.6	432	614	0.9	527
Wheat	144	1.3	181	200	1.3	260
Sugarcane	60	75	450	65	77	505

Sorghum is commercially produced in rainlands (92%) and irrigated schemes (8%). The rainfed portion is primarily mechanized (65%) and the rest is under traditional farming systems. Ninety percent of the irrigated sorghum acreage is under gravity irrigation and the rest is by flush irrigation.

Despite the importance of sorghum and the long experience of Sudanese farmers in sorghum cultivation, yields per unit area are extremely low, both under rainfed (0.7 t ha^{-1}) and irrigated (1.4 t ha^{-1}) production situations. The major constraints contributing to the low yields include use of traditional low-yielding varieties, drought, low soil fertility, *Striga*, and poor cultural practices.

The sorghum breeding research program of Sudan has released several cultivars to farmers. In 1977, two open-pollinated varieties with high yield potential and suitable for combine harvesting were released. In 1983, the first F_1 hybrid was released and recently, in June 1992, two open-pollinated varieties and one F_1 hybrid were released in rainlands and/or irrigated schemes. In addition, several other promising open-pollinated varieties and hybrids have been identified, and are now at an advanced level of testing.

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This paper discusses results of yield evaluation of several experimental varieties and hybrids, some of which have already been released for commercial use.

Materials and Methods

The material used in this investigation consisted of locally bred and introduced varieties and F_1 hybrids as shown in Table 2. The trials conducted to test the material included on-farm trials and National and Advanced Trials at irrigated and rainfed locations. The cultural practices adopted were as recommended by the extension service for each particular agro-ecological zone of testing. Data on grain yield for each single year and location, and for years and locations combined, using analysis of variance and analysis of yield stability were made using regression analysis procedure (Steel and Torrid 1980).

Table 2. Experimental material used in this investigation.

Entry	Source	Pedigree
CR 35:5	Local	(A/239:/1./1/1XG.Hamam)-6-5
CR 35:18	Local	(A/239:/1./1/1XG.Hamam)-6-18
M90393	ICRISAT	[(SPR-148 × E-35-1) × SC 3541]-5-3
YSW/64	Pioneer	Undeclared
T.U.B-7	Local	Pure line selection
Gedam Hamam	Local	Pure line selection
Dabar-1	Local	Pure line selection
DWM	Introduction	Improved landrace
HD-1	Local	ATX623 × Karper 1597

Results and Discussion

Release of varieties and hybrids

The mean grain yields of four selected entries tested at three rainfed locations and one irrigated location are presented in Tables 3 and 4. It is evident that CR 35:18 outyielded all the control varieties at Wad Medani (irrigated), Tozi (medium rainfall), and Agadi (high rainfall), and was not significantly different in grain yield from the highest-yielding control variety (T.U.B-7) at the location at Sam Sam (high rainfall). The result of combined analysis of grain yield over the four locations during the 1978/79 and 1979/80 seasons is shown in Table 5. CR 35:18 also outyielded the control varieties in all the locations in 1978/79 and 1979/80 crop seasons. Mean grain yield over the two seasons and the four locations (Table 6) also showed superiority of CR 35:18 over all the locations and years.

Table 3. Mean grain yield (t ha^{-1}) of four selected entries tested at the Wad Medani and Sam Sam locations over two seasons in 1978/79 and 1979/80.

	Wad Medani			Sam Sam		
Entry	1978/79	1979/80	Combined	1978/79	1979/80	Combined
CR 35:18	4.40 (a)[1]	3.63 (a)	4.02 (a)	0.66 (bc)	1.42 (a)	1.04 (ab)
CR 35:5	3.35 (bc)	2.75 (b)	3.05 (b)	0.46 (c)	0.94 (b)	0.70 (c)
Dabar-1	3.25 (bc)	2.56 (b)	2.91 (bc)	0.55 (c)	1.10 (ab)	0.82 (cd)
T.U.B-7	2.84 (cd)	3.51 (a)	3.18 (b)	0.95 (a)	1.42 (a)	1.18 (a)
Mean	3.31	2.97	3.14	0.747	1.21	0.98
SE 1	±0.231	±0.236	±0.165	±0.072	±0.123	±0.071
CV (%)	14	16	15	19	41	21

1. Means followed by the same letters are not significantly different at $P < 0.05$.

Table 4. Mean grain yield (t ha^{-1}) of four selected entries tested at the Tozi and Agadi locations over two seasons (1978/79 and 1979/80).

	Tozi			Agadi		
Entry	1978/79	1979/80	Combined	1978/79	1979/80	Combined
CR 35:18	0.53 (ab)[1]	3.28 (a)	1.91 (a)	2.71 (a)	2.81 (ab)	2.76 (a)
CR 35:5	0.61 (a)	2.60 (ab)	1.60 (ab)	1.97 (b)	3.15 (a)	2.56 (ab)
Dabar-1	0.27 (c)	1.93 (b)	1.10 (c)	1.98 (b)	2.50 (bc)	2.24 (bc)
T.U.B-7	0.54 (ab)	2.50 (b)	1.52 (bc)	1.98 (b)	2.28 (c)	2.13 (cd)

1. Means followed by the same letters are not significantly different at $P < 0.05$.

Table 5. Mean grain yield (t ha^{-1}) of four selected entries tested at four locations over two seasons, 1978/79 and 1979/80.

	1978/79					1979/80					
Entry	Wad Medani	Sam Sam	Tozi	Agadi	Mean	Wad Medani	Sam Sam	Tozi	Agadi	Mean	Overall
CR 35:18	4.39	0.65	0.53	2.71	2.07	3.63	1.42	3.28	2.81	2.79	2.43
CR 35:5	3.34	0.46	0.61	1.97	1.59	2.75	0.93	2.60	3.15	2.36	1.98
T.U.B-7	2.83	0.94	0.53	1.98	1.57	3.51	1.41	2.50	2.28	2.43	2.00
Dabar-1	3.25	0.54	0.27	1.98	1.51	2.56	1.09	1.93	2.50	2.02	1.76
Location mean	3.30	0.74	0.47	2.10		2.97	1.20	2.43	2.64		
Year mean		1.66					2.31				

Table 6. Mean grain yield (t ha^{-1}) of four selected entries tested at four locations over two seasons, 1978/79 and 1979/80.

Entry	Wad Medani	Sam Sam	Tozi	Agadi	Mean (SE ±0.872)	Percentage over Dabar-1
CR 35:5	3.05	0.69	1.60	2.56	1.98	112
CR 35:18	4.01	1.04	1.91	2.76	2.43	137
T.U.B-7	3.17	1.18	1.52	2.13	2.00	113
Dabar-1	2.90	0.83	1.10	2.24	1.77	
Mean (SE±0.0797)	3.14	1.71	1.46	2.37		

These results supported the release of CR 35:18 and it was officially released in 1992 for use under conditions of medium-high rainfall (500 mm).

The two open-pollinated varieties, C 35:18 and M90393, and the F_1 Pioneer YSW/64 were tested and compared with one another and with the local controls Hageen Durra-1 (HD-1) and Dwarf-White Milo (DWM) under irrigation conditions at the locations at Wad Medani during the 1990–92 crop seasons. The results (Table 7) showed that YSW/64, C 35:18, and HD-1 significantly outyielded both M90393 and DWM, and were not significantly different from one another, whereas M90393 significantly outyielded DWM, the most popular and widely grown commercial variety in irrigated schemes. Interestingly, the open-pollinated variety C 35:18 yielded 99% of the yield of the F_1 hybrid Hageen Durra-1. These observations are confirmed by the results given in Table 8. The results of on-farm testing (Table 9) also confirmed the results of on-station testing discussed in Tables 7 and 8.

The results of analysis of grain yield stability using regression analysis are given in Table 10. The regression coefficient (b-value) obtained for each of the varieties tested is not significantly different from unity, indicating that all varieties have general adaptability.

Table 7. Mean grain yield (t ha^{-1}) of five selected entries tested at Wad Medani over two seasons, 1990/91 and 1991/92.

				Percentage over	
Entry	1990/91	1991/92	Mean (SE ±0.14)	HD-1	DWM
YSW/64	4.96	6.50	5.73 (a)	101	174
CR 35:18	4.84	6.43	5.63 (a)	99	171
M90393	4.38	5.54	4.95 (b)	88	151
HD-1	4.75	6.57	5.66 (a)	-	
DWM	3.11	3.45	3.28 (d)	58	
Mean (SE ±0.21)	4.27	5.60			

Table 8. Mean grain yield (t ha^{-1}) of four selected entries tested at Wad Medani over three seasons, 1989/90, 1990/91, and 1991/92.

Entry	1989/90	1990/91	1991/92	Mean (SE±0.14)	Percentage over HD-1
YSW/64	6.23	4.96	6.49	5.89 (a)	102
CR 35:18	5.80	4.84	6.43	5.69 (a)	98
M90393	5.41	4.38	5.54	5.11 (b)	88
HD-1	6.04	4.75	6.57	5.79 (a)	-
Mean (SE ±0.21)	5.70	4.63	6.05	5.46	

Table 9. Results of the on-farm verification yield trial, Tayba Block, 1990 and 1991.

	Plant height (cm)			Grain yield (t ha^{-1})			Percentage over	
Entry	1990	1991	Mean	1990	1991	Mean	HD-1	DWM
CR 35:18	122	152	137	2.55	4.29	3.42	99	129
M90393	170	182	175	2.59	3.68	3.14	91	118
HD-1	125	163	144	2.74	4.16	3.45	-	130
DWM	148	173	161	1.87	3.43	2.65	77	-

Table 10. Mean grain yield (t ha^{-1}) and regression coefficient of four entries tested at Wad Medani over 3 years, 1989–91.

Entry	Mean	Regression coefficient	SE	R^2
CR 35:18	5.69	1.0708	±0.1778	0.973
M90393	5.11	0.8503	±0.1157	0.982
YSW/64	5.89	1.1054	±0.0780	0.995
HD-1	5.79	1.2654	±0.0678	0.9971

Table 11. Results of sorghum on-farm verification yield trial, Komour Block, 1991/92.

Entry	Plant height (cm)	Agronomic score (1–5)	Grain yield (t ha^{-1})
87/OSH:5283	173	1.0	4.55
CR 35:18	152	1.2	4.29
HD-1	163	2.7	4.16
M90393	182	1.0	3.66
DWM	173	1.5	3.43
Mean	163	2.0	3.77
SE	±1	±0.27	±0.20
LSD (5%)	4	0.82	0.60
CV (%)	2	27	9

Table 12. Results of Sorghum Standard Variety/Hybrid Yield Trial, Wad Medani, 1991–92.

Entry	Time to 50% flowering (days)	Plant height (cm)	Agronomic score (1–5)	Grain yield (t ha^{-1})
87/OSH:5283	66	168	1.0	6.97
HD-1	67	167	2.0	6.57
YSW-64	76	172	1.0	6.49
CR 35:18	76	148	1.0	6.43
89/OSF:2451	75	147	1.0	6.25
M90393	75	182	1.0	5.54
DWM	56	162	3.0	3.45
Mean	73	161	1.4	5.71
SE	±0.5	±2	±0.11	±0.23
LSD (5%)	1	6	0.32	6.50
CV (%)	1	2	27	7

The results discussed above supported the release of YSW/64, C 35:18, and M90393 for use under irrigation and good management, and were officially released in June 1992 for commercial use. YSW/64 was given the name Seikam, CR 35:18 was called Feterita Wad Ahmed, and M90393 was called Ingaz.

Progress in varietal and hybrid development

Sorghum On-Farm Trial: This trial was conducted during 1991/92 crop season, under irrigation at Komour Block in Gezira Scheme. The results of this trial (Table 11) showed that the experimental hybrid 87/OSH:5283 outyielded HD-1 as well as the newly released open-pollinated varieties M90393 and C 35:18, and the commercial variety DWM.

Standard Variety/Hybrid Trials: These were conducted during 1991/92 crop season at Wad Medani and Rahad locations under irrigation. The results (Tables 12 and 13) also showed superiority of 87/OSH:5283 over the other tested F_1 hybrids and open-pollinated varieties at both the locations.

Advanced Variety Trial: In this trial, 23 new lines were tested and compared with the popular varieties Gadam Hamam and Dabar-1 at Wad Medani under irrigation. The results (Table 14) showed that two lines 89/OSF:5021 and 89/OSF:2451, were significantly more productive than the popular varieties Gadam Hamam and Dabar-1. These two lines will be further tested at the on-farm level.

Drought Tolerance Trial: In this trial, nine lines, previously identified as drought-tolerant, were tested and compared with one of the most popular drought-tolerant local farmers' variety, Korakollo, at Wad Medani location under drought conditions. Three lines significantly outyielded the control variety (Table 15).

Advanced Hybrid Trial: This trial contained 16 experimental hybrids and three control hybrids, namely HD-1, P8319, P8320. The results (Table 16) showed that experimental hybrids 87/OSH:5283, 87/OSH:5204, and 89/OSH:124 outyielded the control hybrids.

Reference

Steel R.G. and **Torrie, J.H.,** 1980. Principles and procedures of statistics. 2nd edn. New York, USA:McGraw-Hill.

Table 15. Results of Sorghum Advanced Drought Tolerance Yield Trial, Wad Medani, 1991/92.

Entry	Time to 50% flowering (days)	Plant height (cm)	Agronomic score (1-5)	Grain yield (t ha^{-1})
90/PDT:13	67	118	1.1	2.41
88/OSL-DT:14	66	140	1.0	2.32
88/OSL-DT:22	57	155	2.3	2.18
Korakollo	61	170	1.5	1.61
Mean	59	126	2.0	1.75
SE	±1	±3	±1.26	±05
LSD (5%)	3	7	3.64	0.14

Table 13. Results of Sorghum Standard Variety Hybrid Yield Trial, Rahad, 1991/92.

Entry	Time to 50% flowering (days)	Grain yield (t ha^{-1})
87/OSH:5283	58	6.20
ICSV-230	77	6.03
CR 35:18	66	5.90
YSW/64	68	5.52
88/OSH:4221	63	5.21
HD-1	62	5.24
DWM	52	3.51
Mean	66	5.12
SE		±0.96
LSD (5%)		0.29

Table 14. Results of Sorghum Advanced Variety Yield Trial, Wad Medani, 1991/92.

Entry	Time to 50% flowering (days)	Plant height (cm)	Agronomic score (1-5)	Grain yield (t ha^{-1})
89/OSF:5021	66	138	1.0	6.95
89/OSF:2451	65	143	1.0	6.46
Gadam el Hamam	65	153	1.6	5.40
Dabar-1	72	158	2.0	4.77
Mean	63	141	1.9	5.06
SE	±1	±4	±0.34	±0.17
LSD (5%)	4	9	0.96	0.47
CV (%)	4	5	14	6

Table 16. Results of Sorghum Advanced Hybrid Yield Trial, Wad Medani, 1991/92.

Entry	Time to 50% flowering (days)	Plant height (cm)	Agronomic score (1-5)	Grain yield (t ha^{-1})
87/OSH:5283	64	177	1.1	6.70
87/OSH:5204	68	170	1.0	6.69
89/OSH:124	69	147	1.1	6.65
P83203	68	190	1.3	6.02
HD-1	67	168	2.3	6.0
P8319	68	180	1.3	5.71
Mean	68	176	1.3	6.16
SE	±1	±9	±0.1	±0.28
LSD (5%)	2	24	0.2	0.80
CV (%)	2	8	13	8

Performance of Sorghum Hybrids in Stress Environments

Tadesse Mulatu Ketema and Yilma Kebede[1]

Abstract

*Sorghum (*Sorghum bicolor *L. Moench) is one of the staple food crops grown under a wide range of environmental conditions in Ethiopia. It is the dominant crop in the lowlands (< 1600 m) of the country, where rainfall is limited and crop failures resulting from drought are common. To stabilize food production in such areas, there is a need to develop early-maturing and drought-tolerant sorghum hybrids, with reasonably high and stable yield potentials. Realizing the superior performance of hybrids under stress environments, the Ethiopian Sorghum Improvement Program launched hybrid sorghum breeding programs for areas with very short growing seasons and very erratic and unpredictable rainfall distribution. Over the years, several hybrids were screened and selected, based on earliness, yield potential, and stability of performance. These selected hybrids gave yield advantages of 13–23% at Melkassa, 61–90% at Kobo, and 100–240% at Mieso over the highest-yielding standard control variety, Gambella 1107.*

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the staple food crops grown under a wide range of environmental conditions in Ethiopia. It is the dominant crop in the lowlands (< 1600 m) of the country, where rainfall is limited and crop failures resulting from drought are common. To stabilize food production in such areas, there is a need to develop early-maturing and drought-tolerant sorghum hybrids with reasonably high and stable yield potentials.

Based on the experiences of several workers in various countries (India, USA, and others) a quantum jump in the yield potential of sorghum was recognized when hybrid sorghum appeared in production fields in the late fifties (Rao 1976). The genetic principle responsible for this increase in yield was hybrid vigor. Following the development of hybrid sorghum, the productivity of this crop, which had remained stagnant for a very long time, started an upward trend.

Realizing the superior performance of hybrids under stress environments, the Ethiopian Sorghum Improvement Program (ESIP) launched hybrid sorghum breeding programs for areas with very short growing seasons (90–110 days) and very erratic and unpredictable rainfall distribution.

Seed parents

Since 1975, over 200 pairs of A and B lines were introduced from various sources (ALAD program in Lebanon, ICRISAT, and Purdue and Texas A&M Universities) and evaluated at Melkassa for their overall agronomic desirability and suitability as female parents. The best seed parents selected and used in the hybrid breeding program are given in Table 1.

Table 1. Selected seed parents used in the hybrid program.

Female lines	Origin
ATX 623	Texas
(G × YE 88)–4–1–2–1–1–1A	Ethiopian Sorghum Improvement Program
FLR 101 × 2219B–2–2A	Purdue/Alad
IS 10468A	ICRISAT
A 8115	ICRISAT
MA 33	ICRISAT
MA 44	ICRISAT
CK 60A	Texas
2219 A	India

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Pollination parents

Various sorghum germplasm received from different sources (Texas, Purdue, India) and promising materials derived from the national breeding program were used as pollinators. In the hybrid evaluation, three distinct stages of evaluation (initial screening of hybrids, advanced sorghum hybrids, and elite sorghum hybrids) were followed.

Parental combinations

Two independent advanced sorghum hybrid trials were conducted in 1987 and 1988. The 1987 trial, consisting of 24 hybrids and the varietal control, Gambella 1107, were grown at Melkassa and Mieso. In 1988, seven hybrids, five of which advanced from the preceding season trial and three varietal controls were grown at Melkassa and Kobo. Randomized complete block design (RCBD) with three replications was used. The plot size was 5 rows × 5 m and they were 0.75 m apart. Time to 50% flowering, plant height, and grain yield were recorded from the center three rows and ANOVA were computed.

Results

Significant differences were detected in grain yield, time to 50% flowering, and plant height among hybrids at both Melkassa and Mieso in 1987 (Tables 2–4). There was only one hybrid which outyielded the standard varietal

Table 2. Mean grain yield of 25 entries included in the advanced sorghum hybrid trial (ASHT) grown at Melkassa (MK) and Mieso (MI), 1987.

	Grain yield ($t\ ha^{-1}$)		
Designation	MK	MI	Mean
(G × YE 88)-4-1-2-1-1-1A × T3-294	4.7	1.1	2.9
(FLR101 × 22198B)-2-2A × 148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	4.2	1.4	2.8
ATX-623 × (148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	3.6	1.7	2.7
A8115 × 82 SEPON 27	3.9	1.4	2.7
(FLR101 × 2219B)-2-2A × T3-184	4.0	0.9	2.5
IS-10468A × SPV-138	3.5	1.4	2.5
Gambella 1107	4.4	0.5	2.5
(FLR101 × 2219B)-2-2A × EXP23 (EC1012)	3.5	1.3	2.4
ATX-623 × 13-184	3.6	1.2	2.4
A8115 × (148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	3.6	0.9	2.3
ATX-623 × CS3541	3.7	0.8	2.3
ATX-623 × SPV-138	3.4	1.1	2.3
(FLR101 × 2219B)-2-2A × T3-294	3.1	1.4	2.3
ATX-623 × (C-108-3 × CS3541)-19-1 (SPV 351)	3.2	1.3	2.3
ATX-623 × TC-294	3.4	1.0	2.2
(G × YE88)-4-1-2-1-1-1A × CS-3541	3.3	1.0	2.2
ATX-623 × 77CS5	3.5	0.7	2.1
(FLR101 × 2219B)-2-2A × (E-35-1 × US/R 497)-1-1-1-2	3.1	1.0	2.1
ATX-623 × (E-35-1 × US/R-497)-1-1-1-2	3.3	0.6	2.0
ATX-623 × YE294	2.3	1.4	1.9
IS-10468A	2.7	0.9	1.8
A8115 × 77 CS 3	2.5	1.0	1.8
IS-10468A × YE58	2.8	0.7	1.8
ATX-623 × E × P 23 (ENZ-1012)	2.6	0.9	1.8
A8115 × 77 CS 5	2.0	1.1	1.6
Mean	3.4	1.1	
LSD	2.5	0.6	
CV (%)	4.5	3.7	

Table 3. Mean time to 50% flowering of 25 entries included in the advanced sorghum hybrid trial (ASHT) grown at Melkassa (MK) and Mieso (MI), 1987.

Designation	Time to 50% flowering (days)		
	MK	MI	Mean
(G × YE 88)-4-1-2-1-1-1A × T3-294	65	68	67
(FLR101 × 22198B)-2-2A × 148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	67	68	67
ATX-623 × (148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	67	69	68
A8115 × 82 SEPON 27	67	70	69
(FLR101 × 2219B)-2-2A × T3-184	63	69	66
IS-10468A × SPV-138	66	73	70
Gambella 1107	77	85	81
(FLR101 × 2219B)-2-2A × EXP23(EC1012)	62	69	66
ATX-623 × 13-184	60	71	70
A8115 × (148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	69	73	71
ATX-623 × CS3541	62	69	66
ATX-623 × SPV-138	66	75	71
(FLR101 × 2219B)-2-2A × T3-294	65	71	68
ATX-623 × (C-108-3 × CS3541)-19-1 (SPV 351)	64	71	68
ATX-623 × TC-294	68	70	69
(G × YE88)-4-1-2-1-1-1A × CS-3541	63	68	66
ATX-623 × 77CS5	67	76	72
(FLR101 × 2219B)-2-2A × (E-35-1 × US/R 497)-1-1-1-2	67	80	74
ATX-623 × (E-35-1 × US/R-497)-1-1-1-2	69	86	78
ATX-623 × YE294	63	70	67
IS-10468A	63	72	68
A8115 × 77 CS 3	65	78	72
IS-10468A × YE58	68	76	72
ATX-623 × E × P 23 (ENZ-1012)	65	74	70
A8115 × 77 CS 5	69	71	70
Mean	66	73	
LSD	4	7	
CV (%)	3	5	

Table 4. Mean plant height of 25 entries included in the advanced sorghum hybrid trial (ASHT) grown at Melkassa (MK) and Mieso (MI), 1987.

Designation	Plant height (cm)		
	MK	MI	Mean
(G × YE 88)-4-1-2-1-1-1A × T3-294	163	122	143
(FLR101 × 22198B)-2-2A × 148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	178	132	155
ATX-623 × (148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	178	135	157
A8115 × 82 SEPON 27	175	133	154
(FLR101 × 2219B)-2-2A × T3-184	160	127	144
IS-10468A × SPV-138	168	130	140
Gambella 1107	173	125	149
(FLR101 × 2219B)-2-2A × EXP23(EC1012)	172	125	149
ATX-623 × 13-184	168	115	142
A8115 × (148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	195	115	155
ATX-623 × CS3541	162	120	141
ATX-623 × SPV-138	173	122	148
(FLR101 × 2219B)-2-2A × T3-294	158	132	145
ATX-623 × (C-108-3 × CS3541)-19-1 (SPV 351)	177	113	145
ATX-623 × TC-294	178	123	151
(G × YE88)-4-1-2-1-1-1A × CS-3541	153	117	135
ATX-623 × 77CS5	123	108	116
(FLR101 × 2219B)-2-2A × (E-35-1 × US/R 497)-1-1-1-2	165	120	143
ATX-623 × (E-35-1 × US/R-497)-1-1-1-2	155	105	130
ATX-623 × YE294	132	125	129
IS-10468A	135	117	126
A8115 × 77 CS 3	145	123	134
IS-10468A × YE58	110	92	101
ATX-623 × E × P 23 (ENZ-1012)	163	108	136
A8115 × 77 CS 5	140	128	134
Mean	160	120	
LSD	22	25	
CV (%)	8	12	

Table 5. Mean grain yield and days to 50% flowering of 10 entries included in the advanced sorghum hybrid trial (ASHT) grown at Melkassa (MK) and Kobo (KB) in 1988.

Designation	Grain yield (t ha^{-1})			Time to 50% flowering (days)		
	MK	KB	Mean	MK	KB	Mean
AT × 623 × (148 × E-35-1)-4-1- × CS3541 deriv)-5-4-2-1	4.9	5.2	5.1	69	73	71
(FLR101 × 2219B)-2-2A (148 × E-35-1)-4-1 × CS 3541 deriv)-5-4-2-1	4.3	5.5	4.9	67	72	70
AT × 623 × (E-35-1 × US/R-497)-1-1-1-2	3.9	5.9	4.9	67	75	71
(G × VE 86)-4-1-2-1-1-1A T3-294	4.6	5.0	4.8	66	71	69
AT × 623 × (148 × E-35-1) -4-1 × CS3541 deriv)-5-4-2-1	4.6	5.0	4.8	67	74	71
Dinkmash	3.8	3.9	3.9	70	72	71
A-8115 × 77CS-3	3.0	4.1	3.6	69	73	71
IS 10468A × YE58	2.1	2.6	2.4	73	73	73
Controls						
76T1 # 23	3.2	4.3	3.8	64	66	65
Gambella 1107	4.0	3.1	3.6	78	85	82
Mean	3.8	4.5		69	73	
LSD (0.05)	1.2	1.1		2	2	
CV (%)	1.8	1.4		2	2	

Table 6. Mean plant height of 10 entries included in the advanced sorghum hybrid trial (ASHT) grown at Melkassa (MK) and Kobo (KB) in 1988.

Designation	Plant height (cm)		
	MK	KB	Mean
AT × 623 × (148 × E-35-1)-4-1- × CS3541 deriv)-5-4-2-1	182	192	187
(FLR101 × 2219B)-2-2A(148 × E-35-1)-4-1 × CS 3541 deriv)-5-4-2-1	170	185	178
AT × 623 × (E-35-1 × US/R-497)-1-1-1-2	173	197	185
(G × VE 86)-4-1-2-1-1-1A T3-294	175	187	181
AT × 623 × (148 × E-35-1)-4-1 × CS3541 deriv)-5-4-2-1	187	193	190
Dinkmash	160	150	155
A-8115 × 77CS-3	135	142	139
IS 10468A × YE58	103	122	115
Controls			
76T1 # 23	130	153	142
Gambella 1107	183	180	182
Mean	160	170	
LSD (0.05)	12	11	
CV (%)	4	4	

control Gambella 1107 at Melkassa, and it matured 5–17 days earlier at Mieso. In 1988, hybrids in the trial gave yield advantages of 13–23% at Melkassa and 61–90% at Kobo over the varietal control, Gambella 1107 (Table 5). These hybrids flowered 8–12 days earlier at Melkassa and 10–19 days at Kobo (Table 5) and their height ranged from 103 to 187 at Melkassa and 122 to 197 cm at Kobo (Table 6).

Discussion

In areas where drought as a result of severe lack of moisture is a serious problem such as at Mieso and Kobo, hybrids gave better yields than varieties. This was clearly observed in the 1987 trial at Mieso and in the 1988 trial at Kobo. In these two sites, better performance of hybrids over varieties was well reflected in the resulting higher grain yields. Earlier hybrids that performed well under low (Melkassa, 500 m) and dry low (Kobo, 420 mm and Mieso, 400 mm) sites have been described by Abebe et. al (1984). Brehane (1980) has also described the greater percentage increase in grain yields of the hybrids than in those of varieties under stress environments.

Conclusion

Based on experiences of several workers in various countries and from our own experience, hybrids are capable of withstanding the rigors of drought and moisture stress much better than local and improved varieties.

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Threshing Percentage as an Indicator of Tolerance of Terminal Drought Stress in Sorghum

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Abstract

One of the main difficulties in breeding for tolerance to drought stress is the lack of unambiguous criteria to identify tolerance. This paper describes the effects of postflowering stress on threshing percentage (the ratio of grain mass to total panicle mass) in sorghum, and examines its use as a potential criterion to assess and select for stress tolerance. An analysis of field data from trials grown under stress in Kiboko, Kenya, indicated (1) that threshing percentage under stress is a heritable genetic characteristic and is significantly correlated to estimates of drought tolerance/susceptibility derived from a model of factors controlling yield under stress, and (2) that variation in genotype threshing percentage was the major determinant of the observed variation in grain yield under stress. The paper concludes with a discussion of ways of using threshing percentage to analyze the relative contributions of stress tolerance, stress escape, and yield potential to variation in yields among genotypes under terminal stress, and as a potential selection criterion for terminal stress tolerance.

Introduction

The one factor that most complicates selection for drought tolerance in a breeding program is the lack of a clear measure of the degree to which a genotype is tolerant or susceptible to drought stress. Both insect and disease resistance can be directly measured or scored based on direct observation of degree of infection or infestation: number of deadhearts (shootfly), percentage of leaf area affected (leaf diseases), or a standardized score of the amount of mold on grains (grain mold). No such standardized measurements or scores are available to evaluate drought tolerance.

Physiological measurements of plant water status or plant response to stress (such as leaf water potential or osmotic adjustment) are tedious to make and in general, have not been clearly related to differences in grain yield in stress conditions (Bidinger and Witcombe 1989). The use of grain yield itself, as an index to stress tolerance, is often misleading as differences in inherent yield potential and in drought escape (plus in other, largely unknown factors) are often larger determinants of differences in grain yield under stress than are differences in genotype drought tolerance/susceptibility (Bidinger et al. 1987b). This leads to selection for these factors rather than for actual drought tolerance. Measurement of yield reduction under stress (in comparison to a paired irrigated planting) is also subject to confounding by differences in drought escape and yield potential. This frequently leads to a situation in which more 'susceptible' but higher yield potential genotypes outyield their more 'resistant' but lower yield potential counterparts under stress (e.g. Blum et al. 1992).

We believe that it is highly unlikely that there is any such thing as 'drought resistance' as a universal phenomenon. This is equivalent to claiming that there is, for example, a 'universal insect resistance' which is effective against all types of insects that attack sorghum from the seedling stage to the stored grain stage. Drought resistance, like insect resistance, is most likely to involve very different mechanisms for different types of drought, as does resistance to different insects which attack different plant parts and at different stages of growth. A much more logical approach is to focus on the specific type of stress which is most important in the target area of the breeding program, attempt to understand what plant traits are advantageous in this type of stress, and select for these in the breeding program (Blum 1988). By 'type of stress' we mean primarily the timing and duration of the stress in relation to the crop cycle, plus associated environmental and edaphic conditions, such as high evaporation rates, high temperature stress, or the presence /absence of stored soil water.

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ICRISAT Conference Paper no. CP 1028

Research on drought tolerance in pearl millet at both ICRISAT Asia Center (IAC) and the ICRISAT Sahelian Center (ISC) has followed this approach, concentrating mainly on stress during grain filling, which is the most damaging to yield in this crop (Mahalakshmi et al. 1987). Such research has identified threshing percentage (the ratio of the grain mass to the total panicle mass, measured on a plot basis) as a rapid, useful indicator of how effective a genotype is in setting and filling grains under drought stress during the grain-filling period. As this ability is closely related to tolerance to such a drought in pearl millet (Fussell et al. 1991), it is a potentially useful index to tolerance and a selection criterion for tolerance in a breeding program. It is currently being evaluated as a selection criterion in the IAC Millet Improvement Program.

Threshing percentage has been used in sorghum breeding programs as an indicator of the relative ease of threshing of different genotypes, i.e., the higher the threshing percentage, the more complete the removal of grains from the panicle under test conditions. In this paper, we examine the possible applicability of this ratio as a measure of the relative success of sorghum genotypes in setting and filling grains under terminal drought stress; that is, as an index of tolerance/susceptibility to such a stress.

Theoretical Consideration of Threshing Percentage

Effects of terminal drought stress on threshing percentage

Because the structural parts of the panicle—the rachis and its branches—are formed before flowering, their development and hence their mass are less likely to be reduced by a terminal or postflowering drought than is the mass of those parts of the panicle formed after flowering—the grain. The development and the mass of the rachis and branches can, of course, be affected by a terminal stress if it begins before flowering, while the rachis and branches are growing rapidly. However, when stress begins before flowering and continues through grain filling, the grain mass is likely to be even more severely affected than the mass of the rachis, as many florets will fail to develop or to set seed. This proportionately greater reduction in the mass of the grain than in the mass of the rachis plus branches, results in a fall in the threshing percentage under terminal stress conditions. Table 1 illustrates the types of changes that can be expected to occur in rachis plus branch mass, grain number, single grain mass and threshing percentage, as terminal stress becomes more severe/begins earlier.

Table 1. Examples of effects of terminal drought on panicle components and threshing percentage (hypothetical data).

Drought level	Rachis +branch	Grain number	Single grain mass (g)	Total grain mass (g)	Total panicle mass (g)	Threshing percentage (%)
None	10	1000	0.035	35.0	45.0	78
Mild	10	1000 (−15%)[1]	0.0298	29.8	39.8	75
Mild	10 (−15%)	850 (−15%)	0.0298	25.3	35.3	72
Moderate	10 (−15%)	850 (−30%)	0.0245	20.8	30.8	68
Moderate	8.5 (−15%)	700 (−30%)	0.0245 (−30%)	17.2	25.7	68
Severe	8.5 (−15%)	550 (−45%)	0.0245 (−30%)	13.5	22.0	61
Severe	7.0 (−30%)	400 (−60%)	0.0245 (−30%)	9.8	16.8	58
Very severe	7.0 (−30%)	400 (−60%)	0.0193 (−45%)	7.7	14.7	52
Very severe	5.5 (−45%)	250 (−75%)	0.0193 (−45%)	4.8	10.3	47
Complete	4.0 (−60%)	100 (−90%)	0.0193 (−45%)	1.9	5.9	32

1. Figures in parentheses are the percentage change in the panicle components.

Genotype differences in threshing percentage under terminal stress

In pearl millet, under nonstress conditions, different genotypes commonly differ little in threshing percentage, unless there are differences in seed set due to sterility, or there is insect or bird damage, etc. Threshing percentage is also not particularly affected by genetic differences among genotypes in panicle number, grain number per panicle, or seed size. Therefore, differences among millet genotypes in threshing percentage under a terminal stress are not likely to be due to inherent differences among genotypes; rather, they reflect differential genotype × stress interaction, i.e., differences among the genotypes in how much reduction in grain number per panicle or in grain filling occurs under stress. Presumably the same is true for sorghum, although this remains to be proven. The guinenese types may be an exception, as they would probably have an inherently lower threshing percentage and lower yield than durras or caudatums.

Genotype differences in threshing percentage in a terminal stress can be, broadly speaking, due to two factors: differences in drought escape or differences in drought resistance/tolerance. Early flowering (escape from a terminal drought) means that a genotype proceeds through the various stages of panicle development, flowering, and grain filling under less severe stress conditions than does a late flowering one, and therefore suffers less yield loss. Drought tolerance (due to whatever mechanism) means a genotype's growth and/or development will be less affected than those of a susceptible genotype under identical stress conditions. Hence grain filling rate and/or duration, for example, would be less reduced by the stress in a tolerant genotype.

Use of threshing percentage to assess genotype tolerance to terminal drought stress

Threshing percentage thus has several potential advantages as a criterion of genotype response to stress: (1) In contrast to the actual grain yield in the stress, or reduction in grain yield in the stress, it is generally unrelated to innate genotype differences in yield potential. (2) Threshing percentage is easily measured; if panicle mass is usually taken before threshing, no additional measurements are required. And (3) threshing percentage (at least in pearl millet) characteristically has much lower coefficient of variation under stress conditions than either grain or panicle mass, making the detection of genotype differences easier.

However, because threshing percentage can be affected by drought escape under severe stress conditions, it may be necessary to adjust differences in threshing percentage for differences in drought escape, if threshing percentage is to be used as a measure of drought tolerance/susceptibility alone. Fortunately, this is easily done for terminal stress conditions, as drought escape can be readily approximated by flowering date. One simple way to do this is to regress genotype mean threshing percentage on genotype mean flowering date. In pearl millet, there is characteristically a moderate, negative correlation between the two—the later the flowering, the less the threshing percentage. The deviation from regression (the difference between the actual and regression-predicted threshing percentage) can then be used as a measure of genotype drought tolerance/susceptibility. In this method, a significant positive deviation from regression—a higher actual threshing percentage for the time to flowering than that predicted from the regression based on all genotypes—means that the genotype shows evidence of tolerance to stress, relative to the average genotype in the trial. Similarly, a significant negative deviation indicates relative susceptibility. Genotypes whose actual threshing percentage does not differ significantly from their regression-predicted threshing percentage are neither tolerant nor resistant, but simply show an average response to stress.

How Well Does Threshing Percentage Work as an Indicator of Drought Resistance in Practice?

Test data sets—EARSAM Preliminary Sorghum Yield Trial 2, Kiboko 1991 and 1992

The previous section contained the theoretical arguments for the use of threshing percentage as a measure in drought tolerance. In this section, we report on how well it actually works, using data from the EARSAM Preliminary Sorghum Yield Trial 2, grown at the Kiboko Research Station in Kenya during the short (October 1991 to March 1992) and long (March 1992 to July 1992) rainy seasons of 1991/92. These trials were grown under both rainfed and rainfed plus supplementary irrigation conditions, producing paired stressed and nonstressed treatments, which allowed the effects of genotype yield potential on genotype yield under drought conditions to be estimated.

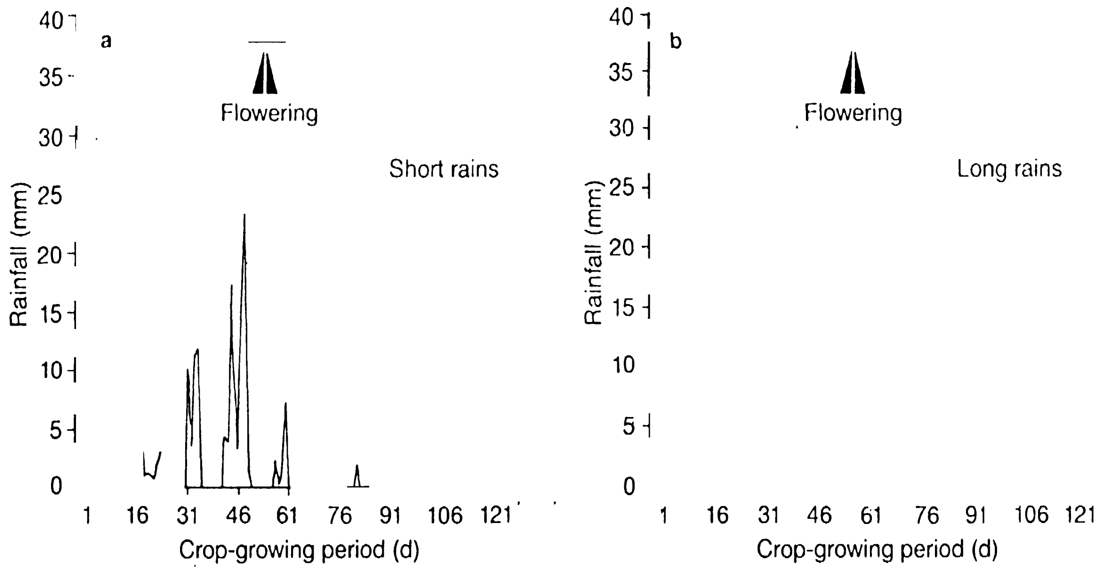

Figure 1. Rainfall received during the crop season in (a) the 1991 short rainy season, and (b) in the 1992 long rainy season at Kiboko. The means and ranges in flowering dates are indicated above the figures.

Table 2. Analysis of variance and heritability (h^2) for grain yield and threshing percentage for EARSAM Preliminary Sorghum Yield Trial 2, grown under rainfed conditions at Kiboko, in the 1991 short rainy season (mild stress) and the 1992 long rainy season (severe stress).

	Grain yield	Threshing percentage
Mild stress		
F (genotype)	2.94***	4.86***
CV (%)	21%	7%
h^2	0.54	0.70
Severe stress		
F (genotype)	1.27^{NS}	1.86**
CV (%)	52%	20%
h^2	0.29	0.41

** = P <.01; *** = P <.001; NS = not significant.

Rainfall in both seasons was very limited, totalling 285 mm in the short rains and only 154 mm in the long rains. There must have been considerable water stored in the soil at the beginning of the season in the long rainy season, as it is very unlikely that any sort of crop would have been possible with the actual rainfall. The rainfall distribution in both seasons (Figure 1) indicated drought stress during the grain filling-period. The stress level would have been particularly severe in the long rainy season (Figure 1b) in which there was no rain after flowering, and the crop would have been forced to fill grain on whatever moisture was stored in the soil from the early part of the growing season. Thus, the two seasons provide excellent test data sets to examine genotype response to grain-filling stage stress of different severities.

Factors affecting genotype grain yields under stress

There were broad ranges in genotype yield in both the mild and severe stress comparisons (Figure 2a). In the irrigated comparisons they ranged from 4.7 to 8.8 t ha^{-1}, for the short rainy season and from 4.6 to 9.4 t ha^{-1} for the long rainy season. Genotype differences were highly significant in both cases. In the mild stress comparison (short rains), genotype differences ranged from 2.2 to 6.1 t ha^{-1}, while in the severe stress comparison, yields ranged from 0.1 to 2.6 t ha^{-1}. These differences were significant in the mild stress, but not significant in the severe stress due to a high level of experimental error (Table 2).

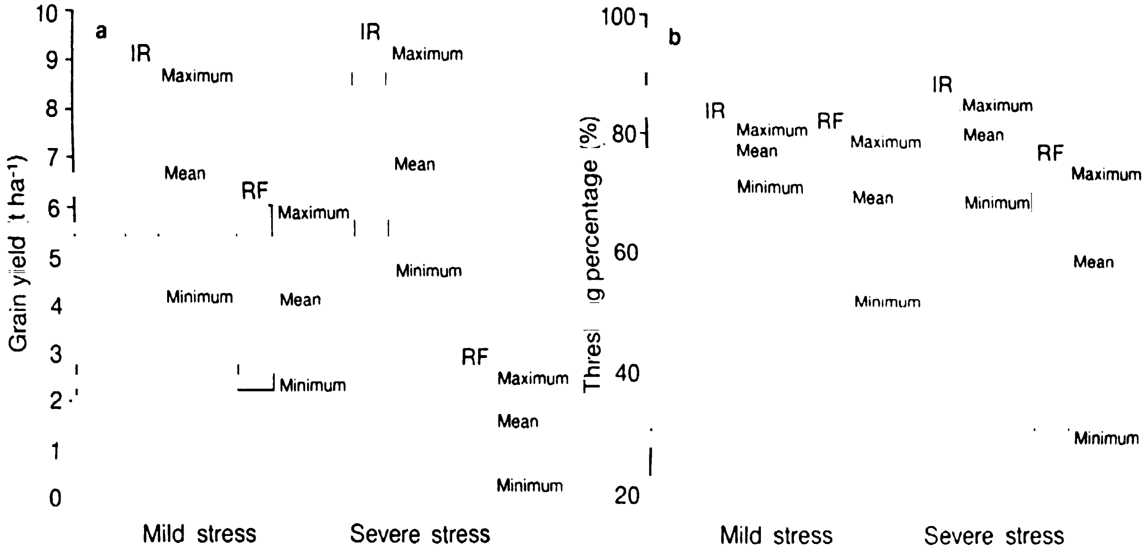

Figure 2. Ranges in (a) mean genotype yield and (b) mean genotype threshing percentage in the EARSAM Preliminary Yield Trial 2, grown in Kiboko during the 1991 short rainy season (mild stress) and the 1992 long rainy season (severe stress) under irrigated (IR) and rainfed (RF) conditions.

Genotype differences in yield in the rainfed plantings were related to yield differences in the irrigated plantings in both the mild stress comparison (r = 0.45, $P < 0.01$) and the severe stress comparison (r = 0.31, $P < 0.05$, Table 3), indicating that yield potential differences were a significant factor in genotype yield under stress (Figures 3a and 3b). In neither case however, were the correlations between grain yield in the rainfed planting and to time to flowering significant (Table 3), indicating that drought escape was not an important factor in the differences in grain yield among genotypes in the rainfed plantings.

The influence of genotype yield potential on genotype yield in the stress is very common in our experience with pearl millet (Bidinger et al. 1987b; Fussell et al. 1991). A similar conclusion seems valid for sorghum. However, the actual correlation coefficients between yield in the irrigated and stressed plantings accounted for only 10–20% of the variability in yields in the stressed plantings. Yield potential improvement alone, therefore, will not have a large impact on grain yields in areas of frequent terminal stress.

Table 3. Selected correlations from EARSAM Preliminary Sorghum Yield Trial 2, grown under rainfed (RF) and irrigated (IR) conditions in Kiboko in the 1991 short rains (mild stress) and 1992 long rains (severe stress).

	Mild stress	Severe stress
Grain yield (RF) with:		
Grain yield (IR)	0.45**	0.31*
Flowering (RF)	−0.03NS	−0.14NS
Threshing % (RF)	0.71***	0.85***
Threshing % (RF) with:		
Flowering (RF)	−0.17NS	−0.30*
Threshing % (IR)	0.45**	0.16NS
Drought response index	0.66***	0.79***
Threshing % (IR) with:		
Grain yield (RF)	0.44**	0.19NS

* = $P < .05$; ** = $P < .01$; *** $P < .001$; NS = not significant.

The lack of any apparent effect of early flowering on grain yields under stress in these experiments is very different from our experience with pearl millet (Bidinger et al. 1987a; Mahalakshmi et al. 1988). This lack of evidence for a role for drought escape might have been due to several factors: (1) differences in the two species (particularly the difference in length of the grain-filling period—20 days in pearl millet vs >30 in sorghum), (2) differences in

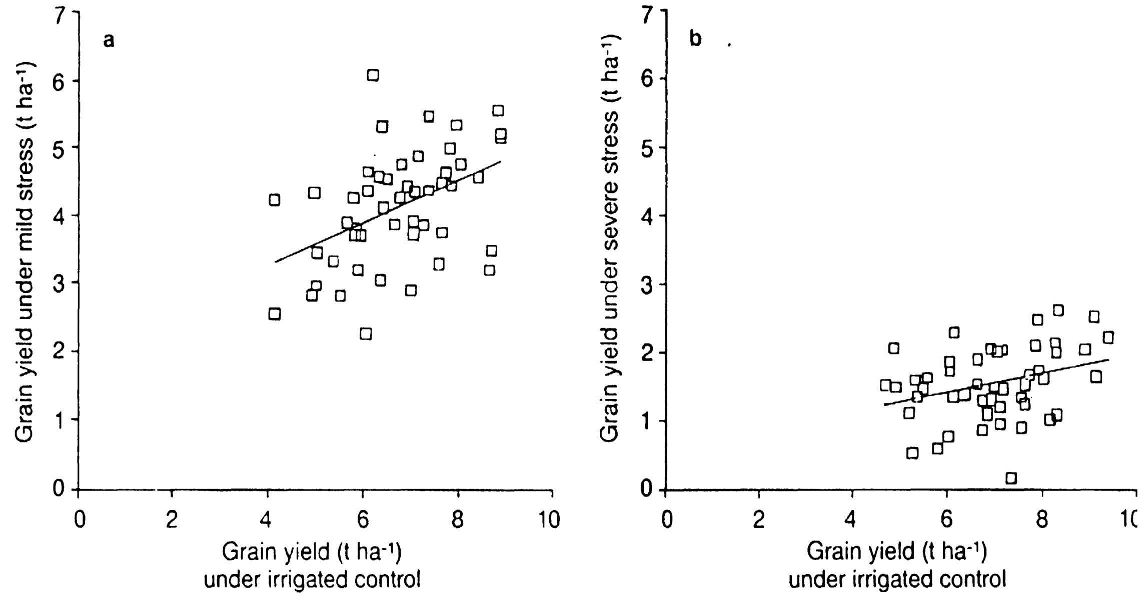

Figure 3. Grain yield in the rainfed plantings in relation to grain yield in the irrigated plantings in the EARSAM Preliminary Yield Trial 2, grown in Kiboko in (a) mild stress conditions in the 1991 short rainy season, and (b) severe stress conditions in the 1992 long rainy season.

environmental and edaphic conditions in test locations, (3) the fact that the range in flowering among genotypes in Preliminary Sorghum Yield Trial 2 (10–12 days) may not have been large enough to detect a significant effect of escape, or (4) other, unknown factors.

Genotype differences in threshing percentage were much larger in the rainfed plantings than in the irrigated ones (Figure 2b), although they were highly significant in both irrigated and rainfed plantings in both seasons. As expected from our work on pearl millet, it was possible to measure threshing percentage much more precisely than grain yield under stress, resulting in larger F ratios for genotype and smaller coefficients of variation (Table 2). It is a rather common observation that ratios of different measures of primary productivity such as harvest index and threshing percentage are more stable than any of the measures of productivity themselves (e.g., biomass, panicle yield or grain yield). It is not completely clear why this should be so.

The most encouraging result was the relationship of grain yield and threshing percentage, which was very strong in both rainfed plantings (Figure 4a and 4b). Genotype differences in threshing percentage accounted for 50% of the variation in genotype yield in the mild stress ($r = 0.71$, $P < 0.001$) and 72% of the variation in yield in the severe stress $r = 0.85$, $P < 0.001$ Table 3). A high threshing percentage was, therefore, the major determinant of a high grain yield in the rainfed plantings. Correlations, however, are not always causal in nature, and it remains to show that genotype differences in threshing percentage in the rainfed plantings actually represent an expression of genotype drought tolerance/susceptibility, and not simply a reflection of the preexisting differences among genotypes. We attempted to do this in several ways in our analysis of the data, which are discussed in the following paragraphs.

Threshing percentage and drought resistance/susceptibility

There were also positive correlations between grain yield and threshing percentage in the irrigated plantings in both the short ($r = 0.54$, $P < 0.001$) and long ($r = 0.48$, $P < 0.01$) rainy seasons, as well as in the rainfed plantings, which indicates that there were differences in threshing percentage among genotypes which were a factor in yield differences

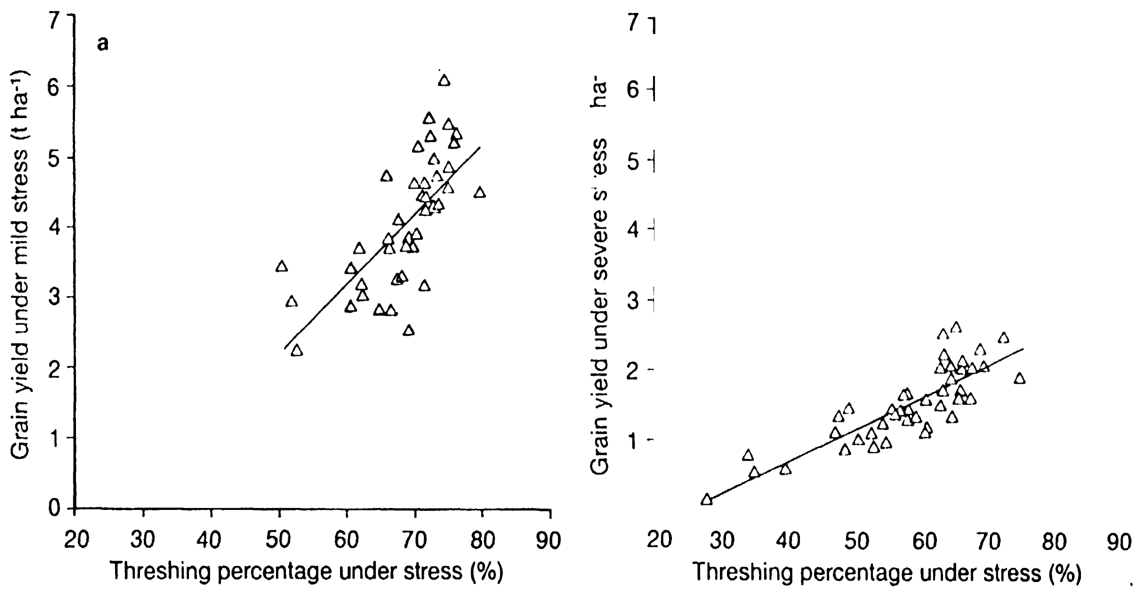

Figure 4. Grain yield in the rainfed plantings in relation to threshing percentage in the rainfed plantings in the EARSAM Preliminary Yield Trial 2, grown at Kiboko in (a) mild stress conditions in the 1991 short rainy season, and (b) in severe stress conditions in the 1992 long rainy season.

in the absence of stress. This suggests that the correlations of yield and threshing percentage in the rainfed plantings may have been simply expressions of a general relationship between these two variables in the materials tested, irrespective of the test environment. If this hypothesis were true, we would expect there to also be (1) correlations between genotype threshing percentage in the irrigated and rainfed plantings (i.e., consistent genotype differences across environments) and (2) correlations between threshing percentage in the irrigated plantings and yield in the rainfed ones (i.e., an effect of the preexisting genotype differences in threshing percentage on yield in the rainfed plantings).

In the short rainy season (mild stress) planting, both of these correlations were significant—r = 0.45 (P <0.01) for threshing percentage between the irrigated and rainfed environments, and r = 0.44 (P <0.01) for rainfed yield and irrigated threshing percentage (Table 3). Therefore, at least a portion of the variation in grain yield and threshing percentage in the rainfed plantings in the mild stress environment was probably a reflection of preexisting differences in threshing percentage among genotypes which had nothing to do with their response to stress. It may have been that some of the trial entries did have some problems with seed setting in the short rainy season that were expressed in both environments and lowered yields in both.

In the long rainy season (severe stress) planting, correlations between threshing percentage in the irrigated and rainfed plantings and between yield in the rainfed planting and threshing percentage in the irrigated one were both nonsignificant (Table 3). Thus, in this planting there was no evidence that threshing percentage differences in the stress conditions represented preexisting differences among genotypes. It is possible that as the stress became more severe, the preexisting differences among genotypes in threshing percentage were obscured by larger ones due to differences in ability to set and/or fill grains under the stress conditions (i.e., by differences in tolerance/susceptibility to stress). This hypothesis was supported by the results of genotype × environment (irrigated and rainfed) analysis for threshing percentage in the short and long rainy-season plantings. In the severe stress in the long rainy season, the mean square for g × e was more than three times larger than the mean square for g × e in the mild stress in the short rainy season. Because of the much higher degree of experimental error in the long rainy season (Table 2), the significance level for g × e for threshing percentage was lower in the long rainy season (F = 1.63, P <0.01) than in the short rainy season ($F = 2.61$, $P < 0.0001$). The fact that g × e for threshing percentage was significant in both cases, however, lends additional mass to the argument that threshing percentage under stress represents primarily an expression of specific genotype response to stress and not simply constitutive differences among genotypes.

Finally, drought tolerance indices were calculated for each genotype in the trial in both seasons, according to the method of Bidinger et al. (1987b) and correlations run between genotype drought index and genotype threshing percentage. This drought tolerance estimation procedure adjusts measured grain yields in the stressed treatment for the effects of differences in genotype yield potential (yield in the nonstressed treatment) and drought escape (estimated by time to flowering), if these two factors have significant effects on genotype yield in the stressed treatment. Remaining differences in yield, following this adjustment, are then considered as measures of drought tolerance/susceptibility, provided they are larger than those expected as a result of experimental error.

The correlations between genotype drought response index and genotype threshing percentage were positive and significant in both the mild stress ($r = 0.66$, $P < 0.0001$) and in the severe stress ($r = 0.79$, $P < 0.0001$, Table 3). In addition, threshing percentage measured in the irrigated plantings was not correlated to genotype drought response index in either of the seasons. Thus, differences in threshing percentage in the nonstressed planting were not related to genotype differences in drought tolerance/susceptibility. The relationship of drought response index with threshing percentage only when the latter was measured under stress, plus the significant g × e interaction for threshing percentage between the rainfed and irrigated plantings strongly suggest that threshing percentage in stress environments is a genuine indicator of genotype tolerance/susceptibility to a grain-filling stage stress, and not simply a reflection of constitutive differences among genotypes, irrespective of the environment. Threshing percentage thus is a promising evaluation/selection criterion for grain-filling stress tolerance in sorghum as in pearl millet, provided that these findings are repeatable over different environments and trials.

Selection for Terminal Stress Tolerance in a Breeding Program

Genotype differences in actual grain yield in a terminal stress environment can be attributed to genotype differences in one or more of three factors, as indicated in the above analysis: yield potential, drought escape, or drought tolerance. The relative importance of each of these varies with the differences in the material being tested and the severity of the stress. For example, in a mild stress, differences in yield potential are likely to be more important than differences in escape or tolerance as a determinant of yield differences among the trial entries. In contract, in a set of genotypes with a broad range in flowering, escape may be the major reason for yield differences under a terminal stress.

Breeding genotypes for higher yields in environments with a frequent occurrence of stress can best be done by combining all three factors influencing yield in such environments. Selection for yield potential and for early flowering are best done in nonstress environments, where genetic differences in these two characters are best expressed. Stress environments should be used to identify differences in drought tolerance—such as differences in threshing percentage for terminal stress environments. Such stress environments are thus used in an analogous way to disease- or pest-screening nurseries, in which an estimate of resistance or susceptibility such as threshing percentage, and **not** grain yield, is the objective.

Kiboko appears to present an ideal opportunity to make the measurements of yield potential and flowering under fully irrigated, nonstress conditions, and at the same time, assess tolerance to grain-filling drought in a second planting in which irrigation is terminated before flowering. The stress should be fairly severe (at least a 50% reduction in trial mean yield) and material of different maturities should be tested in separate trials, as much as is practicable, in which the irrigation can be terminated at the appropriate time. The stressed trial should focus on identifying genotype differences in a measure of drought tolerance such as threshing percentage and **not** differences in grain yield, as discussed above. Where threshing percentage and time to flowering are found to be correlated, some adjustment of threshing percentage for drought escape, such as that described above, will be required.

It should be possible to explain in the order of 60–80% of the variation among genotypes in measured grain yield under stress by (multiple) regression of individual genotype yield on the following three independent variables: (1) yield potential (yield in the absence of stress), (2) time to flowering (measured in the irrigated trial), and (3) threshing percentage measured in the stressed trial. Such an analysis will allow the breeder to estimate which of the three factors influencing performance under stress is the more important in the material under test, by comparing the percentages of the regression sums of squares accounted for by each independent variable. If, for example, drought escape accounts for the largest fraction of the regression sums of squares for yield under stress, then clearly more emphasis on early flowering for terminal stress conditions is needed. Similarly, if differences in threshing percentage account for the majority of the differences in yield among genotypes, selection for threshing percentage in segregating materials under terminal stress conditions may be the logical step.

In the examples used in this paper, drought escape was not an important factor in yield differences in EARSAM Preliminary Sorghum Yield Trial 2 in either the short or long rain plantings at Kiboko in 1991/92. In the short rainy season, genotype differences in yield potential and threshing percentage accounted for 61% of the variation in genotype yield in the rainfed planting. In the long rainy season planting, genotype differences in threshing percentage alone accounted for 71% of the variation in genotype grain yield in the rainfed planting. These results suggest that the EARSAM program should benefit from screening its promising breeding materials for the ability to maintain a high threshing percentage under terminal stress conditions.

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The Performance of Introduced Sorghum Varieties at Imbo and Moso Research Stations in Burundi

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Abstract

The objective of this trial was to evaluate, under Imbo and Moso environmental conditions, the performance of 25 sorghum varieties introduced from EARSAM-Network. Sorghum varieties, 5D × 160 and Gambella 1107 were included as controls. The trial was conducted for three seasons at Imbo, and for one season at Moso. Observations were made on yield, plant height, days to 50% flowering, disease and insect resistance, and grain quality. ICSV 112 produced the highest grain yield at Imbo, but was not significantly different from Gambella 1007 and 5D × 160. At Moso, five varieties were selected for further testing, namely KAT 83347, M36121, CR 35:5, Gambella, and 5D × 160.

Introduction

Among the 11 natural regions of Burundi, Moso is ranked as the first in sorghum production. The sorghum acreage in Moso is estimated at 30 993 ha, with an average yield of 0.79 t ha^{-1}. Imbo natural region is ranked the 10th with 4.155 ha, and an average yield of 0.61 t ha^{-1} (Burundi: Ministère du Plan 1985–86).

In both regions, farmers grow a mixture of local varieties which are tall (up to 3 m high), with low yield, late maturity (6–7 months), and high tannin content in the grains.

In the Moso region, altitude varies from 800 to 1300 m above the sea level, with a total annual rainfall of 1210 mm. The Moso region is characterized by poor rainfall distribution in the early and late stages during the growing seasons. As a consequence, drought of 2–3 weeks occur frequently and can cause significant reduction in yield. In the Imbo region, the average rainfall is 800 mm per year with a better distribution than in the Moso region. The average temperatures are 24°C in Imbo and 21°C in Moso.

In addition to the low-yielding varieties, stem borers are a common constraint to sorghum production in Moso and Imbo. In Moso, however, leaf blight is more important than stem borers. The aim of the sorghum breeding program of Institut des Sciences Agronomiques du Burundi (ISABU) is to breed varieties and hybrids that are potentially high yielding, resistant to disease with good grain quality. To achieve this goal, introduction of foreign germplasm is important.

The objective of this study was to evaluate elite germplasm in Eastern Africa Regional Sorghum and Millet (EARSAM) Elite Sorghum Yield Trial-89 (EESYT-89), obtained from OAU/SAFGRAD/ICRISAT in Nairobi, Kenya.

Table 1. Mean grain yield, plant height, and days to 50% flowering of the EARSAM Elite Sorghum Yield Trial-89 (EESYT-89) varieties at Imbo in 1989.

Varieties	Yield (t ha^{-1})	Plant height (cm)	Time to 50% flowering (days)	Origin
KAT/83369	1.89	167	71	Kenya
ICSV 112	1.69	151	86	ICRISAT
CR:35:5	1.68	147	64	Sudan
KAT/83487	1.56	163	86	Kenya
RSVAT Ent 8	1.55	182	76	Tanzania
M 90411	1.41	150	86	Somalia
76T1/IS76	1.32	150	78	Ethiopia
Dinkmash	1.24	161	81	Ethiopia
1804	1.24	147	76	Rwanda
ICSV 401	1.23	160	81	ICRISAT
Framida	1.23	154	75	Ethiopia
PP-290	1.21	144	78	Somalia
Seredo (Variety control)	1.20	149	70	Uganda
Gudam Hamam	1.20	127	66	Sudan
5D × 160	1.19	160	81	Burundi
M 36121	1.18	150	66	Ethiopia
BTX 629	1.17	117	80	Ethiopia
ICSV 335	1.15	158	81	ICRISAT
ICSV 219	1.14	159	79	ICRISAT
RSVAT Ent 13	1.11	142	73	Tanzania
Hageen Durra-1 (Hybrid control)	0.97	153	84	Sudan
RSAVT Ent 6	0.78	150	83	Tanzania
3 K × 76/7	0.55	145	66	Uganda
IS 2284	0.50	176	60	Ethiopia
Kigufi	0.44	192	89	Rwanda
Observed F	3.29***	4.67***	11.90***	
CV (%)	28.5	8.0		

*** = $P < 0.001$

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Table 2. Mean grain yield, days to 50% days flowering, plant height, and percentage of damage by stem borers at Imbo in 1990.

Varieties	Yield (t ha-1)	Time to 50% flowering (days)	Plant height (cm)	Stem borer damage (%)
KAT/83369	3.88 a[1]	70 ef	180 ab	33 ab
ICSV 112	3.27 ab	75 abc	163 bc	34 ab
Seredo	3.20 ab	67 c	155 bc	46 ab
Framida	3.07 abc	59 h	195 a	44 ab
KAT/83487	3.01 abc	74 bcd	170 abc	49 ab
Dinkmash	2.99 abc	72 bcde	160 bc	27 ab
M 36121	2.87 abcd	59 h	163 ab	43 ab
76T1 23/IS 76	2.85 abcd	66 g	143 cd	54 ab
ICSV 401	2.85 abcd	72 cde	173 abc	32 ab
RSAVT Ent 8	2.79 abcd	71 de	198 a	51 ab
CR:35:5	2.71 abcd	59 h	147 cd	31 ab
PP 290	2.67 abcd	75 b	160 bc	25 ab
1804	2.64 abcd	71 de	170 abc	33 ab
5Dx 160	2.58 bcd	73 bcde	173 abc	41 ab
ICSV 335	2.54 bcd	75 g	162 bc	40 ab
ICSV 219	2.40 bcd	72 bcde	165 bc	36 ab
RSAVT Ent 1	1.06 bcd	68 fg	170 abc	41 ab
BTX 629	1.88 cd	74 bcd	127 d	61 a
M 9041	1.62 d	78 a	147 cd	20 b
Observed F	4.00***	53.1***	8.01**	1.99
CV (%)	18.8	2.2	7.4	38.0

1. Mean followed by the same letter not significantly different from each other.

Table 3. Mean grain yield, days to 50% flowering, plant height, and percentage of stem borer damage at Imbo in 1991.

Varieties	Yield (t ha-1)	Time to 50% flowering (days)	Plant height (cm)	Stem borer damage (%)
ICSV 112	3.59 a[1]	74 ab	146 bcd	23
Gambella	3.53 a	73 ab	177 ab	20
5D × 160	3.12 ab	77 a	177 ab	12
ICSV 1083	3.09 ab	74 ab	186 a	23
M 9041	2.88 ab	74 ab	140 cd	16
76 T1 23	2.78 ab	65 c	136 d	24
ICSV 1089 BF	2.75 ab	74 ab	177 ab	14
Dinkmash	2.62 ab	71 b	140 cd	15
PP 290	2.61 ab	71 b	140 cd	15
CR:35:5	2.60 ab	66 c	143 cd	23
M 36121	2.52 ab	62 c	177 ab	15
KAT/82487	2.46 ab	74 ab	153 bcd	17
ICSV 1079 BF	2.20 ab	71 ab	170 abc	33
ICSV 401	1.76 b	77 a	140 cd	23
Observed F	2.76*[2]	14.19**	7.76	1.6
CV (%)	18.4	2.9	7.5	39

1. Means followed by the same letter not significantly different from each other.
2. * = $P \leq 0.05$, ** = $P \leq 0.01$.

Materials and Methods

The EARSAM Preliminary Sorghum Yield Trial-89 (ESYT-89) trial consisted of 25 varieties from different countries of eastern Africa and from ICRISAT. Among them, Hageen Durra-1, Seredo and 5D x 160 were the controls. 5D x 160 was recommended for release in 1979 in Imbo and Moso. It is characterized by a high yield potential, medium maturity and high tannin in its grain. Its adoption was rather low, probably because of its poor grain quality.

The experiment was conducted for four consecutive seasons in Imbo and for one season in Moso. In Imbo, low-yielding entries were discarded after every season.

Imbo research station and the seed production center of Bugiga were chosen as sites of the experiment. Entries were arranged in a completely randomized block design with three replications. Each plot consisted of five rows, each 5 m long with 0.75 m between rows.

The adopted cultural practices were as follows: sowing in rows, fertilizer application N-P-K (60-20-20), Nitrogen being applied at sowing and at panicle initiation stages, thinning 3 weeks after sowing, weeding as necessary, and bird scaring. Planting times were 13 Jan 1989, 15 Jan 1990, 9 Nov 1990, 22 Jan 1991 (Imbo), and 17 Dec 1990 (Moso).

Observations were recorded on grain yield, plant height, time to 50% flowering, foliar diseases, stem borer damage, and grain quality. Grain quality was scored visually on 10 grains from each variety, using the method proposed by Jeannette et al. 1987.

Analyses of variance were conducted on each recorded trait and differences tested for significance using the F-test. Difference between entries and the controls were tested using the LSD in 1989 and Newman-Kheul test in 1990 and 1991.

Table 4. Mean grain yield, days to 50% flowering, plant height, and percentage of stem borer damage, Moso 1990.

Varieties	Yield ($t\ ha^{-1}$)	Time to 50% flowering (days)	Plant height (cm)	Stem borer damage (%)
ICSV 112	2.30	78 ab[1]	176 de	16.2
KAT/82487	2.29	77 ab	191 cd	13.3
Dinkmash	2.88	73 abcd	166 e	7.8
M 3612	2.50	65 d	196 bc	10
76 TA 23	2.51	67 cd	165 e	8.8
ICSV 401	2.30	74 abcd	180 cde	15.37
CR:35:%	2.00	65 d	166 e	8.4
PP 290	2.24	73 abcd	158 e	13.3
M 9041	2.33	77 ab	161 e	21
ICSV 1089 BF	2.57	80 a	213 ab	8
ICSV 1079 BF	1.56	72 abcd	198 bc	11
5 DX 1607	2.37	75 abc	195 bcd	6.5
Gambella	2.65	69 cd	200 ab	12.6
ICSV 1089	2.18	79 ab	218 a	13.4
Observed F	0.8 NS[2]	6**[3]	16.65	1.5
CV (%)	25.9	4.9	5.5	48.5

1. Means followed by the same letter not significantly different from each other.
2. NS = Not significant.
3. ** = $P \leq 0.01$

Results and Discussion

Imbo

The results showed significant differences between entries for most recorded traits, except for yield in the second season of 1991. ICSV 112 and KAT 83369 consistently gave the highest yield. In 1989, the yield ranged from 0.44 to 1.89 $t\ ha^{-1}$, with a mean of 1.07 $t\ ha^{-1}$ (Table 1). Nineteen varieties were advanced for further testing in 1990

(Table 2). Out of the 19 varieties, 10 were selected to be compared with Gambella 1107, ICSV 1089 BF, and 1079 BF from Mali (Table 3). It was found that ICSV 112 and Gambella 1107 were the highest in yield (3.5 t ha^{-1}) (Table 3).

Time to 50% flowering ranged from 62 to 77 days. This cycle would allow any selected variety to be incorporated in the farming system of Imbo.

Stem borer damage was scored in the 1990 and 1991 seasons. Significant differences were observed only in 1990, with a high coefficient of variation (38%). This shows that it was not possible to select for resistance. As a consequence, the use of insecticide is recommended to control stem borer.

With regard to grain quality, it was found that among the 14 entries in 1991, 9 had 50% or more corneous endosperm. 5D × 160 and CR 35:5, both high in tannin, had 100% floury endosperm. Sorghum grains with floury endosperm are good for beer-making, whereas those with corneous endosperm are suitable for dishes such as ugali, porridges, beer, chapati, etc.

Moso

In Moso, no significant difference was observed for yield (Table 4).

Leaf blight (*Helminthosporium turcicum*) was more severe in Moso than in Imbo. The following varieties were selected and will be tested for one or two more seasons: KAT 83487, M 3612, ICSV 401, CR 35:5, ICSV 1089 BF, 5D × 160, Gambella 1107, and ICSV 1083.

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Genetics of Grain Mold Resistance in Sorghum

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Abstract

*Grain mold damages sorghum (*Sorghum bicolor *(L.) Moench) through actual loss in yield and reduction in quality and nutritional value of the grain.* Fusarium moniliforme *and* Curvularia lunata *are the most important fungi causing grain mold in humid areas throughout the world.*

Development of cultivars resistant to sorghum grain mold should be based on knowledge of the genetics of the disease resistance. This research was designed to contribute to the present knowledge regarding gene-effect associations between known genes controlling pericarp color, presence or absence of a pigmented testa, and thickness of the mesocarp, and the effect they may have in conferring grain mold resistance. Work was conducted using four inbred lines as a base population. Crosses were made to generate F_1, F_2, and backcross populations at College Station, Texas, USA, beginning winter of 1988. Grain mold evaluation was conducted at College Station in 1990, and at Serere and Namulonge in Uganda in 1991.

The presence of a pigmented testa (B_1-B_2-), a red pericarp (RRYY), a thin mesocarp (ZZ), and an intensifier gene (II) were all dominantly inherited.

The presence of a pigmented testa was the single most important character conferring grain mold resistance. Red pericarp color also conferred grain mold resistance, although not as strongly as the pigmented testa. The effect of red pericarp color in conferring resistance was enhanced when the intensifier gene was present. Mesocarp thickness was found to have no significant role in grain mold resistance.

Grain mold resistance attributed to a pigmented testa, red pericarp color, and intensifier gene were dominantly inherited.

College Station and Serere were not significantly different, and could provide good locations for grain mold resistance selection. Namulonge was not a suitable location.

Introduction

Grain mold is one of the most serious biotic constraints in the production of grain sorghum (*Sorghum bicolor* (L.) Moench). Many fungal genera have been associated with grain mold, and most of these are facultative parasites or saprophytes. The predominant species vary with location, season or year, with *Fusarium moniliforme* Sheldon and *Curvularia lunata* (Wakker) Boed, being the most important worldwide (Anonymous 1986, Castor and Frederiksen 1980, Forbes et al. In press, Murthy et al. 1980, Williams and Rao 1981). The most obvious symptom of grain mold is the appearance of pink, orange, grey, white or black discoloration on the grain surface, depending on the specific fungal species present. *Fusarium moniliforme* produces a pinkish-white mycelium which is powdery in the early stages and later becomes fluffy. *Curvularia lunata* appears as a shiny, velvety black, fluffy growth on the grain surface (Bandyopadhyay 1986). The disease is most prevalent in areas where improved cultivars are grown, especially when humid weather conditions prevail during grain maturation. Losses caused by grain mold are both quantitative and qualitative. Quantitatively, grain mold causes actual yield losses. At ICRISAT Asia Center, Patancheru, India, yield losses of up to 100% in highly susceptible cultivars, have been experienced (Williams and Rao 1981). In Texas, USA, unusually heavy rains at grain maturity in 1976 affected 400 000 ha of sorghum, and caused a loss of $ 46 million (Castor and Frederiksen 1980). The disease also causes losses in seed viability, reduction in kernel size, testa mass and 1000-seed mass (Castor and Frederiksen 1980, Forbes et al. In press, Murthy et al. 1980, Williams and Rao 1981). Preharvest sprouting may also occur under prolonged rainfall, high humidity and alternate wetting and drying conditions (Castor and Frederiksen 1980, Forbes et al. In press). Qualitatively, grain mold results in a loss of grain

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market value (Anonymous 1986, Castor and Frederiksen 1980, Forbes et al. In press, Rooney and Miller 1992, Williams and Rao 1981), as well as reductions in processing and nutritional values. (Bandyopadhyay 1986, Forbes et al. In press, Rooney and Miller 1982, Williams and Rao 1981).

Limited information is available on the genetics of grain mold resistance in sorghum. Because many fungal genera and several plant and caryopsis traits are involved, the resistance is thought to be a result of an additive effect of many genes (Ellis 1972, Murthy et al. 1980, Narayana and Prasad 1984, Williams and Rao 1981). The actual association of various caryopsis traits with grain mold resistance is not clear. This knowledge would be useful to sorghum breeding programs which are aimed at the improvement of food and grain quality.

Genes at seven loci are known to be responsible for the different characters affecting caryopsis traits and are designated R, Y, I, Z, B_1, B_2, and S genes (Quinby and Martin 1984, Rooney and Miller 1982, Siegliner 1984, Stephens 1946). The R and Y genes determine pericarp color. If both genes are dominant (R- Y-), then the pericarp is red. When the Y- gene is recessive, the pericarp is colorless or white regardless of the R- gene (R- yy, rryy). A lemon yellow pericarp is found when the R gene is recessive and the Y gene is dominant (rr Y-). The intensifier gene (I-) modifies the color of the pericarp when R- Y- or rr Y- are present, making the color brighter when dominant (I-), and dull when recessive (ii). A pigmented testa is present when the complementary (B_1- and B_2-) genes are dominant. The spreader gene (S-) allows the brown color of a pigmented testa to be present in the epicarp. The mesocarp is thin when the Z- gene is dominant (ZZ) and is thick when the gene is recessive (zz). Pigmentation, controlled by R, Y, I, B_1, B_2 and S genes is associated with the presence of phenolic compounds, that could be antifungal, hence conferring grain mold resistance (Bandyopadhyay et al. 1988, Hahn and Rooney 1985, Kulkarni et al. 1981, Raab 1985, Rooney and Miller 1982). A thin mesocarp, as determined by the amount of starch granules present, is thought to confer grain mold resistance.

This study was designed to elucidate the effects of these various plant and grain characters and their relationship to the development of grain mold, to confirm gender action controlling these characters and to determine their inheritance patterns.

Materials and Methods

Four inbred cultivars with different characters and distinct gene markers for testa pigmentation, pericarp color, mesocarp thickness, as well as known mold reaction were selected for this study (Table 1). Diallel crosses with their reciprocals were made using hand emasculation to generate 12 F_1, 12 F_2, and 24 BC-1 populations, at College Station, Texas. Grain mold evaluation was carried out on these populations and on the parents at College Station in 1990 and at Serere and Namulonge Research Stations in Uganda in 1991. The evaluation was done on inoculated plants in the field. A mixture of *F. moniliforme* and *C. lunata* spores was used as an inoculum source. The mixture was prepared as described by Bandyopadhyay and Mughogho 1988. *F. moniliforme* and *C. lunata* were isolated from naturally infected grain and cultured separately on potato dextrose agar at 300°C for 10–14 days. The fungal cultures were comminuted in distilled water using a blender and then filtered through a double layer of cheese cloth. Suspensions of the two fungi were made separately. Equal quantities of the suspensions were mixed and appropriately diluted with distilled water to make a mixture of 1×10^6 spores mL^{-1} to form the inoculum. A few drops of Tween 20 were added as

Table 1. Sorghum cultivars used to determine grain mold response and explanation of known genotypes and the resulting phenotypes.

Cultivar	Mold reaction	Pericarp color	Genotypic description: Intensifier	Spreader	Testa	Mesocarp	Phenotypic description
RTx 2536	Susceptible	RRyy	ii	SS	$b_1b_1b_2b_2$	ZZ	White pearly grain, no testa
SC 103=12E	Resistant	RRYY	II	SS	$B_1B_1B_2B_2$	zz	Dark brownish red chalk
BTx 3197	Moderately susceptible	RRyy	ii	SS	$b_1b_1B_2B_2$	zz	Present white chalky grain, no testa
BTx 378	Resistant	RRYY	II	SS	$b_1b_1B_2B_2$	zz	Red chalky grain, no testa

a wetting agent. The inoculum was sprayed into the panicles at 50% anthesis, with an air compressor calibrated at 40 p.s.i. Spraying was done carefully to wet the whole panicle to run-off. The inoculated panicles were bagged with pollinating paper bags for 4–7 days to maintain high humidity.

The experiment was planted in 6 m row plots in a completely randomized design with two replications. Grain mold and heritability data were recorded on at least 50 plants in each of the nonsegregating generations, P_0, F_1, and BC-1, and at least 250 plants in the segregating F_2 generations per replication. Each plant in F_2 and BC^{-1} was considered an experimental unit. Studies on gene dominance and inheritance patterns were carried out on the F_2, and BC^{-1} progeny. Grain mold evaluation was made on mature plants in the field by visual estimation of severity based on a 1–5 rating scale, where 1 = no mold; 2 = 1–10% molded grain; 3 = 11–25% molded grain, 4 = 26–50% molded grain, and 5 = over 50% molded grain in panicles. Analysis of variance procedure was used to determine location and genotypic effects. Fisher's LSD was used to determine differences among the means. Genetic ratios were selected for goodness-of-fit by Chi-square test of the observed to the expected number of generations within each of the F_2 and BC^{-1} populations.

Results

The inheritance and effect of a pigmented testa and pericarp color were examined in the cross and progeny from RTx 2536 (P_1) × SC 103 – 12E (P_1) (Table 2). All the F_1 progeny had pigmented testa and red pericarp color. The F_2

Table 2. Relation of sorghum pericarp traits with grain mold in RTx 2536 (P_1) × SC 103-12E (P_2) at College Station, Texas, USA, and at Namulonge and Serere, Uganda.

Generation	Phenotype	Genotype	Phenotypic ratio	Location and grain mold ratings College Station	Namulonge	Serere	Mean[1]
P_1	White pericarp, testa absent	b1b1b2b2RRyy	–	5.0	4.7	4.8	4.83[c]
P_2	Red pericarp, testa present	B1B1B2B2RRYY	–	1.2	1.1	1.2	1.16[a]
Mid-parent	–	–	–	3.1	2.9	3.0	2.99
F_1	All red pericarp, testa present	B1b1B2b2RRYy	–	1.1	1.1	1.3	1.13[a]
F_2	a) Red pericarp, testa present	B1-B2-RRY-	9	1.4	1.4	1.3	1.27[a]
	b) Red pericarp, testa absent	b1b1b2b2RRY-	3	2.8	2.5	2.6	2.57[c]
	c) White pericarp, testa present	B1-B2-RRyy	3	2.1	1.8	1.9	1.87[b]
	d) White pericarp, testa absent	b1b1b2b2RRyy	1	4.7	4.8	4.8	4.76[c]
$F_1 \times P_1$	a) Red pericarp, testa present	B1-B2-RRY-	1	1.2	1.0	1.1	1.10[a]
	b) Red pericarp, testa absent	b1b1b2b2RRY-	1	2.8	2.7	2.6	2.63[c]
	c) White pericarp, testa present	B1-B2-RRyy	1	2.0	1.8	1.8	1.86[b]
	d) White pericarp, testa present	b1b1b2b2RRyy	1	4.4	4.0	4.3	4.17[d]
$F_1 \times P_2$	All red pericarp, testa present	B1-B2-RRY-	–	1.1	1.0	1.1	1.07[a]
Mean				2.37	2.22	2.32[g]	

1. Means with a common letter are not significantly different at $P = 0.05$ using Fisher's LSD.

population segregated in the expected 9:3:3:1 ratio ($P = 0.05$) with 9 for testa with red pericarp, 3 for testa with white pericarp, 3 for no testa with red pericarp, and 1 for no testa with white pericarp. The $F_1 \times P_1$ progeny segregated in the expected 1:1:1:1 ratio ($P = 0.05$), for similar gene combinations. $F_1 \times P_2$ progeny all had pigmented testa and red pericarp. These ratios showed that the genes B_1, B_2 and R, Y genes, at each individual gene locus, were inherited in a dominant manner:

The F_1 (Table 2) was resistant to mold, having a rating of 1.13, which was lower (though not significantly) than that of SC 103–12E (1.16), the resistant parent. This indicated possible additive gene action of both B_1, B_2 and R, Y genes for grain mold resistance. In the F_2 and backcross populations, phenotypes which possessed both gene combinations in their dominant conditions B_1-B_2-RRY - (testa present, red pericarp), had the lowest grain mold ratings (1.07–1.27), indicating high levels of resistance. Genotypes B_1 -b_2b_2 RRyy, $b_1b_1B_2$ - RRyy and $b_1b_1b_2b_2$ RRyy (testa absent, white pericarp), had the highest grain mold ratings (highest susceptibility). Genotypes B_1-B_2 - RRyy (testa present, white pericarp), and B_1 - b_2b_2 RRY-, $b_1b_1B_2$-RRY- (testa absent, red pericarp), showed relatively good resistance. Genotypes with a pigmented testa with white pericarps were more resistant than those with no pigmented testas, but had red pericarps. This demonstrated that both a pigmened testa, and a red pericarp confer grain mold resistance. Resistance conferred by a pigmented testa alone was greater than that by a red pericarp alone. However, the genes are complementary because when both traits were present, higher levels of resistance were obtained.

The inheritance and effect of pericarp color and intensifier genes were studied in the cross and progeny from BTx 378 (P_1) × RTx 2536 (Table 3). All of the F_1 progeny had red pericarp with intensifier gene (R-Y-I-). The F_2 population segregated in the expected 9:3:3:1 ratio ($P = 0.05$), with 9 for red pericarp with intensifier, 3 for red

Table 3. Relation of sorghum pericarp traits with grain mold in BTx 378 (P_1) × RTx 2536(P_2) at College Station, Texas, USA, and at Namulonge and Serere, Uganda.

Generation	Phenotype	Genotype	Phenotypic ratio	Location and grain mold ratings			
				College Station	Namulonge	Serere	Mean[1]
P_1	Red pericarp with intensifier	RRYYII	--	2.0	1.8	1.9	1.90[a]
P_2	White pericarp, no intensifier	RRyyii	–	5.0	4.7	4.8	4.83[e]
Mid-parent	–	–	–	2.4	2.75	2.85	2.87
F_1	All red pericarp with intensifier	RRYyIi	–	1.8	1.7	1.8	1.77[a]
F_2	a) Red pericarp with intensifier	RRY-I-	9	1.8	1.8	2.0	1.87[a]
	b) Red pericarp, no intensifier	RRY-ii	3	2.8	2.4	2.5	2.47[b]
	c) White pericarp with intensifier	RRyyI-	1	3.0	2.8	2.8	2.87[c]
	d) White pericarp, no intensifier	RRyyii	–	4.6	4.5	4.5	4.53[d]
$F_1 \times P_1$	All red pericarp with intensifier	RRY-I-	1	1.8	1.6	1.8	1.80[a]
$F_1 \times P_2$	a) Red pericarp with intensifier	RRY-I-	1	1.9	1.7	1.8	1.80[a]
	b) Red pericarp, no intensifier	RRY-ii	1	3.0	2.9	3.0	2.97[c]
	c) White pericarp with intensifier	RRyyI-	1	3.1	2.8	3.0	2.97[c]
	d) White pericarp, no intensifier	RRyyii	1	4.8	4.6	4.6	4.67[d]
Mean				2.97	2.78	2.88[fg]	

1. Means with a common letter are not significantly different at $P = 0.05$ using Fisher's LSD.

pericarp with no intensifier, 3 for white pericarp with intensifier, and 1 for white pericarp with no intensifier. The $F_1 \times P_1$ progeny had red pericarp with intensifier. The $F_1 \times P_2$ progeny segregated in the expected 1:1:1:1 ratio ($P = 0.05$) for similar gene combinations. These ratios showed that the genes for red pericarp color (R_1 Y) and the intensifier gene (I) are inherited in a dominant manner at each individual gene locus.

There was no significant difference in grain mold reaction between BTx 378 (RRYYII) and the F_1, F_2, and BC^{-1} progeny that possessed dominant R, Y, I genes (Table 3). They all had low grain mold ratings (1.77–1.90), indicating resistance. The F_1 progeny had the lowest grain mold value (1.77), lower than that of the resistant parent, indicating possible additive gene action of R-Y- and I- genes. Genotype RRyyI- (white pericarp, with intensifier), and RRY-ii (red pericarp, no intensifier), showed moderate resistance (2.5–3.0), although RRY-ii had better resistance than RRyyI-. Both R-Y- and I- genes confer grain mold resistance individually, and their effect was complementary when dominant.

The effect of mesocarp thickness was studied in the progeny from BTx 3197 (P_1) × RTx 2536 (P_2) (Table 4). All the F_1 plants had thin mesocarps (ZZ). The F_2 population segregated in the expected 3:1 ratio ($P = 0.05$) for thin-to-thick mesocarp. The $F_1 \times P_1$ segregated in the expected 1:1 ratio ($P = 0.05$) for thin-to-thick mesocarp, while all the $F_1 \times P_1$ progeny had a thin mesocarp. These data demonstrated the dominant inheritance of mesocarp thickness where thin is dominant over thick.

Table 4. Relation of the sorghum mesocarp thickness trait with grain mold in Btx 3197 (P_1) × RTx 2536 (P_2) at College Station, Texas, USA, and at Namulong and Serere, Uganda.

Generation	Mesocarp phenotype	Genotype	Phenotypic ratio	Location and grain mold ratings: College station	Namulonge	Serere	Mean[1]
P_1	Thick	zz	–	3.4	3.3	3.5	3.4^{a}
P_2	Thin	ZZ	–	5.0	4.7	4.8	4.83^{b}
Mid-parent	–	–	–	4.2	3.9	3.7	4.0
F_1	All thin	Zz	–	5.0	4.8	5.0	4.93^{c}
F_2	a) Thick	Z	3	4.9	4.8	5.0	4.90^{c}
$F_1 \times P_1$	b) Thin	zz	1	5.0	4.9	5.0	4.97^{c}
$F_1 \times P_2$	All thin	Z-	1	5.0	4.8	5.0	4.93^{c}
		zz	1	5.0	4.9	5.0	4.93^{c}
		Z-	–	5.0	4.8	5.0	4.93^{c}
	Mean			4.97	4.63	4.78^{d}	

1. Mean with a common letter are not significantly different at $P = 0.05$ using Fishers's LSD.

BTx 3197 had lower mean grain mold ratings (3.4) while RTx 2536 and all the progenies had the highest ratings (4.83–5.0) (Table 4). Grain mold ratings of the F_1 and all the other progenies were higher than the average of the parents (4.90–4.97). Thus all the progenies of this cross, whether segregating for thin or thick mesocarps, were highly susceptible to grain mold, indicating that susceptibility in this cross is probably dominant over resistance.

Grain mold severity at College Station and Serere were not significantly different, although College Station had numerically higher grain mold ratings than those at Serere. Namulonge had the lowest disease ratings.

Discussion

The identification of grain mold-resistant sorghum lines is difficult because numerous fungal species are involved and several types of damage can occur. Further, many plant and caryopsis traits are thought to be involved in conferring the resistance. A broader understanding of the genetic control of the resistance will enhance the development of intermating programs to generate variability which will enable scientists to combine resistance genes.

When inheritance of B_1, B_2, R,Y, and I genes were analyzed by Chi-square goodness-of-fit tests, the results agreed with the findings of earlier authors (Kulkarni et al. 1981, Murthy et al. 1980, Quinby and Martin 1984, Raab 1985, Siegliner 1984, Stephens 1946). Complete dominance was found when each locus was considered individually. Hence, a pigmented testa, red pericarp color, a thin mesocarp, and intensifier gene, are all dominantly inherited.

An examination of the effects of the various gene combinations showed that higher levels of resistance could be achieved by combining different genes. Generally, when genes at the loci were dominant for a pigmented test (B_1-B_2-), red pericarp (R-Y-), and intensifier gene (I-), there was a substantial reduction in grain mold. Progenies with a pigmented testa had higher grain mold resistance than those without. When R-Y- gene loci were considered, disregarding the B_1-B_2, grain mold resistance was observed, though not as great as that for the B_1-B_2- loci. When intensifier gene was considered alone, grain mold resistance was observed. However, its effect was more apparent when in combination with the R-Y- genes. White grain (RRyy) had lower grain mold resistance than red grain (RRY-).

Genotype B_1-B_2-RRY- gave the greatest resistance to molding. Therefore, an estimation of the number of genes for resistance is possible, varying with the particular F_2 population being studied.

The data given here agree with earlier reports involving grain mold resistance conditioned by these genes (Ellis 1972, Kulkarni et al. 1981, Quinby and Martin 1984, Rooney and Miller 1982). Ellis (Ellis 1972) studied the morphological characters for grain mold resistance and reported that a pigmented testa was the most influential seed character affecting weathering resistance in the field. Further, within a given genetic background and where a pigmented testa was absent, lines with red or lemon yellow pericarps were better than lines with white pericarps in grain mold resistance. The ability of a pigmented testa to resist grain mold development is attributed to its high tannin content. Tannins inhibit spore germination or mycelial growth (Bandyopadhyay et al. 1988, Hahn and Rooney 1985, Kambal and Bate-Smith 1976, Raab 1985, Rooney and Miller 1982). Similarly, red pericarp sorghums contain high levels of flavan-4-ols (Hahn and Rooney 1985, Kambal and Bate-Smith, 1976), which confer grain mold resistance.

Sorghums with thick pericarps have many starch granules in their mesocarps. For this reason, it was reported (Raab 1985, Rooney and Miller 1982) that sorghums with thick pericarps are more susceptible to grain mold since they are more capable of supporting fungal growth. Sorghums with thin pericarps have few, if any, starch granules so they are not believed to support fungal development. However, when crosses were made between BTx 3197 (thick mesocarp) and RTx 2536 (thin mesocarp) in these studies, all the progenies in F_1, F_2, and BC^{-1}, whether segregating for thin (ZZ) or thick (zz) mesocarps, were susceptible to grain mold. Moreover, the levels of susceptibility of the progenies were higher than those of either parent. These results signify that mesocarp thickness was not a component in grain mold resistance, and that susceptibility is probably dominant over resistance in this case.

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Breeding Sorghums For Infertile, Acid Soils

L M Gourley[1]

Abstract

Breeding crops for soil stress-related phenomena is a complex process. The necessary field-screening efforts are plagued with genotype-by-environment interactions which can result in little or no genetic gain due to selection. Selecting the proper level of stress for field evaluations, and maintaining this level in as dynamically changeable media as soil, can be difficult.

Additionally, few plant breeding programs involve attempts to develop varieties or hybrids specifically adapted to low-input cropping systems. Selections are generally made in highly fertile, weed-free, high plant population environments. However, many reports in the literature indicate that genes needed to achieve the maximum yield in low-input or stress environments often differ from those required in high-input conditions.

Sorghum is traditionally grown in arid or semi-arid regions of the world, which usually have neutral pH or alkaline soils. It is quite sensitive to the acid soil complex. The demand for cereal grains in tropical environments, characterized by acid soils, has mandated additional breeding research to adapt sorghum to these nontraditional environments. This paper presents the methodology and results of this effort.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is generally relegated to the fringe areas of production in many parts of the world because of it's known stress-tolerant characteristics. Sorghum crops are usually produced in areas where they have a competitive advantage. The question becomes, what is stress to the sorghum plant and how is stress tolerance characterized when breeding sorghum for tolerance to acid soils?

If you consider all of the biotic and abiotic factors, the continuum of time during plant growth in which the factor could apply and the interaction of factors, the list of stress variables becomes infinite. However, when the expectation of yield is reduced from maximum-input, to optimum-, to minimum-input, the list of important environmental stress factors becomes significantly shorter and more manageable. Consideration of an economic return also affects expenditures for inputs. Plant breeders must decide whether to breed for maximum genetic potential under optimum conditions or under a stress environment in which the crop is likely to be grown.

Production Constraints of the Tropics

Production constraints in the tropics are many and generally severe (Sanchez and Salinas 1981). We need to keep in mind that every environment imposes constraints on the growing plant and that a human being can alter only a few of these factors through culture and/or genetic means. In many countries in the tropics, which are considered as developing countries, agriculture inputs are generally expensive or unavailable. Lack of availability of capital, governmental control of prices of imported agricultural inputs, and commodity prices result in there being many low-input technology farmers. In other instances, farmers refuse to take the risk of using purchased inputs for sorghum production.

Considering the above, a few aspects of breeding sorghum for some of the stress environments of the tropics need to be discussed. Drought and infertile soils are probably two of the major sorghum production constraints in the tropics. The discussion will be limited to some of the findings and observations made while conducting research associated with the International Sorghum and Millet (INTSORMIL) project in Colombia, South America, and at

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Mississippi State University. This research is concerned with breeding sorghum for tolerance to infertile soils of the tropics.

In the 1970s, reports started appearing in the literature about the vast areas of infertile soils in the tropics, usually those which were very acid and contained levels of aluminum (Al) and manganese (Mn) too high for crop production using the available cultivars (Cochrane 1978, Foy et al. 1978, Schaffert et al. 1975). Fear of the world's population increasing faster than food production stimulated funding for research into uses of the underutilized agricultural lands of the tropics.

When developing a sorghum breeding program in a new research area, several questions need to be answered. What are the primary constraints? Is there genetic variability for tolerance to the constraint(s)? What is the degree and nature of the inheritance of the tolerance? What evaluation methods are available and have they been field validated? Is an expensive breeding program warranted or can cultural measures overcome the constraints? When my students and I examined these questions in the 1970s, we concluded that little was known about the genetic variability of sorghum tolerance to acid soils. At this time soil scientists were also determining the nature and quantity of acid soils in the tropics.

In the discussion of breeding sorghum for tolerance to the infertile, acid soil complex, I will not attempt a literature review nor try to prove beyond question any of the points made. I feel that a more general overview of findings, observations, suppositions, theory, and philosophy will be of more practical application to the members of this EARSAM workshop. After 15 years, we still have an incomplete understanding of some aspects of the research, but we feel that a great deal of progress has been made.

Firstly, not all acid soils were created equal nor are they uniform. The acid soils of Colombia, Brazil, Zambia, Niger, and Kenya all have their own peculiarities. Constraints also change due to rainfall, temperature, cation exchange capacity (CEC), natural content of essential elements, level of toxic ions, phosphorus (P) fixation capacity, and amount and quality of organic matter. Acid soils in Colombia have a very high Al saturation, while those in Zambia have moderate Al saturation plus very high Mn content (Gourley 1988). Both areas, however, normally receive adequate rainfall during the growing season. The acid soils in Brazil and Kenya can be drought prone during the growing season. The acid soils of Niger have a CEC of 1.0 or less, medium Mn content, low fertility, and are very drought prone.

Cultural Production Practices Used on Acid Soils

Several labor-intensive cultural methods are used in Africa to avoid or ameliorate the toxic effects of Al and/or Mn for sorghum production on acid soils. These methods substitute for purchased inputs of lime and fertilizer. Ashes from trees and bushes, organic residue from recently buried grass, elevated ridges made from topsoil and varying periods of fallow are used in transient agriculture systems instead of using purchased inputs.

Some of the cultural methods take advantage of organic matter to reduce the toxic effects of Al or Mn. Two observations can be made from our experience in Colombia. An ultisol with 7% organic matter is less severe on sorghum plant growth and yield than an oxisol with 4% organic matter, when both soils have 80% Al saturation. This comparison could also be due to other factors. A virgin oxisol acts like it is sterile and must produce one or two seasons of a tolerant crop before the microflora becomes active. Organic matter is more effective when it is fairly fresh than when it is decomposed to residual lignins. Our test plots were developed from land with a heavy sod of acid soil-tolerant pasture species. Two to three years later (four to six cropping seasons), the Al toxicity became very severe and required a much larger quantity of lime to reduce Al saturation than originally applied to the plots. This suggests that an old fashioned green manure crop might be a good investment for our plots and for farmers using low-input methods.

Acid Soil Field Screening in Colombia

Many of the 'quick tests' for Al tolerance appear to be better suited to evaluate different genotypes of wheat, rice or maize than sorghum. Sorghum seems to react somewhat differently than these crops to hematoxylin, Al pulse treatments, and Al in nutrient solutions (Howeler 1987). Many of these tests are reported in the sorghum literature without having been field validated (Furlani and Clark 1981). Another problem is the Al concentration used to evaluate sorghum genotypes both in the laboratory and in the field. Many of the genotypes reported to be acid soil tolerant in the literature are susceptible to 60% Al saturation in the field.

In 1980, when INTSORMIL, Centro Internacional de Agricultura Tropical (CIAT), and ICRISAT signed the memorandum or agreement to start this field project, CIAT and ICA scientists were of the opinion that unless sorghum genotypes could be found, which would tolerate 60% Al saturation and low-input technology, and produce 2 t grain ha^{-1}, the breeding effort was probably a waste of time and money.

Because of a lack of confidence in the so-called 'quick tests' for Al tolerance, a field-screening technique was developed at Quilichao, Colombia (Gourley 1987). The ultisol had an Al-saturation level of about 80%, a pH of 4.5 and an effective CEC of about 5. Five-hundred kilograms of dolomitic limestone were added to provide fertilizer quantities of calcium and magnesium, and to reduce the Al-saturation level to about 65%. Broadcast applications of N-P-K, zinc, and boron were added according to the soil test to ensure that these elements were not limiting. The procedure was designed to measure Al tolerance and, insofar as possible, not the effect of P or the Al-P interaction. The objective was to establish an Al-toxicity level which was high enough to kill sensitive genotypes, but not too high to prevent tolerant genotypes from producing a reasonable yield of grain. A simple visual rating scale was used to evaluate the exotic sorghum genotypes from the world collection.

After screening nearly 6000 sorghum genotypes, we found that about 8% would tolerate 65% Al saturation and a few of these varieties would produce more than 2 t ha^{-1} of grain (Gourley 1988). Most of these high-yielding genotypes were identified in the world collection as originating in Uganda and Kenya, and were classified as Caudatums. Several of these lines appear to be from Dr H Doggett's breeding program at the Serere Research Station in Uganda.

Some early observations at Quilichao, Colombia, indicated that most sorghum genotypes would tolerate 40% Al saturation and visual separation of tolerance and susceptibility was impossible with this level of stress. At about 65% Al saturation, susceptible genotypes such as Tx415 and Tx430 would produce good stands and grow for about 3 weeks and then every plant in the row would die. The soil at Quilichao was uniform enough that susceptible and tolerant genotypes planted in adjacent rows at regular spacings across the test field would, at maturity, be tolerant rows and blank rows. The fact that susceptible genotypes would produce perfectly good plant stands in 65% Al saturation plots casts suspicion on seedling primary root length as a screening technique. It also indicated to us that the seed was in some way protecting the primary root from the toxic effects of Al; however, the adventitious root system failed to penetrate the soil and the plant died.

Another early observation was that all of the higher-yielding, Al-tolerant Caudatums were quite photoperiod sensitive. They were tall and late in Brazil and Zambia. In Niger, they produced tall, late-maturity plants, and when the rains were over, the plants died without producing any grain. We also found that many of the Al-tolerant genotypes produced large root systems which assisted them in obtaining adequate mineral nutrition in low-input environments and that they were also more drought tolerant.

Several variety and combining ability studies in Colombia have compared growth and yield traits at varied Al-saturation levels (Flores et al. 1988 and 1991; Munoz-Arguedas 1988). These studies showed that Al tolerance was conditioned by both additive and nonadditive gene action. Hybrids which were very tolerant to Al were also observed, and these produced little grain. Usually, however, hybrids yielded more grain than either parent. The value of measuring the final product, the grain, was evident. Tolerance to Al toxicity of seedling traits and grain yield are not necessarily the same. Shared experiences with sorghum breeders in Brazil confirmed that Al tolerance appeared to be dominant and that tolerance was conditioned by only a few genes (Borgonovi et al. 1987). Heterosis for tolerance to these infertile soils was also observed.

Mineral element analyses of Al-tolerant genotypes growing on soils with high levels of Al saturation indicated that there may be more than one mechanism for tolerance to Al toxicity (Gourley et al. 1991). Some genotypes accumulate Al in their leaves, while others allow little Al into the plant. We have not seen a definite advantage of one type of tolerance over the other.

The ICA-INTSORMIL collaborative research resulted in the release of two Al-tolerant varieties. Both varieties are photoperiod sensitive and both probably came from Dr Doggett's program in Uganda. It is interesting that no effort was made to evaluate this material on acid soils during the developmental stages. Infertile soils were common at the multiple test sites, and recently some of these sites have been shown to have pH values in the range of 4–5.

Nutrient Solution and Other Laboratory Evaluations

Once Al-tolerant sorghum genotypes had been found using the field-screening technique, these genotypes were used to improve Al tolerance testing using nutrient solution cultures. After Al, the next most common toxic ion in acid soils is Mn. Laboratory experiments were conducted to find tolerance to Mn toxicity and to look at P uptake and efficiency in sorghum (Chintu 1989; Saadan 1991; Yakub 1988).

Manganese tolerance research is complicated by the fact that the toxic Mn ion can be found in the soil solution under several different conditions. First of all, the soil must contain a source of supply of Mn. In many soils, the black nodules or excretions of Mn are the readily available source of the soluble toxic ion. Low soil pH will cause the inert Mn to be converted to the toxic form, but Mn can also cause problems at pH 7. Temporary periods of waterlogging or poor drainage will reduce Mn to the toxic form. The farmer can correct one cause of Mn toxicity and still have the same production constraint caused by another factor. In the case of excess moisture, Mn toxicity can come and go several times during the growing season. In Australia, shifts in pH due to acidifying fertilizer caused Mn toxicity to suddenly become a new production constraint. In this case, several years of research were lost while plant pathologists looked for a virus as the causal agent.

Manganese toxicity has been reported to affect the aerial portion of the plant initially and root growth indirectly. By adding excess Mn to the nutrient solution and measuring top growth reduction, genotypes can be evaluated for tolerance to excess Mn. Mineral analysis of the leaf tissue is a good check to verify that Mn is, in fact, the cause of the growth reduction. We have used this technique to screen several hundred sorghum genotypes to concentrations as high as 7200 μM Mn L^{-1}. A concentration of 3600 μM Mn L^{-1} appears to give better genotype separation than higher or lower concentrations. Increasing the evaluation time to 28 days or longer allows for a better statistical differentiation of Al- and Mn-tolerant genotypes from susceptible ones. It also appears that Al and Mn tolerance are independently inherited.

Zambia has some soils with very high levels of Mn. We have concentrated our efforts by looking for Mn-tolerant sorghum genotypes in the world collection from Zambia. More screening effort is required to ensure that the highest level to Mn tolerance is obtained. Sites in northwestern Zambia, however, have not proven to be good field-screening sites. The soil is not uniform due to human activities (slash and burn) and insect activity (old and new termite mounds). As can also be expected in acid soils, Al toxicity occurs with Mn toxicity, but excess Mn is not always found in acid soils. Our test site at Quilichao, Colombia, has excess Mn, but a uniform screening area has not been found.

We looked at Al-tolerant sorghums first to see if genetic tolerance would be the same for both metal ions. It appears that this is not true. Some sorghum genotypes show selectivity of Mn uptake and others accumulate fairly large quantities of Mn without showing toxic effects. Genetic variability for Mn tolerance has been found and we feel that the level of tolerance identified is sufficient for most soils with the Mn production constraint.

In a recently completed genetic study, heterosis for Mn tolerance was observed and tolerance appears to be partially dominant to susceptibility (Saadan 1991). Additive gene action seems to be responsible for more of the genetic variability than nonadditive gene action. More inheritance research is needed for sorghum tolerance to Mn.

The sorghum plant's requirement for P is quite high over a short period of time and P is translocated in the plant from lower leaves to more active sinks. There is not much time for changes in the morphology or physiology of the plant to react to low P content before the constraint adversely affects yield. Theoretically, since most acid soils fix P to some degree and P is generally deficient in acid soils, sorghums which evolved in acid soil areas of Africa, should be more efficient in P uptake and/or utilization than sorghums which evolved in other soils. There are indications that this is true, but definitive tests are difficult.

We have found genetic variability for P uptake and P concentration and content in sorghum plants (Gourley et al. 1991, Yakub 1988). Increased P uptake appears to be due to the increase in the size of the root mass. We are not sure if a higher concentration of P in the flagleaf means that the plant is efficient or inefficient, only that the P is there. Unless we can show in the field that a genotype can produce more grain with less P than another genotype, we will not be able to say that it is more efficient. However, this is an area of research that should not be neglected.

Conclusion

We are currently conducting combining ability trials of tolerant by tolerant and tolerant by susceptible inbreds in Colombia and Kenya. Hybrids have many advantages over varieties in the infertile soil environment. Hybrid seedlings exhibit more vigor during emergence and early plant growth than varieties. Hybrids are almost always more stress *tolerant and yield more grain than the most tolerant parent or variety. Hybrids generally produce more extensive root* systems and exploit available soil nutrients and water better than varieties. High-yielding sorghum hybrids tolerant to the Al-toxic, infertile soils of the tropics will be the next generation of releases from the collaborative research of the INTSORMIL program.

In summary, the tropics have some of the most severe production constraints of any agricultural area in the world. Sorghum breeders can help overcome some of these constraints by incorporating tolerance factors into varieties and hybrids. Cultural practices are also required to modify the constraints. Resource-poor tropical farmers need these types of economic solutions to help feed their country's increasing population.

Acknowledgments

Research funded by USAID Grant No. DAN 1254-G-00-0021-00 through INTSORMIL, the International Sorghum and Millet CRSP.

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Inheritance of Manganese Tolerance in Sorghum

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Abstract

*Four restorer (R-lines), four male-sterile (A-lines), and 16 F_1 sorghum (*Sorghum bicolor *(L.) Moench) hybrids were evaluated in nutrient solution in three environments at 18 (control) and 3600 mol Mn L^{-1} (excess level of Mn). Visual ratings, plant growth, and dry matter yields of shoot, root, and total plant were the characteristics evaluated.*

Correlation coefficients (r) revealed that some independent characteristics were significant and highly correlated at both levels of Mn. However, some characteristics showed very weak correlation at the control level and increased at the high level of Mn, indicating the toxic effort of Mn on both roots and shoots.

The performance of F_1 hybrids for most of the characteristics studied were superior to those of inbred lines; however, males and females showed more significant differences for the characteristics studied than the male × female interactions. Thus, there were very few significant specific combining ability effects among the F_1 hybrids. Inbreds Tx432 (male) and Tx623 (female) were susceptible parents.

The study confirmed that Mn tolerance was conditioned by additive gene action and very little nonadditive gene action. Therefore, the inheritance of Mn tolerance in sorghum seedlings is additive. Due to the additive nature of genes conditioning tolerance to excess Mn, these genes can be accumulated in a recurrent selection breeding program and one can predict the performance through selection of parents.

Introduction

As the world population increases, the greatest potential to expand agricultural production relies on some of the potentially arable lands in tropical rainforest and savanna regions dominated by acid soils classified as oxisols and ultisols (Gourley 1987). These tropical acid soils are characterized by inherent low fertility, low pH, high levels of aluminum (Al) and manganese (Mn), and a high fixation of phosphorus (P). In most regions of the world where acid soils predominate, it has been difficult to produce cereals or increase production due to the high cost of soil amendments; however, low or moderate input technology, coupled with acid soil-tolerant varieties, can overcome these serious soil constraints.

Generally, Mn toxicity affects the aerial parts of the plant more than the roots. These damaged plant tissues have substantially higher concentrations of Mn than other tissues surrounding them. In nutrient cultures, browning of roots due to Mn toxicity has been reported (Morris and Pierre 1949, Foy 1983). An extremely wide variation in Mn concentration in the tissue of various species and varieties has often been found (Lohnis 1951, 1960, Ouellette and Dessureaux 1958, Morris and Pierre 1949). Tolerance to high Mn may be a result of low absorption capacity or, alternatively, of the ability to endure large accumulations of Mn in tissue without detrimental effects on the growth processes (Morris and Pierre, 1949, Hewitt 1948, Lohnis 1951, 1960).

Researchers have developed several methods of differentiating responses of plant genotypes to Mn toxicity. These include field screening, nutrient solution, and sand and soil pot culture. The advantage of solution culture screening is that there is greater control exerted over the level of exposure to the toxic element, the level of other nutrients in the solution, and pH than in the other methods.

Genetic studies on plant tolerance to Mn toxicity have suggested different theories regarding the factors conditioning tolerance. Duncan et al. (1988) suggested that genes controlling Mn tolerance were additive. Similar results were reported in alfalfa (*Medicago sativa* L.) where the heritability to Mn tolerance was high (Dessureaux 1959).

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Earlier findings at Mississippi State University indicated that there was genetic variation for Mn tolerance in sorghum (Chintu 1989). When different genotypes of sorghum were screened at 3600 mol Mn, there was 27–80% reduction in dry matter yield from the control. The broad sense heritability estimates ranged between 45 and 70%.

The objectives of this study were to:

1. develop a screening method for the evaluation of sorghum seedlings to Mn toxicity;
2. estimate genetic components of variance and heritability to tolerance to excess Mn in F_1 hybrids;
3. estimate correlations among root and shoot characteristics at differing levels of Mn.

Materials and Methods

Sorghum genotypes

Four cytoplasmic genic male-sterile lines (A-lines), differing from the four selected maintainer lines (B-lines) by their cytoplasm, were used as seed parents and crossed with four selected R-lines to produce 16 first filial generation (F_1) hybrids. The four R-lines were IA 28, IS 7254C, Tx430, and Tx432. The four A-lines were Wheatland, Tx623, (1)-52-2-1-2, and (2)-10-6-1-2. Seed of the 16 hybrid combinations were made by hand pollination at the Plant Science Farm, Mississippi State University, USA.

Evaluation procedure and equipment

Eight parent and 16 F_1 hybrid genotypes were evaluated for seedling tolerance to Mn toxicity in nutrient culture at 18 and 3600 mol L^{-1} Mn concentrations. Evaluation was done outside in an open angle iron structure used to support treatment containers. The experiment was carried out at the Plant Science Farm and was planted on 25 Sep and harvested 26 Oct 1989.

Nutrient solutions used in the experiment were composed according to Clark 1982. This was used to prepare a base nutrient solution which had 18 mol L^{-1} Mn, referred to as the control. A Mn stock solution was prepared by dissolving 468 g L^{-1} ($MnCl_2.4H_2O$) in water. A 1.5 mL aliquot of the stock solution was added to the base nutrient solution to produce the 3600 μ mol L^{-1} Mn treatment. The final pH of the solution was adjusted to 4.0 by the addition of either 1N HCl or 1N NaOH.

Seeds were treated in a saturated solution of benomyl [(methyl 1-(butycarbomyl) 2-benzimidazole carbamate] by adding 2 g of bencomyl to 1 L of deionized water. This fungicide was used to reduce the incidence of seedborne fungal pathogens. One hundred seeds were placed in a petri dish, covered with the fungicide solution, and left to soak for 30 min. The treated seeds were placed between moistened paper germination towels. The germination towels were rolled and placed in 1 L plastic cups filled one third with deionized water. These plastic cups were placed in a germination chamber set at a constant temperature of 28°C and 100% relative humidity. Seeds were left to germinate for 2 days and then the cups were placed in light to prevent excessive etiolation of the seedlings. The water in the cups was replaced with half-strength nutrient solution and the seedlings were allowed to grow and harden for 4 days. The seedlings were then transferred to the treatment containers which were filled with full-strength nutrient solution.

Treatment containers used in the experiment were constructed from 609.6 cm lengths of polyvinyl chloride (PVC) pipe, 15 cm in diameter. The pipes were cut into six pieces, 101.6 cm in length. A 15.24 cm^2 PVC plate, 0.635 cm thick with five holes of 2 cm diameter, was used to cover the top of each PVC pipe. Four of the holes were drilled an equal distance from the corners of the plate (5 cm) through which roots of the seedlings could be inserted into the tube. The fifth hole in the center of the plate was used to allow entry of an aeration tube. On the bottom of each PVC tube, another 15.24 cm^2 PVC plate was glued to ensure no leakage of nutrient solution. The volume of each pipe was approximately 20 L.

The experiment was conducted outside, in the open angle iron structure, using the 20-L capacity PVC containers. The PVC containers were supported in eight rows, 609.6 cm long with 85 cm between rows. One seedling was supported with cotton batting in each of the four holes of the cover plate. Roots of the seedlings were inserted through the plate to a depth sufficient for the crown area and adventitious root formation to be below the surface of the plate. Aeration of the nutrient solution was supplied by a 413.4 kilopascal air compressor. From the compressor, a main airline was arranged along all of the PVC pipes. A vaccination needle (25 G2/8) was attached to a 0.95 cm diameter tube, inserted into the main airline, and the other end of the aeration tube was inserted into the nutrient solution. The pH of the solution was monitored and adjusted to 4.0 with 1 N HCl or IN NaOH as required. Water lost from the tubes through evaporation or transpiration was replaced with deionized water. Fresh nutrient solution was placed in the tubes after 11 days. Seedlings were allowed to grow in the tubes for 21 days before harvest.

Data collection

The experiment was arranged in a 2 × 24 factorial arrangement and replicated four times. Experimental design was a randomized complete block. Data were collected for all quantitative measurements on each of the four seedlings grown in a treatment container. For statistical analyses, means of the four plants were used to adjust all data to a per-plant basis.

At harvest, visual rating of root and shoot growth was recorded according to Chintu (1989). Visual rating of shoots and roots was as follows:

Shoots

1 = Healthy, with or without the two bottom leaves with black specks.
2 = Healthy, with not more than five bottom leaves with black specks.
3 = Reduced growth, with more than five bottom leaves with black specks.
4 = Stunted growth, with all leaves having black specks.
5 = Dying plants.

Roots

1 = Very dense, with more than 10 adventitious roots.
2 = Dense fibrous roots, with up to 10 adventitious roots.
3 = Intermediate dense, with about 10 adventitious roots.
4 = Less dense, fibrous with few (five) adventitious roots.
5 = Stunted adventitious roots.

Length of roots and shoots of individual seedlings was measured and recorded. Seedlings were then separated at the crown, washed in deionized water, and each part was placed in a separate envelope. The envelopes were placed in a forced-air oven at 60°C for 3 days. The plant parts were then weighed and recorded. All the parameters were subjected to statistical analysis and the least significant difference (LSD) was used to separate the means. Each Mn level was analyzed separately and then a combined analysis was conducted.

Results and Discussion

The growth rate of seedlings was somewhat retarded due to low night temperatures. However, significant differences were found among genotypes and between Mn levels. Most genotype × Mn level interactions were also significant. There was significant visual contrast among genotypes and also between the two Mn levels.

For the control treatment, significant differences were observed among genotypes for all traits (Table 1). Partitioning genotype sum of squares revealed significant differences among crosses for all traits except visual root score. There were significant differences among parents for visual root score, root length, and total length. The contrast of parents versus crosses was significant for all traits.

Hybrids generally performed better than inbreds. The greatest total plant lengths were attained by hybrids Wheatland × IS 7254C (61.6 cm), Wheatland × IA 28 (60.3 cm), (1)-52-2-1-2 × Tx430 (59.2 cm), and (2)-10-6-1-2 × IA 28 (59.2 cm) (Table 2). Those which had low total plant length included Tx623 × Tx432, (46.6 cm), Tx623 × Tx430 (47.3 cm), and (1)-52-2-1-2 × Tx432 (49.2 cm). Total dry matter yield of hybrids, were high: (2)-10-6-1-2 × IS 7254C (0.449), Wheatland × IS 7254C (0.42 g), and (1)-52-2-1-2 × IS 7254C (0.39 g). Differences for visual ratings of shoots and roots were not very distinctive, as most of the genotypes scored below 2.0.

Table 1. Mean squares from the analyses of variance for eight variables from seedlings of eight parental and 16 F_1 hybrid genotypes grown at 18 μ mol.

		Mean squares							
		Length			Dry matter yield			Visual score	
Source	df	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root
Replication	3	16.70**	36.57	72.77*	0.0022*	0.0010*	0.007*	0.08	1.62**
Genotype	23	31.35**	62.82**	144.95**	0.0063**	0.0026**	0.017**	0.65**	0.84**
Parent (P)	7	3.41	65.90**	69.35*	0.0011	0.0003	0.002	0.35	0.93**
Crosses (C)	15	27.39**	59.01**	88.34**	0.0062**	0.0020**	0.016**	0.53**	0.33
P vs C	1	285.40**	97.77*	833.33**	0.0519**	0.0210**	0.137**	4.38**	7.93**
Error	69	3.73	18.28	26.54	0.0007	0.0004	0.002	0.19	0.24

* = $P < 0.05$, ** = $P < 0.01$.

Table 2. Means for eight variables from seedlings of eight parental and 16 F_1 hybrid genotypes grown at 18 μ mol Mn L^{-1}.

	Length (cm)			Dry matter yield (g)			Visual score	
Genotype	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root
Male								
IS 7254C	25.0	33.3	58.3	0.23	0.17	0.40	1.1	1.2
IA 28	20.3	36.4	56.7	0.17	0.14	0.31	1.6	1.5
Tx430	18.8	36.2	55.0	0.17	0.14	0.31	1.5	1.4
Tx432	19.8	32.8	52.6	0.16	0.12	0.28	1.4	1.4
Female								
(2)-10-6-1-2	21.3	37.0	58.3	0.20	0.16	0.36	1.3	1.2
(1)-52-2-1-2	21.0	32.9	53.9	0.19	0.14	0.38	1.4	1.4
Tx623	20.3	31.4	51.7	0.16	0.12	0.28	1.7	1.7
Wheatland	21.4	37.4	58.8	0.20	0.15	0.35	1.3	1.3
Crosses								
(2)-10-6xIS 7254C	24.3	34.5	58.8	0.25	0.19	0.44	1.0	1.0
(10)-52-2 × IS 7254C	25.0	29.6	54.6	0.23	0.16	0.39	1.3	1.3
Tx623 × IS 7254C	25.6	32.6	58.2	0.20	0.15	0.35	1.0	1.3
Wheatland × IS 7254C	25.1	36.5	61.6	0.25	0.17	0.42	1.0	1.3
(2)-10-6 × IA 28	20.7	38.5	59.2	0.20	0.17	0.37	1.3	1.3
(1)-52-2 × IA 28	19.3	33.3	52.6	0.14	0.12	0.26	2.0	1.8
Tx623 × IA 28	19.2	35.4	54.6	0.14	0.12	0.26	1.8	1.8
Wheatland × IA 28	22.0	38.3	60.3	0.20	0.15	0.35	1.3	1.3
(2)-10-6 × Tx430	19.7	37.0	56.7	0.18	0.16	0.34	1.5	1.5
(1)-52-2 × Tx430	19.9	39.3	59.2	0.20	0.17	0.37	1.0	1.3
Tx623 × Tx430	17.3	30.0	47.3	0.14	0.11	0.25	2.0	1.8
Wheatland × Tx430	18.3	38.4	56.7	0.15	0.13	0.28	1.5	1.3
(2)-10-6 × Tx432	20.3	37.9	58.2	0.17	0.13	0.30	1.3	1.0
(1)-52-2 × Tx432	19.8	29.4	49.2	0.17	0.12	0.29	1.3	1.5
Tx623 × Tx432	19.2	27.4	46.6	0.14	0.11	0.25	2.0	2.0
Wheatland × Tx432	20.0	36.4	56.4	0.18	0.14	0.32	1.3	1.3
Mean	20.9	34.7	55.6	0.18	0.14	0.32	1.4	1.4
LSD (0.05)	1.4	3.3	3.9	0.02	0.02	0.03	0.3	0.3

Table 3. Mean squares from the analyses of variance for eight variables from seedlings of eight parental and 16 F_1 hybrid genotypes grown at 3600 μ mol Mn L^{-1}.

		Mean squares							
		Length			Dry matter yield			Visual score	
Source	df	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root
Replication	3	8.21*	39.24	44.37	.0007*	.0007*	.0026*	2.69**	4.45**
Genotype	23	20.68**	29.49	72.47**	.0026**	.0017**	.0082**	1.28**	1.30**
Parent (P)	7	18.18**	32.05	64.76	.0020**	.0020**	.0083**	1.84**	0.64
Crosses (C)	15	20.31**	24.77	64.32*	.0028**	.0020**	.0090**	1.00**	1.60**
P vs C	1	43.85**	82.36	248.66**	.0030**	.0010*	.0020	1.68*	1.51
Error	69	2.36	22.32	31.83	.0002	.0002	.0008	0.38	0.51

* = $P < 0.05$, ** = $P < 0.01$

When the genotypes were grown at the toxic level of Mn (3600 μ mol L^{-1}), significant differences were observed for all variables except root length (Table 3). Partitioning sum of squares for genotypes into parent, crosses, and parents versus crosses, significant differences were observed for all the variables studied except for root length in all categories; total plant length and root score for parents; and total dry matter yield and root score for parents versus crosses. The ability of a genotype to accumulate high levels of dry matter, and to show vigorous growth under toxic soil conditions is considered as tolerance. Thus, those genotypes which attained greater plant length and higher dry matter yield were considered to be the most Mn tolerant.

The three hybrids produced total plant lengths of 56.2 cm for Wheatland × IS 7254C, 53.3 for (2)-10-6-1-2 × Tx430, and 49.5 cm for (1)-52-2-1-2 × IS 7254C, and were not different from each other (Table 4). All hybrids with Tx432
and IA 28 as males, except Wheatland × IA 28, produced total plant length not significantly different from the lowest hybrid. Genotypes which had vigorous seedlings also produced high dry matter yields. Hybrid Wheatland × IS 7254C produced the highest total plant dry matter yield. These differences were also observed visually.

Manganese toxicity symptoms were observed at early stages of plant growth. Almost all of the genotypes grown at the 3600 μ mol Mn L^{-1} level showed symptoms of Mn toxicity. The symptoms were the presence of black specks on the lower leaves. These symptoms were observed 2 days after transplanting into the 3600 μ mol Mn L^{-1} solution. Although black specks were observed at early stages of growth, tolerant genotypes recovered faster and produced healthier plants than those that were susceptible. Susceptible genotypes were severely affected by Mn toxicity. Leaves of susceptible genotypes were chlorotic with crinkled margins, and black specks were observed on the newly developing leaves. On tolerant genotypes, black specks were found mainly on the lower, old leaves.

Root growth was not severely affected by Mn toxicity, while dry matter yield was reduced by nearly one half that of the control. For both levels of Mn, roots accounted for the majority of total plant length while shoots made up the bulk of total dry matter yield.

Correlations

Correlation coefficients among variables measured were calculated. Correlation coefficients >0.80 for both levels of Mn were observed for shoot length versus shoot and total plant dry matter yield, and for shoot dry matter yield versus root dry matter yield. The correlation of shoot score and root score at 3600 mol L^{-1} was −0.83. The higher correlation coefficient between shoot and root scores for the 3600 μ mol Mn level compared with that for the control was due to the toxic effect of Mn on both roots and shoots.

Genetic analyses

The analyses of the North Carolina Design II mating showed significant differences among males and females at the control level of Mn for most of the characters studied (Table 5). Only dry matter yields of roots and total plant were

Table 4. Means for eight variables from seedlings of eight parental and 16 F_1 hybrid genotypes grown at 3600 μ mol Mn L^{-1}.

Genotype	Length (cm)			Dry matter yield (g)			Visual score	
	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root
Male								
IS 7254C	18.7	31.1	49.8	0.13	0.09	0.22	2.0	2.1
IA 28	14.3	29.8	43.9	0.08	0.06	0.14	2.7	2.8
Tx430	16.1	33.3	49.4	0.11	0.08	0.19	2.7	3.1
Tx432	14.0	29.3	43.2	0.08	0.05	0.13	3.3	3.4
Female								
(2)-10-6-1-2	16.2	30.7	46.9	0.10	0.07	0.17	2.6	2.7
(1)-52-2-1-2	15.3	30.4	45.8	0.10	0.07	0.17	2.6	2.9
Tx623	14.8	30.3	44.8	0.09	0.06	0.16	2.8	3.1
Wheatland	16.8	32.0	48.8	0.11	0.08	0.19	2.7	2.8
Crosses								
(2)-10-6xIS 7254C	19.1	28.0	47.1	0.13	0.09	0.22	2.0	2.0
(10)-52-2 × IS 7254C	18.1	31.4	49.4	0.13	0.09	0.21	1.8	1.8
Tx623 × IS 7254C	16.9	29.8	46.7	0.11	0.08	0.19	2.5	3.0
Wheatland × IS 7254C	20.9	35.3	56.1	0.15	0.11	0.26	1.8	1.5
(2)-10-6 × IA 28	14.9	29.3	44.2	0.09	0.07	0.16	2.5	2.5
(1)-52-2 × IA 28	13.3	29.3	42.6	0.07	0.05	0.12	2.8	3.0
Tx623 × IA 28	12.6	29.7	42.3	0.06	0.04	0.10	2.8	3.0
Wheatland × IA 28	16.2	30.9	46.5	0.10	0.07	0.17	2.8	2.8
(2)-10-6 × Tx430	15.9	37.4	53.3	0.11	0.08	0.19	2.5	2.8
(1)-52-2 × Tx430	15.9	31.5	47.4	0.12	0.09	0.21	2.8	3.3
Tx623 × Tx430	16.8	31.8	48.6	0.12	0.09	0.21	2.8	3.0
Wheatland × Tx430	16.0	32.5	48.5	0.10	0.08	0.18	2.8	3.5
(2)-10-6 × Tx432	14.9	28.3	43.2	0.07	0.05	0.12	3.3	3.5
(1)-52-2 × Tx432	14.1	29.4	43.5	0.07	0.05	0.12	3.0	3.5
Tx623 × Tx432	12.8	30.1	42.9	0.07	0.05	0.12	3.3	3.3
Wheatland × Tx432	14.3	29.4	43.7	0.09	0.05	0.14	3.5	3.5
Mean	15.8	30.9	46.7	0.10	0.07	0.17	2.7	2.9
LSD (0.05)	1.1	3.4	4.1	0.01	0.01	0.02	0.4	0.4

Table 5. Mean squares from the analyses of variance for eight variables for a North Carolina Mating Design II of sorghum seedlings grown at 18 μ mol Mn L^{-1}.

Source	df	Mean squares							
		Length			Dry matter yield			Visual score	
		Shoot	Root	Total	Shoot	Root	Total	Shoot	Root
Replication	3	13.3*	36.1	91.1*	0.0020	0.0010	0.007*	0.02	0.68*
Male (M)	3	121.1**	56.7	97.9*	0.0170**	0.0046**	0.039**	0.08**	0.30
Female (F)	3	3.5	144.7**	198.5**	0.0060**	0.0045**	0.021**	0.68**	0.80*
M × F	9	4.1	31.1	48.4	0.0010	0.0010*	0.005*	0.39	0.18
Error	45	4.1	21.4	31.5	0.0008	0.0005	0.002	0.20	0.22

* = $P < 0.05$, ** = $P < 0.01$.

Table 6. Mean squares from the analyses of variance for eight variables for a North Carolina Mating Design II of sorghum seedlings grown at 3600 μ mol Mn L^{-1}.

		Mean squares							
		Length			Dry matter yield			Visual score	
Source	df	Shoot	Root	Total	Shoot	Root	Total	Shoot	Root
Replication	3	12.0**	18.3	48.2	0.0004	0.0004	0.0001	1.35*	2.26**
Male (M)	3	75.8**	50.5	199.9**	0.0100**	0.0064**	0.0330**	4.18**	5.55**
Female (F)	3	13.4**	9.9	49.8	0.0010*	0.0004	0.0030*	0.23	0.39
M × F	9	4.1	21.1	23.9	0.0006*	0.0004	0.0020	0.18	0.68
Error	45	2.2	22.9	33.6	0.0003	0.0003	0.0010	0.34	0.42

* = $P < 0.05$, ** = $P < 0.01$.

significant (P <0.05) for the male × female interaction. This indicated that a portion of the total genetic variability for these two characters was due to nonadditive genetic variance. The majority of the genetic variance for all variables, however, appeared to be additive.

At the high Mn level, 3600 μ mol L^{-1}, significant differences were observed among males for all variables except root length, whereas only shoot length, shoot dry matter yield, and total plant dry matter yield showed significant differences among females (Table 6). Only shoot dry matter yield showed a significant (P <0.05) male × female interaction.

The small number of significant male × female interactions at either level of Mn demonstrated the greater importance of general combining ability (GCA) relative to specific combining ability (SCA). Thus, the discussion will be mainly focused on GCA effects of the inbred lines.

The means of all the hybrids of a particular inbred and their respective GCA effects for the length variables at 18 and 3600 μ mol Mn L^{-1} are shown in Table 7. For male parents, only IS 7254C had significant positive (GCA) effects. These included shoot length (4.02 cm) at the control level of Mn, and shoot (2.94 cm) and total plant length (3.26 cm) at the high Mn level. Significant negative GCA effects were recorded for Tx432 (–3.06) for total plant length and Tx430 (–2.19) shoot length at the control level. At 3600 μ mol Mn L^{-1}, Tx432 showed significant negative GCA effects for shoot (–1.76) and total plant dry matter yield (–3.41) and IA for shoot dry matter yield (–1.53).

Table 7. Means and estimates of general combining ability (GCA) effects for length of shoot, root, and total plant for hybrids grown at 18 and 3600 μ mol Mn L^{-1}.

	18 μ mol Mn						3600 μ mol Mn					
	Shoot (cm)		Root (cm)		Total (cm)		Shoot (cm)		Root (cm)		Total (cm)	
Genotype	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect
Male												
IS 7254C	25.0	4.02**	33.3	-1.35	58.3	2.75	18.7	2.94**	31.1	0.25	49.8	3.26**
IA 28	20.3	-0.67	36.4	1.73	56.5	0.98	14.3	-1.53**	29.8	-1.07	44.1	-2.68
Tx430	18.8	-2.19**	36.2	1.51	54.9	-0.67	16.1	0.35	33.3	2.40	49.4	2.84
Tx432	19.8	-1.16	32.8	-1.88	52.5	-3.06**	14.0	1.76**	29.3	-1.58	43.2	-3.41**
Female												
(2)-10-6-1-2	21.2	0.28	37.0	2.34**	58.3	2.70	16.2	0.41	30.7	-0.14	46.9	0.35
Tx623	20.3	-0.67	31.4	-3.30**	51.5	-4.08**	14.8	-1.03**	30.3	-0.55	44.8	-1.82
(1)-52-2-1-2	21.0	0.02	32.9	-1.79	52.8	-1.80	15.3	-0.43	30.4	-0.46	45.8	-0.82
Wheatland	21.4	0.38	37.4	2.76**	58.7	3.17*	16.8	1.05**	32.0	1.15	48.9	2.29

* = Significantly different from zero at P >0.05 according to the t-test.
** = Significantly different from zero at P >0.01 according to the t-test.

Table 8. Means and estimates of general combining ability (GCA) effects for dry matter yield of shoot, root, and total plant for hybrids grown at 18 and 3600 μ mol Mn L-1.

	18 μ mol Mn						3600 μ mol Mn					
	Shoot (g)		Root (g)		Total (g)		Shoot (g)		Root (g)		Total (g)	
Genotype	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect	Mean	GCA effect
Male												
IS 7254C	0.23	0.050**	0.17	0.020**	0.40	0.070**	0.13	0.030**	0.09	0.020**	0.22	0.050**
IA 28	0.17	-0.010	0.14	-0.004	0.31	-0.020	0.08	-0.020**	0.06	-0.010**	0.14	-0.030**
Tx430	0.17	-0.017*	0.14	0.001	0.31	-0.020	0.11	0.010**	0.08	0.010**	0.20	0.020**
Tx432	0.16	-0.020**	0.12	-0.020**	0.29	-0.040**	0.08	-0.020**	0.05	-0.020**	0.13	-0.040**
Female												
(2)-10-6-1-2	0.20	0.020*	0.16	0.020**	0.36	0.030**	0.10	0.002	0.07	0.001	0.17	0.003
(1)-52-2-1-2	0.19	0.001	0.14	-0.001	0.32	-0.003	0.09	-0.004	0.06	-0.002	0.17	-0.006
Tx623	0.16	-0.030**	0.12	-0.020**	0.28	-0.050**	0.09	-0.009*	0.06	-0.006	0.16	-0.010
Wheatland	0.20	0.012	0.15	0.004*	0.34	0.020	0.11	0.010*	0.07	0.007	0.19	0.020*

* = Significantly different from zero at *P* 0.05 according to the t-test.
** = Significantly different from zero at *P* 0.01 according to the t-test.

For females, Wheatland and (2)-10-6-1-2 had significant positive GCA effects for root length, the former with 2.76 cm and the latter with 2.34 cm, and Wheatland for total plant length (3.17) at the control Mn level. At the high Mn level, only Wheatland showed significant positive GCA effects for shoot length (1.05). Significant negative GCA effects were observed due to Tx623 for root (−3.30) and total plant length (−4.08) at the control level of Mn and for shoot length (−1.03) at the high Mn level.

General combining ability effects for dry matter yield variable at both levels of Mn are shown in Table 8. Inbred IS 7254C showed significant positive and inbred Tx432 significant negative GCA effects for all dry matter yield variables at both Mn levels. Although Tx430 showed significant negative GCA effects for shoot dry matter yield (−0.017) at the control level of Mn, at the high level of Mn, significant positive GCA effects were observed for this inbred for shoot (0.010), root (0.010), and total plant (0.020) dry matter yields. Inbred IA 28, at the high level of Mn, showed significant negative GCA effects for shoot, root, and total plant dry matter yields.

For females, (2)-10-6-1-2 showed significant positive and Tx623 significant negative GCA effects for shoot, root, and total plant dry matter yield at the control level of Mn. Wheatland showed significant positive GCA effects at the control level for shoot dry matter yield, and at the high level of Mn for shoot and total plant dry matter yields. Inbred Tx623 showed significant negative effects for shoot dry matter yield at the high level of Mn.

For visual rating, IS 7254C showed significant negative GCA effects for shoot score (−0.33) at the control and (−0.66) at the high level of Mn; and for root score (−0.80) at high Mn level. Inbred Tx432 showed significant positive GCA effects for shoot score (0.59) and root score (0.58) at the high level of Mn. Due to the rating scale, negative GCA effects indicate less damage and positive GCA effects indicate more damage. For females, Tx623 had significant positive GCA effects for shoot and root scores at the control level of Mn. No female had significant GCA effects at the high level of Mn.

Conclusion

These results indicate that Mn tolerance as measured by root and shoot length and dry matter yield was mainly conditioned by additive gene action. Very few crosses had significant SCA effects (SCA effects not shown) for the traits observed. Nonadditive gene action made little or no contribution to tolerance of excess Mn. Due to the additive nature of genes conditioning tolerance to Mn toxicity, one could predict the performance of a hybrid on the basis of the performance of the parents.

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Discussion Session 1:
Improvement and Production of Sorghum

Title of Paper: Sorghum Breeding at ICRISAT Asia Center

Name of Speakers: B V S Reddy and J W Stenhouse

Question: *A M Mbwaga*

In your presentation, utilization of sorghum was not mentioned. Are you carrying out any research work on this aspect? From the point of view of small scale farmers, I consider sorghum utilization as one of the main factors which could promote sorghum production in eastern Africa.

Answers: *J W Stenhouse*

The Crop Quality Unit at IAC looks at various aspects of sorghum utilization such as malting, starch production, and feed uses. However, we do not breed for specific quality traits or for specific end uses.

B V S Reddy

We have worked on grain-evident traits associated with the quality of various food types, e.g., soft endosperm texture useful for '*kisra*' and '*injera*', with hard endosperm, useful for '*toi*' making. We do not look at the nutritional quality. But, our Crop Quality Unit is exploring alternative uses—starch, glucose, syrup, malt, brewing, etc.

Questions: *Adipala Ekwamu*

1. On what basis does ICRISAT decide on particular disease/pest problems as its research priorities?
2. Clarify on the genetics of resistance to drought on terminal stress. What is the genetic basis of resistance? The term *tolerance* has been used in respect with "resistance" to stress. In a genetic sense, are these two words interchangable?

Answers: *B V S Reddy*

1. ICRISAT scientists discuss these problems with the NARS scientists, consult libraries, reports, etc., and visit different programs. From the experience, they decide collectively on the themes and priorities that ICRISAT should have. Now ICRISAT has developed a structured analysis to decide on the themes. Dr D E Byth is the right person to address this question.

D E Byth

1. The current Medium Term Plan (MTP) process involved priority action by representatives of NARS, of research themes proposed by ICRISAT scientists. These priority areas were then assessed for impact in terms of benefit/cost ratio of the research equity of impact, internationality, and sustainability. Finally, ICRISAT was required to decide on its comparative advantage to undertake that type of research. Thus overall, the ICRISAT research portfolio will focus on the priority areas recognized by the NARS and in which ICRISAT has some comparative advantage and a potential to achieve a strategic impact.

F R Bidinger

2. We have no information on the genetics of tolerance to terminal stress, but as this is a complex character, the inheritance will almost certainly be quantitative. The use of the terms "resistance" and "tolerance" is a personal choice. I prefer to use "tolerance" as plants are subject to the effects of stress, in contrast to disease situations where plants can truly resist the pathogen. Differences among genotypes under stress are really differences in how well they tolerate the stress.

Question: *A B El Ahmadi*

In your conversion, what consideration have you given to drought tolerance?

Answers: *J W Stenhouse*

We have not included drought-tolerant lines among the lines we are converting to male sterility on alternative cytoplasms, mainly because the best resistant source lines we have are completely unimproved and suffer the defects usual in such material. This could, however, be done if there is need for drought resistant male steriles of this type.

B V S Reddy

We found that there is no universal drought resistance: early stage drought is different from mid season and postflowering drought, and hence their resistance mechanisms. Also, within each drought the resistance mechanisms also differ with the intensity of drought. It has been shown that high yielding potential lines in the given maturity adaptations do well under drought also. Materials from the early maturity project contribute to drought escape, and will be useful to terminal drought-affected locations.

Question: *L Gourley*

You stated that you found a positive correlation between earliness and yield. Across maturity gene groups, there is a positive correlation between lateness and yield. Are you speaking only of the early maturity group?

Answer: *J W Stenhouse*

Yes. We found a small positive correlation—not significantly different from zero—among a range of early material alone. The importance of this is that we could identify early maturing material with high yield among relatively unimportant test entries.

Question: *J P Esele*

In your medium maturity projects, you use caudatum and durra types, while in the grain mold project, you use guinea types. What specific qualities do each of these types of sorghums have relative to the projects? Why can't you use both types of sorghum for each of the projects?

Answer: *J W Stenhouse*

These races carried the resistance traits in which we were interested. In the medium duration project, we focus on insect resistance. The best sources of resistance to shoot fly come from durra sorghums, particularly those from India. Stem borer sources are predominantly durra. High yield potential has come from caudatums. In breeding for grain mold resistance, and white grain, the other traits we were interested in were found in guinea sorghums. Hence breeding materials in these projects are dominated by these particular races.

Question: *L G Olugbemi*

Despite all the research that has gone into sorghum improvement and management within the last decade or so, you indicated that sorghum yield per unit area in eastern Africa from 1981–92 has gone down. What is the explanation for this?

Answer: *J W Stenhouse*

The figures should be treated with great caution as they are subject to large year to year variation due to climatic variation. The general trend is for large increases in area and small increases in productivity.

Question: *Zenon Kabiro*

How are you handling the insect storage problem?

Answers: *J W Stenhouse*

We have no activities at IAC on postharvest storage problems. We feel that this is an area where we have no comparative advantage and which would be best addressed at regional or national level so that storage or insect control methods suited to local requirements can be developed.

B V S Reddy

Dr Klaus Leuschner, Entomologist, is looking into this aspect at ICRISAT/SADC, Bulawayo, Zimbabwe. Further input in this area depends on the themes of research that are approved in MPT by CGIAR, and which become operational from 1994–98.

Title of Paper: Breeding Sorghum for Irrigated High and Low Rainlands of the Sudan

Name of Speaker: Osman El Obeid Ibrahim

Question: *L B Olugbemi*

In view of the low level of yield obtained by sorghum farmers in the Sudan, what yield level should these farmers obtain, in order to break even?

Answer: *O E Ibrahim*

1. Farmers who practice rainfed traditional and mechanized farming tend to invest minimum in sorghum production with minimum land preparation, no fertilization, and minimal land weeding. Under this situation, it does not take much to break even, and an average of 0.15 t ha^{-1} would be sufficient.
2. The situation in irrigated farming is different when high technology is available. The use of high techonology requires a high yield per unit area to break even.
3. In the present situation, and due to a rapidly changing economy, from a government-controlled economy, to a new economy, it is very difficult to give a general statement on the minimum field required to break even, and that is because prices of inputs are changing. For instance, fertilizer prices went up from LS 300 in 1990 to LS 1600 in 1992 for 50 kg of urea.

Comment: *O E Ibrahim*

The Sudan is having great hope on private seed companies to promote commercial hybrids because we admit that our seed production system is not qualified to promote hybrids in this country. However, I found that the process of releasing new hybrids is very slow even with the presence of the Pioneer company in this country and in spite of the simplified release procedure adapted by the ARC release committee.

Title of Paper: Inheritance of Manganese Tolerance in Sorghum

Name of Speaker: H M Saadan

Question: *Zenon Kabiro*

I would like to know if there is any association between aluminium toxicity and cold tolerance.

Answer: *L Gourley*

I have no evidence of a correlation between these factors.

Comment: *S Z Mukuru*

I believe that what Z. Kabiro was asking is whether you have sources of tolerance to acid soils combined with cold tolerance for use in the high-altitude areas of Burundi. If these are not available, I suggest screening the high-altitude-adapted germplasm for sources of tolerance to acid soils.

Answer: *L Gourley*

We have not screened the high-altitude, cold-tolerant material. This needs to be done. We cannot provide sources of aluminium tolerance, but first of all, a soil test needs to tell us if the major constraint is aluminium or manganese or both, or if the problem is phosphorus. This would determine which source to use in a breeding program. I would be happy to cooperate with the sorghum researchers in Burundi to help solve their acid soil problem.

Question: *D E Byth*

The use of nutrient solution screens allows control of the species of the element under study, whereas the soil medium does not do so. How do you recommend we deal with this important level of complexity?

Answer: *L Gourley*

We breeders need some help from the soil chemists and plant physiologists. However, our laboratory tests must be field validated in "hot spots" in the different acid soil constraint areas.

Questions: *Brhane Gebrekidan*

1. Are the screening methods used for Al and Mn toxicity similar? What are correlations between Al and Mn toxicity (i.e., genotypes screened under Al and Mn)?
2. Please comment on the importance of screening of sorghums for drought stressed and acid soils of western Africa (e.g., Niger)

Answers: *H M Saadan*

The screening methods used for Al and Mn toxicity are similar, except for the toxic concentration of Al and Mn. There is no correlation between Al and Mn toxicity, since Al tolerance is dominant while Mn tolerance is additive.

L Gourley

We found that Al-tolerant genotypes of sorghum have better root systems (more mass) than nontolerant genotypes, but this in itself does not make them drought tolerant. Some of the acid soils in Niger are below pH 5.2, so soluble Al should not be the problem. Some of these soils do have sources of Mn which could become soluble and toxic. I feel the first constraint to sorghum productivity in Niger is drought. The soils have a very low CEC, but we do not know what the primary acid soil constraint is. To overcome the problem, drought tolerance needs to be added to tolerance of the soil constraint.

Questions: *A Ekwamu*

1. What is the relationship, i.e., correlation, between seedling and adult plant resistance (tolerance) to Mn?
2. Could you comment on nutrient solution versus toxic ion in the soil for Mn and Al tolerance in sorghum germplasm.

Answers: *L Gourley*

1. The studies were based on seedling screening; therefore, the relationship of the seedling to a fully grown (matured) plant was not carried out.
2. Toxic ions in soil are more complex than in nutrient solution; thus, screening in nutrient culture is more reliable since the amount of nutrients and concentration can be controlled.

Title of Paper: Performance of Sorghum Hybrids in Stress Environments

Name of speaker: Tadesse Mulatu

Question: *F R Bidinger*

Was the advantage of the hybrids due to their generally earlier flowering, or do they have specific drought tolerance characteristics?

Answer: *Tedesse Mulatu*

So far we are looking for hybrids with early flowering (<70 days) and reasonable yield potentials (3.5–4.0 t ha^{-1}) in stress environments.

Question: *A B El Ahmadi*

Have you tested your hybrids for acceptability by consumers?

Answer: *Tadesse Mulatu*

We did not conduct any in depth study as to the acceptability. However, when we selected hybrids, we arrived at some visual conclusions regarding the seed color, size, and shape.

Question: *S Z Mukuru*

You indicated in your presentation, that sorghum hybrids produced higher grain yields than varieties under drought stress. Have you identified a high-yielding sorghum hybrid for release to farmers in drought-stressed environments? If not, why not?

Answer: *Tadesse Mulatu*

By the time we identified good hybrids for release, the seed company was at its infant stage and capable of producing only open-pollinated varieties.

Question: *J P Esele*

One of the leading production constraints to sorghum production in most of Africa is lack of an efficient seed production and distribution system. Certainly, if you promote hybrid sorghum production, then the seed production and distribution system has to be efficient. Do you have such an efficient system in Ethiopia?

Answer: *Tadesse Mulatu*

So far we have only one seed corporation and this corporation could not cope with the high demand for improved seed. Recently, the policy has been improved and in the near future, more efficient companies could emerge.

Title of Paper: Threshing Percentage as an Indicator of Tolerance of Terminal Drought Stress in Sorghum

Name of Speaker: F R Bidinger

Question: *Hassan El Awad*

Is there any correlation between threshing percentage and seed size or 1000-seed mass? I want to make sure they are not the same.

Answer: *F R Bidinger*

Variation in threshing percentage can be due to variation in 1000-seed mass as well as in seed number per panicle. Under terminal stress, seed number per panicle is likely to vary more than 1000-seed mass, especially if the stress is very severe. We do not measure seed size, but this is related, although not perfectly, to 1000-seed mass.

Question: *L B Olugbemi*

Do you have any information on the possible relationship between threshing percentage and harvest index?

Answer: *F R Bidinger*

Both are ratios of grain mass to a total vegetative mass. In the case of harvest index, the vegetative mass is that of the whole plant, whereas with threshing percentage, the vegetative mass is that of the panicle only. Threshing percentage could be called *panicle* harvest index.

Question: *O E Ibrahim*

Threshability is controlled by environment as well as genetics. Don't you think that this technique should be restricted to specific types of sorghum with known level of threshability under optimum growing conditions?

Answer: *F R.Bidinger*

I agree – threshing percentage as I use the term under stress conditions, is a measure of g × e (where e = moisture availability) True genetic differences in threshing percentage are another problem If genetic differences exist in a set of genotypes, apart from the effects of stress, it might be better to compare threshing percentage under stress to threshing percentage in the absence of stress (e g , in an irrigated location) as a measure of tolerance susceptibility to terminal stress

Question: *A B El Ahmadi*

Threshing percentage has been used as an indicator of the ease of threshing As an indicator of terminal drought tolerance, it is a new, and in my view, a novel idea Our Hageen Durra 1 has been considered drought tolerant because it yields relatively better than other genotypes under stress But because of poor seed development, I suspect that HD 1 will have low threshing percentage under stress Will this be judged susceptible to drought stress?

Answer: *F R Bidinger*

Actual grain yield under stress is a function of both yield potential and drought tolerance Hageen Durra 1 may yield well under stress because of its high yield potential, rather than any drought per se I would suggest, however, that you compare the threshing percentage of HD-1 to that of other varieties and hybrids under terminal stress conditions

Question: *J P Esele*

I would like to seek clarification on some of the terminology used in this presentation What is terminal stress? In the Kiboko data, short rains were described as mild stress and long rains as severe stress I thought you would get severe stress in the short rather than in the long rains?

Answer: *F R Bidinger*

I based the description of the stress on each season on the time that the rains ended, relative to the time of flowering of the entries in the field In the short rainy season of 1991/92, the rains ended after flowering, whereas in the long rains of 1992, the rains ended before flowering and yields were much lower than those in the short rainy season

Title of Paper: Genetics of Grain Mold Resistance in Sorghum

Name of Speaker: J Peter Esele

Question: *J W Stenhouse*

Do you have information on grain hardness in your material? The reason I ask is that your resistant lines would be classified as susceptible in the tests we conduct at ICRISAT Asia Center, and I suspect that different grain hardness might be confounding your results

Answer: *J P Esele*

I did not consider endosperm texture in this experiment However, if we consider that endosperm corneousness is related to the amount and looseness/tightness of starch granules present, or their numbers, then it may be related to the situation of the granules in the mesocarp Since the number of starch granules have no effect on grain mold resistance, one can assume that grain endosperm corneousness may not have much to contribute to grain mold resistance This, however, is subject to experimentation and I would encourage scientists to undertake it

Questions: *Adipala Ekwamu*

1 How do you rate grain mold problem vis-a-vis other disease problems in sorghum in Uganda?

2 Although some known sorghums are attacked by grain molds, your data suggests that the white grains are generally susceptible Do you think this is a major hindrance to popularizing white sorghums in Uganda?

Answer: *J P Esele*

1 Considering that grain mold is more damaging on the improved sorghums which are high yielding but which unfortunately, mature when weather conditions favor mold development, I would classify grain mold as a potential

problem The other problem on leaf diseases, mainly anthracnose (*Collectotricum graminicola*) is serious, but not as serious as grain mold

2 We are worried about the susceptibility of the white sorghums because they are the sorghums that we are advancing for industrial application, especially for the manufacture of bread, biscuits, etc However, from my data, if we could incorporate the intensifier gene (I-gene), a modifier gene for grain color, I think we should be able to get reasonable levels of resistance to mold

Question: *Girma Tegegne*

Grain mold is associated with different fungi Do you think the resistance factor you mentioned could do well for other diseases as well?

Answer: *J P Esele*

Grain mold is caused by a wide range of fungi—in fact, over 40 different genera In this experiment, I chose to use only *Fusarium moniliforme* and *Curvularia lunata* because these two fungi are the most predominant grain mold fungi throughout the world I believe that the resistance against these fungi applies to all other fungi

Question: *S B King*

I understood you to say during the discussion session, that there is grain mold resistance in tan plant types Please confirm this, and if the statement is correct, would you please tell us the basis for this resistance?

Answer: *J P Esele*

In a different experiment in which I considered the effect of plant color (tan, purple, and red), I found that tan plants were more resistant to grain mold than the other types I have not found out what, in the chemistry of the tan plant, contributes to resistance I needed an input from a chemist

Question: *D L Byth*

There has been a discussion on grain hardness Is it a matter of endosperm hardness, or is it really associated with pericarp and/or mesocarp hardness/texture/compaction?

Answer: *J P Esele*

In my personal opinion, mesocarp hardness is related to endosperm texture

Question: *S Z Mukuru*

You concluded that grain mold reaction at Serere and College Station were not significantly different and that these two locations were good for grain mold resistance selection, but that Namulonge was not a suitable location What are the major factors that make Namulonge not suitable? Namulonge is wetter and more humid than Serere

Answer: *J P Esele*

At the time data were ready for collection, the weather at Namulonge was drier and was therefore not suitable for grain mold development

Session 2

Improvement and Production of Millets

Performance of Elite Pearl Millet Varieties Under the Dry Conditions of Western Sudan

El Hag Hassan Abuelgasim[1]

Abstract

*Pearl millet (*Pennisetum typhoides*) is the preferred staple food for the majority of the 6 million inhabitants of western Sudan (Kordofan and Darfur states). Among the cereals, it comes second to sorghum in area and total production in the country. The average pearl millet area sown annually is about 1.6 million ha, with 90% of this area being found in western Sudan, mainly in the extensive sandy soil zone. The crop is mainly raised under traditional rainfed farming methods, with most of the production being centered in the drier marginal areas with annual rainfall of less than 500 mm. Yields are generally low, the average being around 200 kg ha^{-1}.*

A pearl millet trial comprising two promising selections bred at El Obeid Station (Bristled population and Tafra), three local varieties (Kordofani, Buda, and Dembi), a released variety (Ugandi), and four exotic varieties (7701, Nuhifed, and Kano) were evaluated at El Obeid Station during the 1991 rainy season. The results of the trial are presented and discussed.

Introduction

Pearl millet (*Pennisetum typhoides*) is the preferred staple food for the majority of the 6 million inhabitants of western Sudan (Kordofan and Darfur states). Among the cereals, it comes second to sorghum in area and total production in the country. The average pearl millet area planted annually is about 1.6 million ha, with 90% of this area being found in western Sudan, mainly in the extensive sandy soils zone. The crop is mainly raised under traditional rainfed farming methods, with most of the production being centered in the drier marginal areas of less than 500 mm of annual rainfall. Yields are generally low, the average being around 200 kg ha^{-1}.

Low and unreliable rainfall is the most important constraint to millet production. Other constraints include poor genetic stocks, poor cultural practices, low soil fertility, losses due to pests and diseases, and socioeconomic constraints such as lack of inputs, transportation, etc.

The objectives of the pearl millet program, are to develop high-yielding, drought-tolerant, early-maturing varieties with acceptable grain quality and resistance to prevailing pests and diseases. A number of breeding approaches have been followed, including collection and screening of indigenous germplasm, introduction and evaluation of exotic material, hybridization, and population improvement by recurrent selection methods. During the past few years, the performance of several thousand entries has been evaluated in a set of preliminary, advanced, and standard variety trials. This paper reports the performance of elite pearl millet varieties from the Standard Pearl Millet Variety Trial grown at El Obeid Agricultural Research Station during the 1991/92 rainy season.

Materials and Methods

Ten varieties of pearl millet were grown in a randomized complete block design with four replications. Each experimental plot consisted of 6 rows of 5 m length, with a spacing of 75 cm between rows and 50 cm between plant holes within the row. Two plants were left in each hole after thinning. Planting was done on 31 Jul 1991.

Data were recorded only from the four central rows of each plot. The varieties tested included two promising selections bred at El Obeid Station (Bristled Population and Tafra), three local varieties (Kordofani, Bauda, and Dembi), the released variety (Ugandi), and four exotic varieties (7701, Nutrifeed, Maiwa, and Kano).

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Table 1. Amount and distribution of rainfall at El Obeid during May-Sep 1991.

Month	Date	Amount of rainfall (mm)	Total (mm) per month
May 1991	10	5.8	
	11	3.8	
	15	11.0	
	21	8.5	
	22	17.0	46.1
Jun 1991	-	-[1]	-
Jul 1991	16	9.5	
	22	46.0	
	31	6.5	62.0
Aug 1991	3	35.5	
	4	4.5	
	9	15.0	
	14	12.0	
	23	17.5	
	27	11.0	95.0
Sep 1991	15	18.0	
	21	9.0	27.0
			230.1

1. - = Nil rainfall

The trial was conducted under rainfed conditions. The total amount of rainfall received during the season was only 230.1 mm, with 128.5 mm falling after planting, which amounts to the effective rainfall (Table 1).

Results and Discussion

Table 2 shows the performance of the 10 pearl millet varieties for the different agronomic traits studied. There were significant differences among the varieties for all the seven characters studied.

The grain yields obtained, ranging from 146 to 392 kg ha^{-1}, were generally low, mainly due to the low total rainfall and the poor distribution of rains, specially the occurrence of a long dry spell in the middle of the growing season. Generally, the early-maturing varieties gave better grain yields than the late-maturing varieties (Kano, Maiwa, and Bauda). Such a result is expected and it matches the experience gained during the past few years, where it has been shown that whenever there is a dry season of below-normal average rainfall, the varieties that will give yields under this harsh environment are those having a maturity period of 90 days or lower. In this trial, the three late-maturing varieties had many plants without heads, as reflected by the low number of heads per plant (Table 2). On the other hand, these varieties showed higher values for straw yield per hectare, indicating that they tend to show a high rate of vegetative growth but the length of the growing season does not allow their optimum heading and maturity.

Table 2. Performance of 10 elite pearl millet varieties for different agronomic traits, El Obeid, Sudan, 1991-92 season.

Yield rank	Variety	Grain yield (kg ha^{-1})	Time to 50% flowering (days)	Plant Population ('000 ha)	Number of heads per plant	1000-grain mass (gms)	Plant height (cm)	Straw yield (kg ha^{-1})
1	7701 (YM 352)	392	54	42	1.8	5.2	104	683
2	Nutrifeed	346	51	49	1.4	6.8	117	458
3	Dembi	338	56	47	1.4	5.8	96	675
4	Tafra	325	55	50	1.4	5.6	124	742
5	Ugandi	317	52	51	1.4	7.3	107	617
6	Bristled Population	313	54	40	1.3	7.9	99	767
7	Kordofani	313	53	49	1.2	6.1	101	742
8	Bauda	258	68	50	0.5	5.0	78	892
9	Maiwa	192	63	47	0.9	5.7	111	867
10	Kano	146	67	52	0.7	4.7	99	1025
	Grand mean	294	57	48	1.2	6.0	103	747
	SE (mean)	±46	±2	±3	±0.1	±0.8	±8	±108

The highest grain yield (392 kg ha^{-1}) was given by the exotic variety 7701, followed by the variety Nutrifeed (346 kg ha^{-1}). However, these two varieties were not significantly different in grain yield from the varieties Dembi, Tafra, Ugandi, Bristled Population, or Kordofani. The Bristled Population had the largest grain size followed by the variety Ugandi; while the variety Tafra had the highest plant height (124 cm).

The results generally indicate that the emphasis should be put on early-maturing varieties that would better suit this dry environment, while medium-maturing varieties, with higher yield potential, should be the choice for higher-rainfall southern areas of western Sudan.

Cooperative Breeding of Open-pollinated Varieties

E Weltzien R and C T Hash[1]

Abstract

In the past years, the Pearl Millet Breeding Unit at ICRISAT Asia Center (IAC) has created several new breeding populations with differing genetic backgrounds. These populations have a wide range of maturity, differences in plant architecture, and good levels of downy mildew resistance. They also have a wide range of potential adaptation, including areas which are not well represented by our main selection site, IAC in central India. To increase the range of selection environments, and to encourage the involvement of more pearl millet scientists in population improvement, we initiated several types of cooperative breeding programs at national program sites in northern India.

In most cases, we follow a procedure whereby the bulk of a promising, variable population is given to the cooperating breeder for sowing. During the main growing season, she/he self pollinates selected plants in the population bulk. Seeds of the selfed progenies are then returned to IAC for downy mildew screening in the greenhouse. The downy mildew-resistant progenies are then recombined in isolation during the off-season to form the new variety, which can be submitted for testing for potential release in the All-India Coordinated Program.

Recently, a few cooperating pearl millet breeders have begun to share the work of multilocational progeny testing and the preliminary phase of evaluating potential breeding populations. All the public sector pearl millet breeders of northwestern India have been participating in the multilocational evaluation of these newly developed varieties in their main target areas.

During the past 3 years, the first varieties thus bred have completed the All-India testing program. Results from these trials show that indeed better adaptation of these new locations can be observed, particularly better adaptation to locations with low mean yields in general.

Introduction

Collaboration among national agricultural research systems (NARS) and international research centers (IARCs) is often cited as the key to successful transfer of technology and favorable impact on food production in the concerned area (TAC 1990, cited in Ravnborg 1992). With this emphasis on technology transfer activities, collaboration of IARCs with NARS has focused on workshops, training exercises, and worldwide multilocational yield trials and disease nurseries. This may be the most efficient approach to collaboration if the NARS's breeders from each collaborating institution have a reasonable probability of finding suitable material for their target area in these trials and nurseries. However, for rainfed crops grown over a wide range of very diverse environments, this approach was often resented by breeders in national programs as it involved spending too much of their limited resources on evaluating mostly poorly adapted material, and thus supporting research priorities of IARCs by returning data from these trials.

Pearl millet [*Pennisetum glaucum* (L.) R.Br.] is an example of a crop grown over a range of production environments, with adaptation to extremes of different stresses. ICRISAT's pearl millet improvement research has become substantially regionalized, with the formation of the Sahelian Center and the southern and eastern African programs. Within each of the regional programs, the breeders have increased their efforts to target the breeding material to specific regions to improve the probability of gains from selection. This change of focus in the international breeding program, from a search for wide adaptation to breeding for more specific adaptation to particular areas, has also resulted in a change in the role of the cooperating national programs. Rather than simply 'receiving new technologies'

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ICRISAT Conference Paper no. CP 1029.

(i.e., finished varieties), the national programs have become genuine partners in the design, development, and testing of new technologies.

In this context, we would like to describe alternative forms of collaboration between the pearl millet breeding unit at ICRISAT Asia Center (IAC), India, and different institutions in India, which have evolved over the past 4–5 years; the methods by which population formation and improvement have been conducted cooperatively; and some initial results of these approaches.

Composing New Populations of Pearl Millet

Genetic variability in pearl millet is extensive (Burton and Powell 1968; Rattunde et al. 1989). It covers wide ranges of maturity, photoperiod responses, plant architecture, and a wide range of adaptations to stress. The population improvement project at ICRISAT has recently begun to explore some of this variability more systematically. Realizing that the extremely variable pearl millet-growing environments may require specific maturity types or plant architecture, we have begun to sample the available variation within the breeding material and the germplasm collection.

One approach has been to develop populations emphasizing specific yield components. This approach has led to the development of a series of populations with higher than average tillering ability (HiTiP 88, HiTiP 89), larger than average grain size (LaGraP 88), and high head volume (HHVBC).

Another goal pursued in the formation of new composites has been the need to widen the range of maturity of our breeding material, especially towards earliness. New composites such as the Bold Seeded Early composite (BSEC), Early Composite II (EC II), and their population cross Early Composite 87 (EC 87) have been formed. Further, the selection for earliness within older, medium-maturity ICRISAT populations appears to have been successful in creating significantly earlier, high-yielding material, e.g., the early selection from Smut Resistant Composite II (ESRC II).

A third approach to the creation of new populations has been to combine local landraces from the target area and select for specific characters. This approach was followed in instances when either previous results of germplasm evaluation trials showed superiority of local germplasm, or when poor adoption of available new cultivars indicated that local varieties were preferred. Two populations developed in this manner are WRaJPop 88, the Western Rajasthan Population, and the newly initiated Sudanese Population. In both instances, we used the population formation and random-mating phase to select for improved seed set and spikelet density, and against off-type and nonproductive plants.

Cooperative Breeding of Varieties

Recurrent selection programs offer many opportunities for cooperation among breeders working in different institutions but with similar goals. Collaboration is possible at each of the following four major stages of such a program: (a) the identification of suitable population bulks, (b) the formation of test units, (c) the testing of these test units, and (d) recombination of selected units and seed production.

In northern India, four types of collaborative breeding efforts have evolved between ICRISAT and different research organizations since 1988. The most frequent form of collaboration is one where the collaborator selects and selfs single plants from the population bulk to create test units (S_1 progenies) during the rainy season. This improves the probability that test units have good adaptation to the target environment represented by the cooperating research station. The test units are forwarded to IAC, where we perform a seedling test for resistance to downy mildew, and recombine the selected progenies during the off-season. Responsibility for further seed increase of these new varieties is shared by both institutes, depending on the facilities available. Varieties bred in this manner are then entered into the variety testing scheme of the All India Coordinated Pearl Millet Improvement Project (AICPMIP). At present eight such varieties, resulting from our collaboration with three different institutes, are at various stages of testing in this scheme.

The second form of collaboration is one where the collaborating institute allocates some land (103 ha) for collaborative trials, including all stages of recurrent selection except recombination. These trials are managed by an IAC staff member under shared supervision of scientists from IAC and the respective station. This type of collaboration facilitates more intense evaluation of test units for recurrent selection program, and of new source material, as well as the new varieties in the target environment. It further stimulates collaborative research to improve selection methodology for the particular target environment. At present, three varieties made from selections using S_1 progeny performance data from such collaborative research are being tested in the All-India variety testing scheme.

The third type of collaboration is similar to the second. The main difference is that the collaborative trials are managed entirely by the cooperating scientists. Commonly 1–4 trials are grown, i.e., S_1 progeny trials, advanced variety trials, or specific research of common interest is done. Progenies selected from the trials at that location, as well as progenies selected across locations are recombined at ICRISAT to form new varieties as well as the next cycle bulk of the population. The collaborator also uses the advanced variety and population trials to identify one or two population bulks for further collaborative variety breeding efforts.

Individual collaborators often participate in more than one of the described forms of collaboration. Further, all three types of collaboration provide opportunities for the cooperating breeder to channel new sources of breeding material into his/her program. Collaborators can also have access to off-season nursery space at IAC to enhance the efficiency of their breeding work.

The fourth type of collaboration is still in the experimental phase, and is at present only concerned with the identification of appropriate breeding material for a particular target area. Here, collaboration extends beyond the NARS's breeders to include government and nongovernmental organizations, engaged in purely adaptive research and development work in the target area. With the help of these organizations, farmers compare new types of material with their own varieties. This method gives breeders from both the international center and NARS a better understanding of farmers' preferences for particular varietal characteristics of pearl millet, and also allows the identification of specific constraints to production. We expect that this type of collaboration will lead to more acceptable cultivars more rapidly. Further, this direct collaboration with locally based development organizations could open the way for locally oriented seed production and seed security schemes.

Progress from Cooperative Selection Programs

The first collaboratively bred variety, RCB-IC 9, using the first form of collaboration, was released for cultivation in the state of Rajasthan in 1991. The next two varieties developed by this approach to cooperative breeding were submitted for All-India variety testing in 1989. These were MP 222 derived from BSEC and MP 223 from EC 87, after the first cycle of cooperative selection in these new early-flowering populations. In both populations cooperative selection was continued for two more cycles and the resulting varieties were also entered in the All-India variety testing scheme in 1990 and 1991 (MP 240 and MP 254 for BSEC, and MP 241 for EC 87).

Comparisons of grain-yield performance of these varieties with released varieties (controls) show that these selections are superior to the existing cultivars under most testing conditions (Table 1). Compared with their respective initial population bulks [MP 205 (= ICMV 88907) for BSEC, and MP 204 for EC 87], progress from selection is more often expressed in Zone B locations (receiving >400 mm rainfall). The grain yield response of the BSEC varieties is slightly higher than that of the EC 87 varieties. This may be caused by stronger selection for earliness in EC 87, as the same cut-off dates for selfing were used in the selection program for both populations. This should affect EC 87 more strongly as it flowers 2–3 days later than BSEC.

The BSEC-derived varieties can also be compared with a variety from the same population bulk (MP 211, selected for high threshing percentage in the off-season drought nursery conducted at IAC (Table 1). The All-India test results indicate that the response to the two very different selection environments is similar, when compared within the two rainfall zones (Table 1). However, when we compared the two types varieties after grouping the 23 locations into seven low-yielding sites (<1 t ha^{-1}) and eight medium-yielding sites (>1 t ha^{-1} and <2.05 t ha^{-1}) and eight high-yielding sites (>2.2 t ha^{-1}), a different pattern emerged. The cooperative varieties showed consistent superiority in the low-yield environments, and inferior performance in the high-yield environments (Table 2). These results indicate that the adaptation of the cooperative varieties has actually changed in favor of the lower-yielding environments. As most of the pearl millet in India is grown under fairly poor-fertility conditions, these results are of practical significance and warrant further investigation.

Acknowledgements

First, we would like to thank Dr J R Witcombe, who initiated these collaborative projects, for the many open discussions on this topic. We would further like to thank Dr K L Vyas for his interest and dedication to the cooperative

Table 1. Response of ICRISAT pearl millet composites to selection by cooperators in Rajasthan (grain yield, t ha^{-1}), as measured in national trials in India[1], 1989–91.

Composite variety	Cycle	1989 Zone A[2] (6)[3]	1989 Zone B[4] (32)	1990 Zone A (3)	1990 Zone B (23)	1991 Zone A (3)	1991 Zone B (20)
Bold-Seeded Early Composite							
MP 204	CO[5]	1.20	2.03	1.36	1.87	–[6]	–
MP 221	IC	1.17	1.98	1.30	2.08	1.01	2.11
MP 222	C1	1.14	2.07	–	–	–	–
MP 240	C2	–	–	1.31	1.95	0.81	2.06
MP 254	C3	–	–	–	–	1.02	2.18
Early Composites '87							
MP 204	CO	1.21	2.01	1.47	1.96	–	–
MP 223	C1	1.28	2.16	1.52	1.91	0.86	2.01
MP 241	C2	–	–	1.50	1.99	1.09	2.16
Controls							
ICTP 8203		–	–	–	–	0.97	1.86
WC-C75		0.98	1.90	1.23	1.81	0.88	1.73

1. Data extracted from Progress Reports of the All-India Coordinated Pearl Millet Improvement Project, 1989–90, 1990–91, 1991–92.
2. Zone A refers to trial sites in low rainfall areas (annual mean <400 mm).
3. Numbers in parentheses are the number of sites reporting in each zone × year combination.
4. Zone B refers to trial sites in high rainfall areas (annual mean <400 mm).
5. CO, C1, C2, and C3 refer to the number of cycles of cooperative mass selection completed before testing the variety. IAC indicates that this variety was selected only at ICRISAT Asia Center.
6. – = data not available.

Table 2. Grain yield (t ha^{-1}) of BSEC-derived varieties at low-, medium-, and high-yield locations in India, 1991[1].

Variety	Low-yield locations	Medium-yield locations	High-yield locations
MP 221	0.66	1.92	3.03
MP 240	0.71	1.93	2.81
MP 254	0.70	1.97	2.98
Trial mean	0.64	1.72	2.71

1. Data extracted from Progress Report of the All-India Coordinated Pearl Millet Improvement Project, 1991–1992.

breeding programs and the many challenging discussions. Thanks are also due to Dr G K Arya, Dr D L Singhania, Dr U Menon, Dr T R Sharma, Dr N B L Saxena, Dr V K Manga, Dr O P Yadav, and Dr D S Virk for their many contributions to these cooperative breeding programs. Special thanks are due to Dr S D Singh and the staff of the Cereals Pathology Unit at IAC for screening an ever-increasing number of progenies for their reaction to downy mildew in the greenhouse.

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Recurrent Selection for Downy Mildew Resistance in a Highly Susceptible Pearl Millet Population

E Weltzien R[1] and S B King[2]

Abstract

*Downy mildew (*Sclerospora graminicola *(Sacc.) Schroet.) is the major disease of pearl millet (*Pennisetum glaucum *(L.) R.Br.) in Asia and Africa. So far, useful major genes for resistance to this disease have not been identified. In India, resistance of released, open-pollinated varieties has been found to be more durable than that of homogeneous single-cross hybrids. This suggests that multigenic resistance to downy mildew is present in pearl millet.*

We used a greenhouse seedling screening technique developed at ICRISAT Asia Center to improve the efficiency of breeding for downy mildew resistance. Potted plants (about 50 per pot) at the coleoptyle to 1-leaf stage were spray-inoculated with an aqueous suspension of sporangia, incubated overnight at 20°C and >95% relative humidity, and returned to greenhouse benches. After 2 weeks, the downy mildew reaction was determined as the frequency of plants with systemic symptoms.

Using this procedure, we completed one cycle of S_1-recurrent selection, and a second cycle of full-sib recurrent selection in a highly susceptible population composed of landraces from northern India (WRajPop88). To evaluate the progress from selection for downy mildew resistance, we tested 50 random S_1-progenies and 50 random full-sib progenies from the base population and each of the two improved cycle bulks using the same greenhouse screening procedure, as well as field screening in the downy mildew nursery.

Both the S_1- and the full-sib progeny evaluations showed significant increase in resistance over two cycles of selection. The C_2-cycle mean was not significantly different from the resistant controls included in the trials. The genetic variances among the S_1-progenies were lower than those among full-sib progenies in all cycles. Over cycles, the genetic variances among both types of progenies decreased, indicating that a limited number of genes is involved in controlling resistance in this population. The experimental error variance associated with S_1-progeny evaluations in the greenhouse was about twice the error association with full-sib progeny evaluation. Thus the heritability (single pot basis) of the S_1-progeny trial was only 0.46, compared with 0.73 for the full-sib progeny trial. In field screening, such a difference was not observed. The overall heritabilities on a plot basis were 0.63, and 0.73.

These results indicate that genes for resistance to downy mildew can be present in populations with high levels of susceptibility. Their frequency can be increased by recurrent selection, using either S_1- or full-sib progenies.

Introduction

During the past 5 years, the pearl millet breeding unit at ICRISAT Asia Center (IAC) has devoted special efforts to compose new populations and to breed open-pollinated varieties for the drought-prone millet-growing areas of northwestern India. In these areas, adoption of released hybrids and varieties is much lower than in other Indian pearl millet-growing areas. (Jansen 1988). In germplasm evaluation trials, landraces from these areas showed superior productivity under drought conditions (Weltzien and Witcombe 1989). As a consequence, we started exploring these local landraces as a source for new breeding material. In further evaluations, this material proved to be extremely susceptible to downy mildew [*Sclerospora graminicola* (Sacc.) Schroet.], the major obstacle for its direct use for breeding of improved varieties.

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ICRISAT Conference Paper no. CP 1030.

We therefore explored the possibilities of improving downy mildew resistance by recurrent selection within a population composed of superior landrace accessions, using a greenhouse screening procedure. The greenhouse screening procedure used in this study was adapted from a procedure described by Singh and Gopinath (1985), to allow for the screening of a large number of progenies. This study thus provides a test for the effectiveness of the modified screening methodology.

Materials and Methods

Genetic material

For this study, we used WRajPop 88 (Western Rajasthan Population, 1988), established by random mating 13 selected landrace accessions from northwestern India. Two random matings with moderate mass selection for seed set, earliness, and tillering were done in isolation at IAC during the 1988 rainy season and the 1989 dry season. During the 1989 rainy season, 330 single plants were selfed at Fatehpur and Jodhpur in northwestern India. The selection experiment was initiated with these 330 S_1 lines. The procedures for the selection experiments are summarized in Table 1. To make full-sib progenies among S_1 progenies, we used bulk pollen from single $5S_1$ progenies to pollinate 3–4 plants in the other parental S_1 progeny. Crosses among the S_1 progenies were made as a partial diallel to avoid assortative mating. To constitute the improved cycle bulks, equal quantities of seed from each cross were bulked. For the evaluation experiments, 50 random plants were selfed in each cycle to form the S_1 progenies. Similarly, 100 random plants were crossed in each cycle bulk to derive 50 random full-sib progenies. All selfing and crossing was done in the postrainy season 1990 at IAC.

Downy mildew greenhouse screening

For the greenhouse screening for downy mildew resistance, 50 seeds were sown per pot, with two pots per entry. At the coleoptile to one-leaf stage, plants were spray-inoculated with an aqueous suspension of sporangia. Inoculated plants were incubated overnight at 20°C and 95% RH. Later on, they were returned to the greenhouse benches and the frequency of plants with systemic mildew symptoms was counted after 2 weeks. The S_1 progenies (S_1 P) and full-sib progenies (FSP) were evaluated at the same time in two separate trials randomized as simple 13 × 13 latices.

Table 1. Outline of selection procedure for the two cycles of recurrent selection for downy mildew resistance in WRajPop88.

Year	Season	Activity
1989	Rainy	330 single C_0 plants self pollinated in Rajasthan.
1989	Postrainy	330 S_1 progenies screened in greenhouse for downy mildew resistance in two-stage procedure.
1990	Summer	40 S_1 progenies selected and recombined by making full-sib progenies to form C_1 cycle (12% selection intensity).
		45 full-sib families screened in greenhouse for downy mildew resistance.
1990	Rainy	42 full-sib progenies selected and recombined to form C_2 (17% selection intensity).
1990	Postrainy	In the C_0, C_1, and C_2-bulks random full-sib progenies (FSP), and random S_1 progenies (S_1 P) were developed.

Field screening for downy mildew resistance

For the field screening for downy mildew resistance, the same test entries were sown after downy mildew spreader rows began sporulating profusely. Spreader rows were sown every ninth row as described by Williams et al. 1981. Plots were 2 m long, and spaced 60 cm apart. The trial was laid out as a simple 13 × 13 lattice. Plots were oversown and thinned to 20 plants per row, 14 days after planting. The total number of plants and plants with downy mildew symptoms were counted 30 days after sowing. The number of plants with downy mildew symptoms was recounted at flowering time.

Statistical analysis

We analyzed square root transformed data for the evaluation trials. To test for significance of differences among entries and populations, Duncan's multiple range test was performed on the means of transformed values. For presentation, these means were retransformed to percentages. All variances, and their components are reported for transformed values only. As the lattice design proved not to be more efficient than a randomized complete block (RCB) design, the data were analyzed as RCB, using the ANOVA and VARCOMP. procedures of SAS.

Results

When evaluated in the greenhouse, both as S_1 progenies (S_1 P) and full-sib progenies (FSP), significant progress from selection for improved downy mildew resistance could be shown (Table 2) for this population. The initial cycle (C_0) had, in both cases, a level of resistance most similar to the once susceptible inbred control 843B, whereas the second cycle bulk (C_2) had reached levels of resistance not significantly different from the resistant controls, ICMP 423 and 81B. The same trend was observed when the material was evaluated under field conditions, except that for S_1P evaluation, no significant difference between the initial (C_0) and the first cycle bulk (C_1) could be observed. For the greenhouse evaluation trial, the disease pressure is considered moderate; in the field it was high, as judged by the performance of the control entries.

Genotypic variance for downy mildew resistance among the progenies within a cycle decreased rapidly with selection, such that after the second cycle of improvement, not enough variation was left to allow for further improvements, especially when estimated from S_1 P performance (Table 3). The error variances also tended to decrease, but not nearly as much as the genotypic variances (Table 3). The same variance components for an noncorrelated trait, ear length, showed no such trends (Table 3). The genotypic variance among FSP tended to be larger than that among S_1 P for seedling resistance in the greenhouse, as well as in the field. The error variance for the S_1 P trial in the greenhouse was much higher than that for the FSP trial. This may be due to poorer emergence in the S_1 P trial as the mean number of plants per pot was only 17.0, compared with 43.5 for the FSP trial. Under field testing, no differences in emergence were observed, and the error variances were of the same order of magnitude.

The correlation between the field results (first count) and the greenhouse results was highly significant, but only at a medium level; 0.66 for the FSP means and 0.51 for the S_1 P means. Correlation between the first and second field counts were a little higher, with 0.71 for FSP and 0.62 for S_1 P. As expected, the seedling test in the greenhouse showed the lowest correlation to the second count of downy mildew-infected plants in the field, with 0.61 for FSP means and 0.50 for the S_1 P means.

Table 2. Progress from one cycle of S_1 progeny (S_1 P) selection and a subsequent cycle of full-sib progeny (FSP) selection for downy mildew resistance in WRajPop88 population of pearl millet.

	Greenhouse evaluation		Field evaluation	
Cycle	S_1 P	FSP	S_1 P	FSP
C_0	10.2 db*	15.6 c	4.3 b	13.4 b
C_1	5.2 c	4.9 b	3.4 bc	3.8 c
C_2	2.1 a	3.0 a	1.6 cde	1.8 d
Controls				
ICMP 423	2.7 ab	2.4 a	0.0 e	0.8 d
81A	4.2 ab	2.3 a	0.9 de	1.9 cd
843A	8.7 abc	32.7 d	3.3 bcd	9.9 b
NHB3/7042	34.5 c	57.7 e	42.7 a	64.8 a

* = Means followed by different letters are significantly different at $P \leq 0.05$.

Table 3. Genotypic (s^2g) and error variances (s^2e) among 50 random S_1 progenies (S_1 P) and full-sib progenies (FSP), derived from the initial and the two improved population bulks of WRajPop 88, after selection for downy mildew in the greenhouse.

		Cycle of selection		
		C_0	C_1	C_2
Downy mildew, greenhouse				
S_1 P	s^2g	1.82	1.75	0.00
	s^2e	3.19	2.31	2.24
FSP	s^2g	2.27	0.75	0.50
	s^2e	1.35	0.95	0.76
Downy mildew, field-seedling stage				
S_1 P	s^2g	2.47	1.30	0.10
	s^2e	1.26	1.54	1.66
FSP	s^2g	3.79	1.44	0.66
	s^2e	2.32	1.40	1.17
Downy mildew, field-adult plants				
S_1 P	s^2g	0.06	0.62	0.56
	s^2e	1.95	1.31	0.76
FSP	s^2g	1.02	0.00	0.02
	s^2e	2.26	1.14	0.43
Ear length				
S_1 P	s^2g	3.86	6.33	5.63
	s^2e	3.50	4.07	3.81
FSP	s^2g	4.89	3.14	3.17
	s^2e	3.68	3.04	4.34

Discussion

The results of this study indicate that genetic variability for downy mildew resistance does exist in this highly susceptible population, derived entirely from landrace accessions collected in the dry parts of northwestern India where downy mildew occurs only rarely. Using a standardized greenhouse screening method, this variability could be successfully exploited by two cycles of recurrent selection, using S_1 progenies and full-sib progenies successively. Thus, this material can be used without introgression of unadapted sources of resistance in breeding programs for the area of origin, if adequate screening facilities for downy mildew resistance are available.

These results also indicate that seedling resistance to downy mildew in this population is controlled by a relatively small number of genes, since a rapid loss of genetic variance was observed after only two cycles of selection, despite recombining 30–40 progenies per cycle. However, for disease or insect resistance, this is frequently observed in other crops, such as maize (Jinahyon and Russell 1969; Penny et al. 1967).

The results further indicate that full-sib progenies can be used successfully for the improvement of seedling resistance to downy mildew. In breeding, pearl millet full-sib progenies have rarely been used in recurrent selection schemes (Rattunde and Witcombe 1992; Singh et al. 1988). The genotypic variances for ear length (Table 3) and other traits (not reported) indicate that full-sib progenies could be successfully used in recurrent selection programs for pearl millet. Using full-sib progenies would be more feasible for recurrent selection conducted in stress locations, as they are not inbred, and thus are generally more vigorous. Using full-sib progenies reduces the length of one recurrent selection cycle by one generation, compared with S_1 progeny selection. If an off-season nursery is available, one cycle of full-sib progeny selection can be completed in 1 year.

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The Status of Sorghum and Millet in Central Tanzania

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Abstract

The production of sorghum and millets in Tanzania is important throughout the country. Most of it is grown in the mainland Tanzania, especially in the marginal rainfall areas, which mostly cover the central regions comprising Dodoma and Singida.

Traditionally these crops are normally grown together; either in association or in pure stand, such that it had been difficult in the past to separate the production figures of sorghum and millets.

Across the country, the importance of sorghum and millets production is second only to maize. With changes in the distribution, amount and unreliable pattern of rainfall in the past, the national emphasis has been on the production of sorghum and millets. About 60% of the country's millet is produced in the central zone. In 1982/83 to 1986/87 growing season, the central zone produced a total of 80 000 t of sorghum out of a countrywide production of 416 000 and 148 000 t of millet out of a countrywide production of 259 000 t.

Introduction

Sorghum and millets have been grown as traditional food crops almost throughout the country. Most of it is grown in the mainland Tanzania, especially in the marginal rainfall areas which mostly cover the central regions comprising Dodoma and Singida Sorghum and millets are among the most common and well-adapted food crops in the seasonally dry and semi-arid areas in Tanzania (Mitawa, et al. 1984.)

Traditionally, these crops are normally grown together, either in association or in pure stand, such that it had been difficult in the past to separate the production figures of sorghum and millets (Mitawa 1981). This is done to avoid risk in case of adverse weather conditions to reduce susceptibility to pest attack and disease infestation, and to promote maturity differences which allow the farmers to spread their harvest and replenish food reserves.

The importance of the production of the group of sorghum and millets is second only to maize across the country. In the mid 1970s, there was a marked change in the rainfall pattern, amount and distribution almost throughout Tanzania, with the central region receiving the least amount of precipitation.

Production Trends

The general trend of unreliable and inadequate rainfall prompted farmers to change from growing maize to other cereals, particularly sorghum and millets, which resist drought conditions better than maize. Likewise, Tanzania, in its efforts to curb this situation, divided the country into agroecological zones, whereby the central zone was emphasized as the major sorghum- and millet-growing areas. The rainy season is generally short in central Tanzania, starting mid November or early December, up to April, with a dry spell in late January or the fist half of February. About 60% of the country's millet is produced in the central zone. In 1982/83 to 1986–87 growing season, the central zone produced 80 000 t of sorghum out of countrywide production of 416 000 t, and 148 000 t of millet out of a production of 259 000.

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Varieties Grown

Like any other farmers in the developing countries, farmers in the central zone in Tanzania prefer to grow traditional landraces of both sorghum and millets. Such varieties are normally low yielders, long-maturing types but well adapted to local environments in all aspects such as weather, and pests and diseases. The local sorghum landraces include Lugugu and Sandala in the central zone. They are tall, with white grains which are corneous and flinty, and hence, store relatively well for a long period of time with or without minimum seed treatment.

Improved sorghum varieties recommended for this area include Lulu (D), Lulu (T), Tegemeo, and Serena. The first three are white, whereas Serena is brown. They are generally early-maturing types, taking about 110 days from sowing to maturity. Lulu D and Lulu T yield higher than the local types, but do not store well, become mouldy easily, and hence pose germination problems in the field. Tegemeo has hard flinty grains and mills well compared with the other two and hence is the only acceptable recommended improved variety in the region.

Serena has many qualities similar to Lulu D and Lulu T. Similar conditions prevail for the sister crop, pearl millet. The traditional landraces include Buruma and Singida 2 and 3. They have characteristically long panicles (about 70 cm in average). They are late-maturing types, and take about 4–5 months. Grains are small and grey; though low yielding, they store relatively well for a long time.

The recommended improved varieties include Serere Composite 1 (bristled) and Serere Composite 17 (non-bristled). Farmers prefer the latter to the former, mainly due to the labor and time required in threshing. The bristled type takes longer to thresh and winnow, and the bristles irritate the skin. However, bristles provide some sort of defence mechanism against birds. The nonbristled type, though vulnerable to bird attack, yields relatively higher than the bristled type. Both these types take about 3 months from sowing to maturity. The grains are bold and grey, and the plant grows to about 1 m tall. Sometimes farmers lose almost the entire crop to birds in the field because the Serere Composites mature earlier than the grass seeds in the area, hence providing the only food source to the birds (Chambo 1989).

Uses

Most of the sorghums and millets produced are used as human food. The white-grained sorghums are milled, ground into flour, then cooked into stiff porridge (*Ugali*). The brown grain sorghums are mainly used in the preparation of local brews. Millets are also used as food as well as to make local brew. The long stalks are used as thatch on roofs and for livestock fodder.

Problems

- Diseases, particularly ergot, smuts, rust, mold, and downy mildew.
- Stalk borers, midge shootfly, *Calidea* spp.
- Birds especially the quelea on early-maturity types.
- Rejection of improved high-yielding varieties by farmers due to the lack of a hard flinty grain and because they store poorly—the traditional late-maturing varieties are more palatable and store well.
- Tillage practices (no till or shallow tillage) encourage weed growth, shallow root zone water run-off, etc.
- Weeds, especially parasitic weed *Striga* ssp.

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Biology of, and Resistance to Finger Millet Blast in Kenya and Uganda

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Abstract

*Blast of finger millet (*Eleusine coracana*), caused by the fungus* Pyricularia grisea, *is a foliar and panicle (neck and/or fingers) disease of great destructive potential throughout finger millet-growing regions in Kenya and Uganda. Panicle blast alone can cause more than 50% loss in grain yield. The pathogen overseasons on both seed and infected crop debris. Weeds and wild grasses were found associated with the buildup and carryover of* P. grisea. *Wild species of finger millet,* E. indica *and* E. africana, *and crow's foot grass (*Dactyloctenium aegyptium*) were found to be infected by* P. grisea *at Kiboko and Alupe in Kenya, and in farmers' fields in Uganda. This might serve as an inoculum reservoir for finger millet infection. Infected debris of these grasses and finger millet was used as inoculum to establish a simple but effective field scale resistance screening procedure at Kiboko. Inoculum and irrigation were the two essential components of this technique. Out of 2500 cultivars evaluated, most were susceptible to blast. However, KNE 812, KNE 814, KNE 904, and P 224 were slow-blasting types which gave high yields in advanced trials.*

Introduction

Finger millet [*Eleusine coracana* (L.) Gaertn], also known in Kiswahili as *Wimbi*, is one of the important cereal crops in Uganda and Kenya. In Uganda alone, it annually occupies an estimated area of 330 000–500 000 ha, that produce up to 500 000 t of grain (Zake and Khizzah 1989). In Kenya, > 65 000 ha are grown annually in Western, Nyanza, and Eastern Provinces (Mburu 1989). In both countries, finger millet plays an important role in the dietary habits and economy of subsistence farmers. Its grain is used for brewing and for preparing a thick porridge, *ugali*, which is a staple food and thin porridge *uji*, which is an important food in the diets of pregnant and lactating women, and infants and children. Finger millet grain is generally sold at three to five times the price of other cereals (including maize).

Sixteen fungal, three viral, and at least one bacterial pathogen have been reported to infect finger millet (Rachie and Paters 1977). Although several of the diseases caused are of sporadic importance, blast disease caused by the fungus [*Pyricularia grisea* (Cke.) Sacc.] is a destructive and economically important disease annually throughout the finger millet-growing regions of the world (Ramakrishnan 1963). McRae (1922) reported >50% reduction in grain yield due to blast. The disease is common in Uganda and Kenya, and it is particularly severe in very wet years (Dunbar 1969).

Blast affects finger millet in all stages of growth, from seedling through grain formation. In general, symptoms of blast on finger millet are very similar to those of blast disease on rice. Elongate, spindle or oval lesions of varying sizes are formed on leaves. These are usually greyish-green in the center with a yellowish margin, but later the central portion turns whitish and gradually disintegrates. Panicle blast (neck and/or finger) is the most destructive phase of the disease. It can cause failure of grain set or shriveled seeds, which sometimes results in total yield loss of the panicle.

Though blast was first recorded in 1933 in Uganda (Emechebe 1975), very little is known about the biology of the causal organism and the epidemiology of the disease in finger millet-growing countries of eastern Africa. Proper surveys have not been conducted to assess the severity and relative importance of the different phases of blast disease

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ICRISAT Conference Paper no. CP 1031.

in farmers' fields. Resistance screening techniques are not available. Therefore, the objectives of this study were to:

- ascertain the importance of the different phases of the disease;
- initiate studies on the biology of the pathogen and epidemiology of the disease; and
- develop a resistance screening technique and identify blast-resistant finger millet lines.

Prevalence and Importance of the Different Phases of Blast

We surveyed 293 farmers' fields, 125 in southwest Uganda, 62 in western Kenya, and 106 in eastern Kenya during January and February 1992, to ascertain the occurrence and importance of finger millet diseases. Most of the crop was in postflowering growth stages at this time.

All three phases (leaf, neck, and finger) of blast disease were widely distributed. Neck and finger blast were the most important phases of the disease, with >30% severely infected panicles in 272 fields out of the 293 surveyed. Foliar blast was generally restricted to lower leaves, with >10% leaf area covered by the disease in only 33 fields (Table 1). Leaf blight (*Helminthosporium nodulosum*), tar leaf spot (*Phyllachora eleusines*), and Cylindrosporium leaf spot (*Cylindrosporium* sp.) were frequently spotted, but only at low severities (2–3 scores on a 1–9 rating scale). Diseases caused by bacteria and viruses were not observed.

Table 1. Relative prevalence of the blast disease of finger millet in the agroecological zones of Uganda and Kenya during the rainy season (short rains), 1991/92.

Country/ region	Total fields surveyed	Plant part		No. fields by blast-severity category 2–3	4–5	6–7	8–9
Uganda							
Southwest region	125	Leaf	10	51	41	15	8
		Neck	2	31	55	22	15
		Finger	0	17	33	45	30
Kenya							
Western province	62	Leaf	0	46	11	4	1
		Neck	0	24	33	5	0
		Finger	0	8	24	24	6
Eastern province	106	Leaf	28	61	11	4	2
		Neck	0	36	30	28	12
		Finger	0	4	17	41	44
Total	293	Leaf	38	158	63	23	11
		Neck	2	91	118	55	27
		Finger	0	29	74	110	80

1 Leaf blast severity scale
1 = No disease, 2 = Few nonsporulating lesions on lower leaves, 3 = Few nonsporulating lesions on upper leaves also, 4 = Typical sporulating blast lesions infecting <2% leaf area, 5 = Typical blast lesions infecting 2–10% leaf area, 6 = Typical blast lesions infecting 11–25% leaf area, 7 = Typical blast lesions infecting 26–50% of the leaf area, 8 = Typical blast lesions infecting 51–75% of the leaf area, 9 = More than 75% leaf area covered

2 Neck and finger blast incidence rating scale
1 = No disease all panicles (neck and finger) healthy, 2 = ≤ 1–5% severely infected panicles, 3 = 6–10% severely infected panicles, 4 = 11–20% severely infected panicles, 5 = 21–30% severely infected panicles, 6 = 31–40% severely infected panicles, 7 = 41–60%, severely infected panicles, 8 = 61 80% severely infected panicles, 9 = 81–100% severely infected panicles

Estimated Yield Losses Caused by Blast Disease

Blast causes grain yield losses by reducing grain number and grain mass (Rath and Mishra 1975, Ekwamu 1991). It extensively damaged the crop and caused near total loss in grain yield in some fields in India (McRae 1922) and in

Uganda (Dunbar 1969). Based on visual estimations and comparisons between diseased plots and disease control plots, yield losses of 10–90% have been reported (Emechebe 1975, Esele 1989, Bisht 1987). However, the relationship of finger blast severity scores to yield losses have not been documented. To investigate this, we evaluated different severity levels of blast in fingers in an agronomically elite line P 224 and compared loss in yield in terms of finger mass, grain mass, and 1000-grain mass, at Kiboko during the 1991/92 rainy season.

The severity of finger blast varied from panicle to panicle and only a few panicles had completely blasted fingers. Leaf blast developed only in traces, therefore it was not considered a significant deterrent to yield. To obtain blast severity categories, we randomly harvested 1500–2000 panicles from each of four replicated plots. Diseased and healthy fingers were separated manually from each panicle. We erected 11 severity classes of 500 fingers each and compared the yields of each class in each replication (Table 2). Fresh mass was determined, and after 48 h of sun drying and threshing, grain mass was taken.

A linear relationship was found between the severity of the disease and loss in yield. Maximum loss in grain yield was estimated to be about 64% when all the fingers were blasted (Table 2).

Table 2. Comparison of percentage of yield loss in finger mass, grain mass, and 1000-grain mass at different levels of blast disease severity on a finger millet variety P 224, at Kiboko Research Station, Kenya, rainy season (short rains), 1991/92.

Finger blast severity classes	Yield (g)			Loss in yield (%)		
	Finger mass	Grain mass	1000-grain mass	Finger mass	Grain mass	1000-grain mass
0%[1]	883.45	668.95	2.40	-	-	-
10%	823.83	619.40	2.28	6.75	7.41	5.0
20%	751.73	527.00	2.10	14.90	21.21	12.50
30%	698.40	473.05	2.00	20.94	29.28	16.67
40%	649.30	438.23	1.79	26.50	34.49	25.42
50%	621.68	408.63	1.68	29.63	38.91	30.00
60%	578.15	375.70	1.60	34.55	43.87	33.33
70%	513.45	354.73	1.49	41.88	46.97	37.92
80%	485.40	328.55	1.37	45.06	50.88	42.92
90%	463.38	298.73	1.25	47.55	55.34	47.92
100%[2]	402.48	238.58	1.07	54.44	64.33	55.42

1. 0% = Healthy control, all fingers were healthy.
2. 100% = Diseased control, all fingers were blasted to a level of 50%.

Note: 1. Data are the mean of four replications.
2. Based on a total of 500 fingers collected from 70–80 panicles in each replication.

Biology of the Pathogen

Culturing the pathogen. We isolated *P. grisea* on potato dextrose agar (PDA commercial formulation) from infected finger millet leaves, necks, and fingers. At early growth on PDA with 25°C ± 2°C incubation temperature, colonies were grey, later becoming greyish brown or olivaceous brown, and after 8–10 days, incubation colonies generally formed concentric rings. Conidia first observed on 5-day-old cultures increased in number as cultures became older. We found that the pathogen also grows well on sorghum leaf extract medium, oat meal agar, and casine hydrocylate agar medium. This study concluded that *P. grisea* can grow and sporulate profusely on a range of media commonly used in the laboratory.

Relationship of Source of Pathogen Isolate to Infectivity

It is believed that leaf, neck, and finger isolates of *P. grisea* may represent different strains of the pathogen since they differ significantly in the rate of autolysis and growth at 5°, 10°, and 40°C (Kulkarni and Govindu 1976). However, these authors also mentioned that neck and finger isolates of *P. grisea* are cross infective. We undertook studies to determine if the source (leaf, neck, finger) of an isolate influences its ability to infect various plant parts.

Isolates of the pathogen were obtained from leaf, neck, and finger tissues and maintained on PDA using standard procedures. The susceptible genotype, KNE479, was grown in pots and inoculated using an aqueous suspension of conidia (8×10^4 conidia mL^{-1}). High humidity was maintained and the time from inoculation to initial symptom expression was recorded.

Isolates infected the three plant parts, regardless of their source. Hence, we concluded there were no pathogenic differences among isolates. Symptoms were generally first noted in leaves (5–8 days after inoculation), followed by those in fingers (7–11 days) and necks (8–11 days).

Seedborne Nature of *Pyricularia grisea*

There is no information on the seedborne nature of the blast pathogen in Kenya and Uganda, although *P. grisea* is reported to be seedborne in India (Ramakrishnan 1963, Ranganathaiah and Mathur 1978). Therefore, we assayed 20 samples of finger millet seed from farmers' fields and village markets in the two countries in January-February 1992, and from research plots at Kiboko. Seed health testing was conducted at the plant pathology laboratory, Muguga, following standard procedures of the International Seed Testing Association (1976). In this paper, we report the results of the blotter method only.

Twenty-five seeds of each sample were sown on two layers of moistened filter paper and one layer of folded tissue paper in petri dishes (replicated four times) and incubated at 22°C ± 2°C in a chamber under alternating cycles of 12 hours light and darkness. After 6 days, seeds were examined for fungal growth under a stereoscopic binocular microscope.

Drechslera nodulosa and *P. grisea* infection was found to be associated with seeds of all 20 samples (Table 3). Often, two pathogens were found on the same seed. Generally, heavily infected seeds showed poor or no germination.

Table 3. Percentage of infection by *Drechslera nodulosa, Pyricularia grisea*, and other fungi, and germinability of 20 samples of *Eleusine coracana* seed from farmers' fields, village markets, and Kiboko research station.[1]

Sample no.	Country and location	*D. nodulosa*	*P. grisea*	Other fungi[2]	Germination (%)
	Uganda				
1	Mwizi-1	22	19	48	38
2	Busibo-1 (White)	28	40	32	2
3	Busibo-1 (Red)	27	24	49	32
4	Rubare-Bushenyi	21	34	48	45
5	Rowentobo	19	25	56	75
	Western Kenya				
6	Kericho-Kisii	33	55	12	8
7	Nandi (storage)	33	35	31	18
8	IRIMIS	21	21	57	76
9	Kadongo (market)	26	18	53	63
10	Kadongo (market)	31	14	45	70
	Eastern Kenya				
11	Mutunga	28	26	45	52
12	Ciothirai	35	38	27	0
13	Ruiri	40	43	17	0
14	Nkubu	40	33	27	73
15	Kiboko (farmer)	22	15	55	0
16	Kiboko-90 (research)	13	19	68	90
17	Kiboko-91	4	7	12	88
18	Kiboko-92	33	37	23	23
19	Kiboko-92	22	29	49	60
20	Karatina (market)	38	39	23	0

1. 100 seeds of each sample tested for fungal infection by the blotter method and for germination by the between paper method.
2. Mainly species of *Fusarium, Curvularia, Aspergillus*, and *Phoma*.

Germinated seedlings that were heavily colonized by fungi were either killed or had poorly developed root and shoot systems.

Role of Weeds and Wild Grasses in Blast Disease Epidemiology

We observed blast-like lesions on several weeds and wild grasses in and around the Kiboko Research Station. One of the grass species, crow's foot (*Dactyloctenium aegyptium*), a common weed at Kiboko, was found to have panicle disease symptoms similar to finger millet neck and finger blast. Further, its leaves had typical spindle-shaped lesions resembling those of blast disease on leaves of finger millet and rice. *Pyricularia* spp. have been reported to infect several common grass weeds in finger millet fields in India (Ramakrishnan 1963). Thomas (1940, 1941) found that *P. grisea* from finger millet failed to infect rice or ginger, but infected wheat, barley, and oats. Cross infection tests have not been reported for eastern Africa, but we observed that finger millet fields in Kenya and Uganda were heavily infested by weeds including crow's foot, *E. indica*, and *E. africana*, and that these weeds had disease symptoms resembling those of blast on finger millet. Hence, a study was undertaken to better understand the possible role of wild grasses in finger millet blast disease epidemiology.

Isolation and identification of fungi. Following standard mycological techniques, we isolated fungi from infected parts of 14 grass species. Cultures of *Pyricularia*, identical to those of *P. grisea* from finger millet, were isolated from four wild species of *Eleusine*, two species of *Digetaria*, and one species each of *Dactyloctenium*, *Panicum*, and *Pennisetum*. We also obtained colonies of *Helminthosporium nodulosum* from each of these grasses. Neither *P. grisea* nor *H. nodulosum* were isolated from grass species of *Eragrostis*, *Cynandon*, or *Rottboellia*, although species of *Helminthosporium* with larger conidia were isolated.

Cross inoculation test. We performed two types of cross inoculation tests. In one test, a set of grass species including *E. coracana*, *E. africana*, *D. aeyptium*, *Setaria verticillata*, and *Digitaria macroblephora* was inoculated with *P. grisea* from each grass species. Another set of the same grass species was inoculated with *H. nodulosum* isolated from each grass species. Plants of each species were grown in pots, and young leaves and fingers were spray-inoculated with an aqueous suspension of conidia (6–8 × 10^4 conidia mL^{-1}) and four drops of Tween-20 per 100 mL suspension. For neck inoculation, a piece of cotton was dipped in the inoculum suspension and then tied around the peduncle. Inoculations were performed in the evening (1830) and plants were kept in plastic humidity chambers (2 × 2 × 2m). High humidity (about 80%) and 15–28°C temperature were maintained during the entire period from 4 days before inoculation until several days after the first lesions appeared.

Both *P. grisea* and *H. nodulosum* inoculum from each of the five grass species was able to inflict and produce lesions (leaf, neck, finger) on each grass, although some host-pathogen isolate combinations were more compatible than others. *Pyricularia grisea* and *H. nodulosum* were isolated from lesions produced by the respective inocula. No lesions developed on plants sprayed only with water.

These results indicate a strong collateral host relationship between finger millet and the wild grass species tested. Further, they suggest that these wild grass species may play an important role in the epidemiology of blast caused by *P. grisea* and blight caused by *H. nodulosum*. This appears to be the first report of this relationship in Kenya.

Natural Infection Using Diseased Plant Debris and Irrigation

Field Experiment. We conducted a field experiment to determine the effect of diseased plant debris and sprinkler irrigation on the development of blast disease. Six finger millet cultivars (KNE 479, KNE 755, KNE 808, KNE 739, KNE 884, and KNE 842) were planted in a split-split-split plot design in four replications. Each genotype was planted in four rows of 4 m length. Sprinkler irrigation was allocated to main plots, cultivars subjected to subplots, and debris to sub-subplots. Plants in the two central rows of each plot were dusted with powdered, blast-diseased debris 1 month after emergence. Four treatment combinations were produced: (1) irrigation and debris (I × D), (2) irrigation and no debris (I × ND), (3) no irrigation and debris (NI × D), and 4) no irrigation and no debris (NI × ND). In irrigated treatments, sprinklers were run morning and evening (30 min each).

Blast was recorded on leaf, neck, and finger plant parts at six growth stages: tillering (TL), boot (BT), flowering (FL), milk (ML), soft dough (SD), hard dough (HD), and physiological maturity (PM).

Since all the genotypes responded similarly to a treatment combination, we averaged the disease scores across genotypes to calculate the treatment mean. Maximum leaf, neck, and finger blast developed in the I × D treatment, at all growth stages. However, leaf blast severities were equally high in the NI × D treatment. We believe this was due to the fact that there were some rain showers, early morning fog, and heavy dew on some days which may have substituted for the effect of irrigation. Though we could not analyse the data statistically, we found that irrigation, together with debris considerably increased the neck and finger blast incidence (Table 4).

Table 4. Blast severity[1] in finger millet[2] at seven growth stages in four treatment combinations, Kiboko, Kenya, short rains, 1991/92.

		Plant growth stages[3]						
Plant part	Treatment[4]	TL	BT	FL	ML	SD	HD	PM
Leaf	I × D	4.5	5.0	5.2	5.7	6.4	7.3	7.7
	I × ND	3.7	4.2	4.4	4.6	5.2	5.7	5.9
	NI × D	3.6	4.2	4.8	5.0	5.3	6.3	6.8
	NI × ND	3.5	3.7	3.8	3.9	4.2	4.4	4.5
Neck	I × D	1.0	1.1	2.0	2.9	4.2	5.6	6.3
	I × ND	1.0	1.1	1.5	2.1	2.9	4.7	4.6
	NI × D	1.3	1.6	2.1	2.7	3.1	3.8	4.1
	NI × ND	1.0	1.0	1.3	1.6	1.6	2.2	2.9
Finger	I × D	1.0	1.4	2.3	3.4	4.6	5.9	7.0
	I × ND	1.0	1.3	1.8	2.9	3.4	4.4	5.5
	NI × D	1.0	1.4	2.1	2.8	3.4	4.3	5.2
	NI × ND	1.0	1.1	1.4	1.8	2.4	3.4	4.0

1. Blast severity rating on a 1–9 scale where 1 = no disease and 9 = severe disease.
2. Six varieties were used (KNE numbers 479, 755, 808, 739, 884, and 842). Since all reacted similarly to blast, average scores were calculated for each treatment and are presented here.
3. Plant stages: TL = tillering, BT = boot, FL = flowering, ML= milk, SD = soft dough, HD = hard dough, and PM = physiological maturity.
4. I × D= Irrigation and Debris, I × ND = Irrigation and No Debris, NI × D = No Irrigation and Debris, NI × ND = No Irrigation and No Debris.

Pot experiment. The effect of diseased debris on the development of blast disease at seedling stages of growth was studied in pots maintained in plastic humidity chambers. Five treatments were applied: (1) debris incorporated into the soil at the time of sowing, (2) debris spread on the soil surface, at sowing, (3) debris spread on the soil surface, 8 days after emergence, (4) seedlings spray-inoculated with a suspension of conidia, 8 days after emergence, and (5) seedlings sprayed with water, 8 days after emergence (control).

In treatments where debris was incorporated into the soil or spread on the soil surface at sowing, seedlings wilted within 7 days of emergence and 70–90% of them died within 15 days of emergence. Blast lesions developed in leaves of seedlings that were either debris-inoculated or spray-inoculated; however, severity of disease was much lower. Water-sprayed plants did not become diseased.

These results suggested that adding diseased debris to plots might be a good way to enhance blast disease in a screening nursery.

Resistance Screening Technique

We used the information derived from the field and pot experiments (above) to develop a technique for field screening for blast resistance under Kiboko conditions. The main components of this technique are described below.

Inoculum. *Pyricularia grisea* infected finger millet debris (diseased leaves and panicles) from the previous crop season are ground or broken into small pieces for use as inoculum.

Inoculation. Test plots of finger millet are irrigated to field capacity, and on the evening (1600–1700) of the next day, debris is uniformly spread on the moist soil surface within test rows and powdered debris is dusted on leaves. Inoculation should be done when entries are tillering.

Environmental conditions. High humidity and warm weather favor blast disease infection and development. We found that day temperatures at Kiboko were generally favorable (20–25°C) for blast development. However, humidity was unfavorably low, except for a few hours in the very early morning. Therefore, on rainfree days, plots were sprinkler-irrigated twice a day, from 1100 to 1200 and from 1630 to 1830. This continued until grain filling.

Disease evaluation and rating scale. The first symptoms of blast were observed on the lowest leaves, 6–8 days after inoculation. Leaf blast did not develop much further in most varieties. Initial symptoms of neck and finger blast developed 12–15 days after inoculation. This phase of the disease continued to increase and early-maturing varieties were especially susceptible, sometimes failing to set seed.

Each entry was evaluated separately for leaf, neck, and finger blast on a 1–9 rating scale (Table 1). Leaf blast was scored about 10 days after inoculation, while entries were still tillering. Neck and finger blast were scored between hard dough and physiological maturity of the grain. Entries were also rated for agronomic desirability at physiological maturity, using a 1–9 scale, where 1,2,3, - good; 4,5,6 - fair, and 7,8,9 - poor.

Identification of Resistance to Blast

More than 2500 finger millet germplasm and breeding lines were evaluated at Kiboko, for their reaction to blast using the screening method described above. The incidence of panicle blast in susceptible controls was >75%. The resistant lines identified are presented below:

Finger millet nursery. Out of 263 lines in this nursery (also evaluated at Alupe in western Kenya), 45 were found to be resistant and 15 were both resistant and agronomically elite. These lines are KNE nos. 269, 388, 392, 404, 423, 603, 629, 632, 634, 638, 639, 643, 659, 667, and 701.

Germplasm lines from Uganda. A total of 129 lines were evaluated (1991 long rains and 1991/92 short rains), and resistant and agronomically desirable lines were found to be M1, M11, M12, RAS 51, RAS 121, RAS 169, RAU 6, RAU 8, RAU 67, RAU 161, RAU 172, SLA 53, SRA 56, and SRA 79.

Germplasm lines from SADC/ICRISAT. A total of 273 lines (mostly late, >80 days to flowering) from Malawi, Tanzania, Zimbabwe, and Zambia were tested and the blast-resistant medium maturity (62–70 days to flowering) lines identified were SDFM nos. 2253, 2254, 2255, 395, 1707, 1734, 1748, and 1574.

Germplasm lines from ICRISAT Asia Center. Of the 1000 lines tested, > 70% were highly susceptible to blast disease. Lines with less blast and good agronomic desirability were IE nos. 100, 168, 906, 907, 994, and 999.

Elite lines nursery. Eight-one elite lines were evaluated under both irrigated and rainfed conditions. Based on blast and agronomic performance, we selected Serere 1 and KNE nos. 1080, 805, 655, and 738 for multilocational testing in the region.

Disease Progress in Different Genotypes

Although blast can cause extensive damage to finger millet, loss in yield depends to a large extent on the time of infection, with early infection causing more loss than late infection (Ramakrishnan 1963). However, very little is known about disease progress in different genotypes. An experiment was conducted at Kiboko during the 1991/92 rainy season, with 29 finger millets to determine differences in rate of disease development. Single-row plots (5m) in a randomized block design with three replications and four sowing dates were used. Artificial inoculation was not done, but to enhance disease development, overhead sprinklers were run two times a day on rainfree days.

Table 5. Maximum blast disease scores[1], range in days to 50% flowering, and agronomic acceptability scores[2] of the 29 entries sown on four dates at Kiboko, rainy season 1991–92.

Entry	Days to 50% flowering	Blast disease score						Agronomic score
		Leaf		Neck		Finger		
		FL[3]	PM[3]	FL	PM	FL	PM	
KNE 479	60-69	6.0	7.7	6.0	9.0	6.0	9.0	5
KNE 672	67–74	4.0	5.0	3.7	9.0	3.3	9.0	5
KNE 701	62–71	4.0	5.0	1.3	3.7	2.7	6.7	3
KNE 719	62–79	4.0	4.0	1.0	5.0	2.0	5.0	3
KNE 739	63–79	4.0	4.0	1.0	5.0	1.7	4.7	3
KNE 744	61–70	4.7	6.7	3.3	9.0	3.3	9.0	5
KNE 755	61–71	5.0	5.0	2.7	9.0	2.7	9.0	5
KNE 784	63–79	4.0	5.0	2.0	5.7	2.0	6.0	3
KNE 796	66–74	2.7	5.3	1.0	5.0	1.0	5.3	3
KNE 801	59–74	4.7	5.0	3.0	9.0	3.0	9.0	5
KNE 808	64–79	5.0	7.7	2.3	9.0	1.7	9.0	5
KNE 812	63–79	2.0	3.0	1.3	3.7	2.0	3.0	1
KNE 814	58–79	4.0	6.0	1.0	2.7	2.0	3.3	1
KNE 842	61–75	2.0	2.7	1.0	2.7	1.3	3.3	1
KNE 884	63.79	4.0	4.0	1.3	5.7	2.0	6.3	2
KNE 891	62–79	4.0	4.7	1.0	7.7	1.3	9.0	5
KNE 892	68–85	4.0	5.3	1.7	6.0	1.7	6.7	3
KNE 898	62–79	2.0	4.7	2.0	8.0	2.0	9.0	5
KNE 904	61–79	4.0	4.0	1.0	2.7	1.7	5.0	2
KNE 911	64–79	4.0	4.7	1.0	5.3	1.7	6.3	3
KNE 920	58–78	4.0	5.0	1.0	8.0	2.3	9.0	5
KNE 946	55–79	4.0	5.0	2.0	8.0	2.0	8.7	3
KNE 1012	59–79	4.0	5.7	2.0	7.3	3.0	8.3	5
KNE 1043	70–79	4.0	4.7	1.3	5.3	2.0	5.7	3
KNE 1124	63–79	5.0	5.0	3.7	7.3	3.7	8.7	5
KNE 1127	61–79	4.7	7.0	1.0	8.0	1.0	9.0	3
KNE 1142	61–79	5.0	7.0	3.0	9.0	3.3	9.0	5
KNE 1159	58–79	4.7	7.0	2.0	3.0	2.0	3.3	1
P 224	57–79	4.0	5.0	1.3	5.7	2.0	6.3	1

1. Disease rating scale: 1 = no disease, 9 = very severe disease.
2. Agronomic score: 1 = very good, 5 = poor.
3. FL = at time of flowering, PM = at physiological maturity.

Three plants in each row were tagged and evaluated for disease severity on leaf, neck, and finger at tillering (TL), boot leaf (BT), days to 50% flowering (FL), milk (ML), soft dough (SD), hard dough (HD), and physiological maturity (PM) stages of growth to monitor development of disease. We used the 1–9 disease rating scale described in Table 1.

Neck and finger blast progressed gradually across growth stages, irrespective of planting dates. A majority of genotypes tested were found to become highly susceptible during grain filling (>60% severely infected panicles). However, of the 29 genotypes tested, KNE 842, KNE 1159, and P 224 were found to develop less disease in all the four plantings.

Since presentation of the detailed data of all the entries is beyond the scope of this paper, we have summarized the results by giving the maximum leaf, neck, and finger blast scores recorded at flowering and physiological maturity growth stages (Table 5). Based on the disease progress patterns of the 29 entries, some entries could be grouped into the following two classes:

Fast blasting. Disease progressed at an exponential rate and most of the panicles showed maximum disease within 2–3 weeks of initial disease appearance. This pattern of disease development caused maximum grain yield loss. Entries that supported fast blasting were: KNE 479, KNE 672, KNE 744, KNE 755, KNE 801, KNE 808, KNE 891, KNE 898, KNE 920, KNE 1124, KNE 1142, and KNE 1012, with KNE 479 and KNE 755 severely affected.

Slow blasting. Disease progressed at a slower rate and did not become very severe by physiological maturity. Entries that showed slow blasting were KNE 701, KNE 719, KNE 739, KNE 784, KNE 796, KNE 812, KNE 814, KNE 842, KNE 904, KNE 1159, and P 224, with KNE 812, KNE 814, and P224 the least affected.

Research Needs

1. Determination of geographical and local variation in *Pyricularia* spp, pathogenic to *Eleusine coracana.*
2. Improved understanding of primary inoculum, its source, survival, and carryover on alternative hosts such as wild species of *Eleusine* and other graminaceous weeds.
3. Development of meaningful screening techniques to identify resistant genotypes and to determine mechanisms of field resistance or susceptibility.
4. Determination of the effects of cropping systems and/or sequences, tillage, and cultural practices on disease severity.
5. Correlation between seedborne propagules of *Pyricularia grisea* and *Helminthosporum nodulosum*, and their interaction and effect on blast development.

Acknowledgements

We sincerely thank Messrs J Kibuka, R O Odhiambo, E Manyasa, J Were, Ms Florence Wambi, and Ms Charity, who helped us in many ways in meticulously conducting the experiments at Kiboko, Muguga, and Alupe in Kenya.

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Progress in Breeding for Resistance to Finger Millet Blast Disease at Serere Research Station

J Peter Esele, and S E Odelle[1]

Abstract

Blast caused by Pyricularia grisea *(Cooke) Sacc. has been rated the most important disease limiting the production of finger millet,* Eleusine coracana *(L.) Gaertn. in Uganda. Yield losses due to the disease range from 10% to 80%. Good yielders seem to be more susceptible than the poor yielders. A research program was initiated in 1965 to breed for resistance to the disease, using the locally available germplasm. The derivatives from the breeding program were later screened for resistance using an infector and test material technique, under conditions of natural infection in the field. The program has identified good yielders with reasonable levels of resistance to blast.*

Introduction

In Uganda, finger millet [*Eleusine coracana* (L.) Gaertn] is the most important cereal, being grown in the northern, eastern, and western parts of the country. It is recognized both by the people and the government that finger millet has high potential in Uganda. The increasing demand for this crop shows that it could form an important part of the agricultural cash economy in the finger millet-growing areas of the country.

Blast disease [*Pyricularia grisea* (Cooke) Sacc.] has been rated as the most important disease of finger millet in Uganda (Esele and Odelle 1983). Although actual figures of losses are not available, it is apparent that the initially estimated 10% loss (Emechebe 1975) of heads has been exceeded. In some of the highly susceptible varieties at Serere, up to 80% loss in yield has been estimated (Esele and Odelle 1983). The disease attacks finger millet at all stages of plant development causing seedling blight, leaf blast, node blast, neck blast, and head blast. Research at Serere concentrates on the neck and finger blast stages of infection. Neck blast causes the head to droop, resulting in loss of the grain, especially if infection was before grain filling. Head blast causes partial or no filling of the grain. A program was started in 1965 to breed for finger millet-resistant varieties. Derivatives from the breeding program were screened for resistance to the disease, beginning 1983.

Materials and Methods

A line from Mozambique, W 359, from the Serere Collection, which has large glumes, does not thresh well, and has a low yield, was identified as resistant to head blast. The Uganda local varieties W 16 (Serere 16), W 21 (Serere 21), Emiroit, Engeny, and Emoru were also identified from the collection. These are susceptible to head blast, but are good yielders. Crosses were made between the resistant W 359 with these susceptible, but otherwise high-yielding varieties. The hot water emasculation technique was used. There were a total of eight crosses involving three single and five reciprocal crosses which, together with their parents, totalled 36. Selfing and backcrossing were initiated in 1967 and continued to the fourth backcross (Table 1). Some of these derivatives were susceptible to lodging. Lodging resistance was identified from Ethiopian entries P 102, P 263, and P 238, and incorporated into the breeding progenies. This lodging resistance was incorporated as a three-way cross. Selections were then made, based on both lodging and blast resistance.

1. Serere Research Station, P.O. Soroti, Uganda.

Table 1. Development of blast-resistant materials.

Initial cross 1965		Name of cross 1966	Name of 1st backcross 1967	Name of 2nd backcross 1968	Name of 3rd backcross 1969	Name of 4th backcross 1970
W 16	W 359	5E × 1	5E × 11	5E × 21	5E × 31	5E × 41
W 21	W 359	5E × 2	5E × 12	5E × 22	5E × 32	5E × 42
Emirot	W 359	5E × 3	5E × 13	5E × 23	5E × 33	5E × 43
W 359	W 16	5E × 4	5E × 14	5E × 24	5E × 34	5E × 44
W 359	W 21	5E × 5	5E × 15	5E × 25	5E × 35	5E × 45
W 359	Engeny	5E × 6	5E × 16	5E × 26	5E × 36	5E × 46
W 359	Emoru	5E × 7	5E × 17	5E × 27	5E × 37	5E × 47
W 359	Emiroit	5E × 8	5E × 18	5E × 28	5E × 38	5E × 48

In 1983 and 1984, a preliminary blast resistance screening program was initiated under conditions of natural infection in the field. The experiment consisted of 156 selections from these breeding materials and their parents. They were planted in 5-m row plots in a randomized block design, replicated twice. At maturity, the following data were recorded:

1. Grain color
2. Panicle characteristics
3. Days to 50% flowering
4. Neck blast rating
5. Head blast rating

For neck blast, the incidence of infection was taken as a mean of the number of plants infected as a percentage of the total number of plants in the row. For finger blast, severity of infection was taken as a mean of the number of fingers infected per head. In either case, 10 plants per row were randomly selected for disease score. Disease data were recorded using a 0–10 scale, where 0 = disease absent, and 10 = total or nearly total destruction of susceptible plant parts. The preliminary screening nursery categorized the entries to either highly susceptible (rating of 7–10) or moderately susceptible (rating of 4–6) or resistant (rating of 0–3). From 1985, the experiment entered into an advanced screening nursery stage comprising infector materials and test materials. The very highly susceptible entries identified in the preliminary screening nurseries were used as infector material. The lines that scored lower ratings of 0–6 comprised the test material. The experimental design was a randomized block design replicated twice. The materials were planted in 13-m row plots with the infector material consisting of 3 one-meter bands within each row (Figure 1). Every fifth row consisted of infector material, while the intermediate four rows consisted of test material. A susceptible control was planted every 11th row. The infectors were planted 2 weeks before the test material. The test and infector materials were selected in such a way that their maturity periods were approximately the same.

Results and Discussion

The results of the best 20 entries in the 1986 advanced resistance screening is shown in Table 2. Generally, there appear to be no entries that are immune to blast disease. All derivatives showed some degree of infection. Segregation data, however, were not taken. The compact-headed progenies were more resistant than the open-headed ones. Short cultivars and/or early-maturing cultivars were highly susceptible. Also, white-seeded cultivars, which are generally higher yielding, were unfortunately more susceptible than the darker ones. Derivative 5E × 42 × Serere 21/8 was the most resistant.

Both neck and finger blast were noted as important. However, data have shown that the severity of finger blast is greater than that of neck blast.

1 m 5 m 1 m 5 m 1 m

- Highly susceptible infector lines
- Test entry

Figure 1. Layout of infector and test entries in the blast advanced screening nursery.

Table 2. Blast disease rating of the best 20 entries in the disease-resistant crosses, 1986.

Pedigree	Panicle characteristics	Grain color	Neck blast rating	Head blast rating
5E × 28 × Emiroit 12	Open	Brown	2	2
5E × 42 × Serere 21/8	Open	Brown	0	1
5E × 13/1	Open	Brown	2	2
5E × 25 × Engeny/2	Open	Brown	2	2
5E × 38 × Emiroit/1	Open	Brown	2	2
5E × 32 × Emoru/11	Open	Brown	2	2
5E × 32 × Serere 21/8	Open	Brown	2	2
5E × 33 × Emiroit/5	Open	Brown	1	2
5E × 23 × P 102/4	Open	Brown	2	2
5E × 38 × Emiroit/5	Open	Brown	1	2
5E × 42 × Serere 21/1	Open	Brown	2	1
5E × 38 × Emiroit/6	Open	Brown	2	2
5E × 33 × Emoru/3	Open	Brown	2	2
5E × 37 × Emiroit/2	Open	Brown	1	2
5E × 22 × Emiroit/2	Open	Brown	2	2
5E × 23 × Emoru/1	Open	Brown	2	2
5E × 32 × Serere 21/2	Open	Brown	2	2
5E × 45 × Serere 21/2	Open	Brown	2	2
5E × 33 × Engeny/3	Semi-compact	Brown	2	2
5E × 36 × Engeny/4	Semi-compact	Brown	2	1
W 359	Open	Brown	0	1
Serere 16	Semi-compact	Brown	4	5
Serere 21	Semi-compact	Brown	5	5
Emiroit	Semi-compact	Brown	4	4
Engeny	Semi-compact	Brown	4	5
Emoru	Semi-compact	Brown	5	4
Mean			2.19	2.35

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Discussion Session 2: Improvement and Production of Millets

Title of Paper: Progress in Breeding for Resistance to Finger Millet Blast Disease at Serere Research Station

Name of Speaker: S E Odelle

Question: *El Hilu Omer*

Are there any morphological or anatomical characters that can help identify resistant genotypes. Blast depends very much on the environment and requires high moisture for infection. Do you ever use artificial methods to induce infection?

Answer: *J P Esele*

Morphologically, we have observed that open-headed finger millets are more susceptible than the compact-headed ones.

We plan to undertake a study to determine the most optimal stage of plant development for artificial inoculation of *Pyricularia grisea*. Personally, for head blast infection, I think anthesis stage, when pollen grains are available, is the best stage as pollen would provide essential nutrients for fungal development. However, we are still unable to undertake this study, as we do not have a workable greenhouse facility.

Question: *S Z Mukuru*

You mentioned that W 359 from Mozambique is highly resistant to finger millet blast. Is this line available with you? And if so, have you looked at it recently and screened it again to confirm its blast resistance? Is it a late- or early-maturing line? Late-maturing lines tend to escape blast attack.

Answer: *S E Odelle*

It is unfortunate that following the problems in the area and the breakdown of the cold storage at Serere, this line is no longer available in the collection. We are however working with the crosses only.

Question: *S B King*

1. How did the breeder know that crosses were actually made?
2. How strongly do you feel about the association of blast resistance to grain color and maturity (early material more susceptible than late material)?

Answers: *S E Odelle*

1. Where crosses are made and male sterility is not involved, whoever is concerned, has always to look for the dominant marker genes. In finger millet, purple nodes are dominant to green nodes, so the problem here should be easy. However, where there are no marker genes, parents are normally grown along with the crosses and the differences observed.

J P Esele

2. Our observation is that the darker-grained finger millets are more resistant to blast than the lighter ones. We believe that some component in the chemical composition of the grain is anti-fungal, preventing the establishment of *Pyricularia grisea*, the causal fungus. Similarly in our collection, the early-maturing varieties, on average, are more susceptible than later-maturing ones. Most of these early entries are of Indian origin. We are not sure whether it is due to weather phenomena or simply that Indian accessions are susceptible.

Title of Paper: Cooperative Breeding of Open-pollinated Varieties

Name of Speaker: E Weltzien R

Question: *D E Byth*

1. Given that the focus is on regionally specific adaptation, why is it necessary or appropriate to incorporate the resulting pearl millet populations in the AICPMIP, which has a broader adaptation focus?
2. The proposed breeding schemes appear well focused on achieving directed genetic change, but involve no attention to agronomic management change for the modified populations. How can this be addressed effectively in order to achieve a superior analysis of potential impact?

Answer: *E Weltzien R*

1. The first set of pearl millet populations used in the schemes do have quite general adaptation, and thus a chance to succeed on this level. Now, as we are having varieties with more specific adaptations to the drought-prone areas of northwest India, we have initiated a trial statewide to test all these varieties, which should help to encourage state-level releases.
2. We try to encourage agronomists to include these varieties in their trials. Some farmers expressed interest in experimenting with fertilizers. On the other hand, we have reduced the fertilizer levels in our relative fields, to come close to farmers' field levels.

Commen: *B N Mitaru*

It may certainly be a good idea to involve scientists from Africa in the initial stages of your trials so that materials tested are from a wider area than just one, India.

It would certainly be desirable to start programs for certain areas in Africa.

Question: *A M Mbwaga*

The technology transfer you are talking about, is it from IAC to National scientists or does it go as far as to the target group, i.e., farmers? What kind of inputs do you give from IAC to NARS/farmers to carry out such activity?

Is it possible to have a similar collaboration with NARS from African continent on the problem of ergot on pearl millet, which is a major problem on the crop.

Answer: *E Weltzien R*

We generally do not reimburse collaborators monetarily, but rather try to solve specific problems together, i.e., lending a staff member, sharing the thresher to farmers; we only give seeds.

The possibility of an ergot project should be discussed with all concerned, at ICRISAT Asia Center as well as at the Regional Africa Programs.

Title of Paper: Recurrent Selection for Downy Mildew Resistance in a Highly Susceptible Pearl Millet Population

Name of Speaker: E Weltzien R

Question: *O E Ibrahim*

Varietal maintenance in pearl millet seems to be a problem in at least some pearl millet programs I have visited. What is your favorite method for maintenance?

Answer: *E Weltzien R*

I prefer to use isolations in order to rogue effectively and have optimum random mating. In case we need less seed of many varieties, we increase seed by sibmating. This involves collecting pollen of at least 20 heads at a time, pollinating over the whole flowering period, and pollinating a total of 500–1000 heads.

Question: *Abd Elkahb Mohamed*

1. Why were estimated genotypic variances associated with large error values?
2. Does not the depletion of genetic variances with recurrent selection defeat the purpose of recurrent selection?

Answer: *E Weltzien R*

1. The errors reported were the errors associated with entry means for downy mildew resistance. They reflect the number of seedlings used to estimate downy mildew percentage.
2. These data indicate that only very few genes for downy mildew resistance are present in this population. Once the frequency is increased to a high level, genetic variation will be very low.

Question: *Adipala Ekwamu*

You mention that there are more rapid gains in early yields of selection, and therefore possibly a few genes are involved in resistances. In many cases, the rate of genetic gain declines considerably in inter cycles of selections. Why is this so?

Answer: *E Weltzien R*

Gain from selection for a trial depends on genetic variability and selection maturity, in addition to heritability. For traits which are controlled by a few genes, usually highly heritable, the gene frequency can be increased rapidly. At higher gene frequency, the variability goes down; thus even with a constant selection intensity, the gains will be much lower in later cycles.

Title of Paper: The Status of Sorghum and Millet in Central Tanzania

Name of Speaker: H S Chambo

Question: *Adipala Ekwamu*

1. Is finger millet grown in Tanzania? If so, in which areas is it grown?
2. I noticed in the figure you showed that apart from 1972, production of pearl millet has remained almost constant, in contrast to increased production of sorghum. What are the possible reasons for these different trends?

Answer: *H S Chambo*

1. Yes, finger millet is grown in Tanzania almost all over the country especially around the slopes of Mt. Kilimanjaro, and Mt. Meru in Arusha, southern highlands around Mbeya and Sumbawanga, Kondoa, Mara, and Serengeti areas, also some areas in the Singida region.
2. This could have been contributed to the continuous use of low-yielding landraces.
   In places where improved versions were used, the low yield could have been due to appreciable loss of some grains in the field due to bird damage, which is one of the problems leading to rejection of early-maturing improved varieties such as Serere Composite 17.

Question: *S B King*

Has there been a survey of yield loss due to ergot in Tanzania?

Answer: *H S Chambo*

No, the problem has not been the yield, but the effect of ergot on human beings. After consumption of ergot-contaminated food products, some people have been feeling dizzy, and have been having headache for more than a day. Even dogs do not eat "ugali" contaminated with ergot. Farmers are therefore, complaining of ergot but not of yield loss. Local varieties compete very well with improved varieties in terms of yield.

Session 3

Agronomy and Resource Management

Soil and Water Management Options to Increase Infiltration and Productivity on SAT Soils

P Pathak and K B Laryea[1]

Abstract

Most of the existing land use and agricultural systems on Vertisols and Alfisols of the semi-arid tropics (SAT) often result in low and unstable yields, high runoff and soil loss, reduced ground water recharge, and frequent flooding of downstream agricultural lands. In this paper, we review the soil-related limitations of Vertisols and Alfisols for sustainable resource utilization, and discuss the role of watershed-based soil and water conservation and a land management system for Vertisols, based on broadbed and furrows. Measurements on runoff, soil loss, and crop yields at ICRISAT Asia Center, Patancheru, India, show that on Vertisols, a system of broadbeds and furrows constructed at a gradient of 0.4–0.6% is effective in increasing crop yields by ensuring good surface drainage of water, control of erosion, and in conserving water in the soil profile.

For Alfisols, we discuss several promising soil and water management practices involving raised land surface configurations, small excavations on soil surface (pits or scoops), frequent shallow interrow pre- and early rainy-season tillage, deep tillage, and tillage practices to manage crusting and sealing. Our experiments showed that pitting increased crop productivity by 15 to 30%, reduced losses of soil by 80% and those of water by 50% when compared with cultivation on flat land.

Introduction

In many regions of the SAT, there is a paradoxical situation that the area suffers from both a general water shortage and destructive floods. The main reasons for this are the great variability of rainfall in time and in space, and poor infiltrability of most soils in the region. Thus, drought years as well as years having high intensity rain stornis that produce high runoff and serious erosion are common. The present crop yields in most farmers' fields in the SAT are very low and variable. As a result of high runoff and soil loss, the land resource base is shrinking and its productive capacity is diminishing (Kampen and Burford 1980). Therefore, we urgently require a resource management scheme which combines effective conservation and utilization of soil and water with crop production systems that increase and stabilize productivity.

A wide range of soil and water conservation and tillage systems has been studied at ICRISAT Asia Center, Patancheru, India. These studies were conducted both on small natural watersheds and on small plots. In this paper, we report some of the results from these studies conducted under rainfed conditions on Vertisols and Alfisols. The main aim of these studies was to increase crop productivity by improving the soil environment for plant growth. An additional aim was to decrease soil erosion by decreasing and controlling runoff.

Soils

Vertisols at ICRISAT Asia Center belong to the Typic Pellusterts subgroup (Murthy and Swindale 1982). These soils are deep and rich in swelling clay minerals and their water storage capacity is relatively large. For example, the average field capacity of a 185-cm profile is 810 mm and the lower limit of plant available water is 590 mm (Russell 1980). A 2-m deep profile, therefore, can hold more than 250 mm of plant available water. The soil is self-mulching, exhibits cracking, and becomes hard when dry and sticky when wet. Because of relatively high montmorillonitic type of clay content, Vertisols are usually imperfectly drained and have a moderate-to-low hydraulic conductivity.

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ICRISAT Conference Paper no. CP 1032.

Alfisols at ICRISAT Asia Center belong to the fine, isohyperthermic Udic Rhodustalfs subgroup (Soil Survey Staff 1975). The major characteristics of these soils have been reported in detail by El-Swaify et al. (1985) and Pathak et al. (1987). It has an unstable structure and a strong tendency to display crusting and hardening when dry. These soils are low in organic matter, nitrogen, and phosphorus. They are well drained, sandy loam to sandy clay loam at the surface. They have a 8–12 cm thick top layer underlain by a compact and hard argillic horizon. The top soils are friable, nonsticky when wet but hard when dry. The particle size distribution and clay mineralogy favor easy slaking, packing and compaction. Alfisols have inherently low water retention characteristics.

In the following sections, we discuss in detail, soil-related constraints, their management for optimized resource utilization and increased productivity for Vertisols and Alfisols in the SAT.

Physical Constraints and their Management

Vertisols

The most important physical constraints to rainfed crop production on Vertisols are their (i) narrow range of soil water content for tillage, (ii) high erodibility, (iii) tendency to become waterlogged and (iv) poor trafficability. Vertisols are hard when dry and sticky when wet. Tillage at an inappropriate moisture content leads to compaction of the subsoil. Traditionally, rainy-season fallowing is quite common on these soils. The reasons for rainy-season fallowing of Vertisols are the difficulties farmers encounter in preparing the hard dry soil before the onset of the rainy season and/or the sticky nature of the wet soil after the onset of the rainy season (Krantz and Russell 1971, Jodha 1979, and Michaels 1982). The frequent threat of flooding when heavy rains occur, and the possibility that rainy-season cropping may reduce soil moisture available for postrainy season crops are also some of the reasons for fallowing Vertisol during the rainy season.

A system of improved management for Vertisols has been developed at ICRISAT. The essential components of this management strategy (Kanwar 1981, Kampen 1982) include:

- a system of resource conservation, management, and use based on small watersheds;
- a well-designed, semi-permanent or permanent broadbed and furrow system or well-graded flat system;
- land smoothing and installation of drains to ensure effective surface drainage and runoff disposal from the field;
- performing primary tillage operations for both postrainy as well as rainy season crops immediately after harvesting the previous season's crop, when the soil has adequate moisture and is friable;
- shallow cultivation of the land (only the beds) whenever an effective rainfall (>20 mm) is received;
- application of moderate amounts of N and P fertilizer, followed by dry sowing about 1 week before the expected date of onset of the rainy season;
- use of high-yielding varieties and other recommended agronomic practices.

Using the above techniques, Vertisols have been managed successfully at ICRISAT Asia Center to produce high and stable yields even under very fluctuating rainfall conditions (Table 1). Various aspects of this approach for the management of Vertisols have been discussed in detail by El-Swaify et al. (1985), Kanwar (1981), and Kampen (1982).

In addition to its direct benefit to crop yield, improved soil and crop management has been more effective in reducing resource losses in terms of runoff and soil erosion than the traditional rainy season fallow system (Pathak et al., 1985). On an average, the improved system reduced annual runoff to one-third, soil loss to one-eleventh and peak runoff rate to one-half when compared with traditional rainy-season fallow system (Table 2). As shown in Table 2, the performance of the broadbed and furrow system was consistently superior to the traditional system in reducing annual runoff, soil loss, and peak runoff rate. In 1977, when rainfall was very low and moisture conservation was crucial, the broadbed and furrow system conserved most of the annual rainfall, producing an annual runoff of only 1 mm. In contrast, when removal of excess water by drainage was crucial, during the high rainfall years of 1975 and 1978, this system produced substantial runoff of 162 mm in 1975 and 273 mm in 1978. The good control of runoff in the improved system was due to good crop cover during the rainy season, land smoothing, slope adjustment, and controlled runoff velocity as it flows through many furrows and disposed through grassed waterways.

Table 1. Grain yields under improved and traditional technologies on a deep Vertisol at ICRISAT Asia Center in 12 successive years.

Year	Seasonal rainfall (mm)	Grain yield ($t\ ha^{-1}$): Improved system: double cropping — Sorghum/Maize	Sequential chickpea/ intercropped pigeonpea	Traditional system: single crop — Sorghum	or	Chickpea
1976–77	708	3.20	0.72	0.44		0.54
1977–78	616	3.08	1.22	0.38		0.87
1978–79	1089	2.15	1.26	0.56		0.53
1979–80	715	2.30	1.20	0.50		0.45
1980–81	751	3.59	0.92	0.60		0.56
1981–82	1073	3.19	1.05	0.64		1.05
1982–83	667	3.27	1.10	0.63		1.24
1983–84	1045	3.05	1.77	0.84		0.48
1984–85	546	3.36	1.01	0.69		1.23
1985–86	477	2.70	0.73	-[1]		0.84
1986–87	585	4.45	0.38	0.37		1.27
1987–88	841	4.26	1.35	0.80		0.92
Mean	776	3.20	1.10	0.60		0.80
SD	±200	±0.70	±0.40	±0.20		±0.30
CV (%)	26	21	34	27		38

1. - = No crop sown.
Source: Virmani et al. 1991.

Table 2. Annual rainfall, runoff, soil loss, and peak runoff rate for a cropped Vertisol with broadbed and furrow system and a traditional rainy season fallow system (1975–1980).

Year	Rainfall (mm)	Broadbed and furrow at 0.6% slope, cropped — Runoff (mm)	Peak runoff rate ($m^3\ s^{-1}\ ha^{-1}$)	Soil loss ($t\ ha^{-1}$)	Traditional flat, rainy season fallow — Runoff (mm)	Peak runoff rate ($m^3\ s^{-1}\ ha^{-1}$)	Soil loss ($t\ ha^{-1}$)
1975	1041	162	0.06	1.39	253	0.15	5.21
1976	687	73	0.09	0.98	238	0.16	9.20
1977	585	1	0.01	0.07	53	0.06	1.68
1978	1125	273	0.11	2.93	410	0.15	9.69
1979	690	73	0.08	0.70	202	0.15	9.47
1980	730	116	0.06	0.97	166	0.11	4.58

Alfisols

Alfisols occur extensively in the SAT and are often found in the upper sections of watersheds in India. These soils present serious physical and chemical limitations to efficient and conservation-effective crop production.

Alfisols and related soils usually support poor crop stand because of crusting, sealing, consolidation of soil profile, rapid drying of top soil, low profile water storage capacity, high soil temperature, inadequate nutrient status, soil erosion, presence of root-limiting argillic horizon and stoniness.

On Alfisols containing a greater proportion of silt (>20%), crusting is one of the primary causes of poor crop stand because it inhibits seedling emergence. On these soils, it is difficult to get a good crop stand because of rapid surface soil drying due to very intense radiation early in the rainy season, loose surface soil and relatively high permeability of the surface soil horizon.

Moisture deficit is probably the most predominant constraint to good crop growth and yield in the SAT Alfisols. During the early part of the rainy season, the problem of moisture deficit is exacerbated by the low-profile water storage capacity and the surface crusts which tend to shed water because of their low infiltrability. Hard setting is yet another problem which contributes to poor crop growth on Alfisols. The hard-setting characteristic induces high soil strength which restricts the timing of land preparation and planting (Ley and Laryea 1992). The high soil strength also inhibits seedling emergence and root growth in the soils.

In terms of sustainable agricultural development, the most serious problem of Alfisols is soil erosion. Multiple, diversified sloping topography, low depression storage and the unstable nature of the surface structure cause high runoff and soil loss from Alfisols.

Soil and Water Management Practices

Graded land configurations on Alfisols which have less than 1.5% slope, cultivation on flat seed bed is effective in reducing runoff and soil loss as well as in increasing crop yields (Table 3). Graded raised land configuration (e.g., BBF, ridge and furrow system) does not offer any particular advantage for cereal production on Alfisols occurring on these gentle slopes (Pathak et al. 1987). Where supplemental irrigation is part of rainfed crop production, ridge and furrow system is appropriate. On slopes greater than 1.5%, a gated-outlet-contour bund system has shown a good potential to increase and stabilize crop yield (Table 3). The performance of these practices have been discussed in detail by Pathak et al. (1985), Pathak et al. (1987), and El-Swaify et al. (1985).

However, for groundnut, raised land surface configurations such as broadbed and furrow has been found to be beneficial in increasing pod yield (Sujatha 1992). In an experiment at ICRISAT Asia Center, using two groundnut genotypes ICGS-11 and ICG(FDRS)10, grown on three land surface configurations–broadbed and furrow, 30-cm narrow ridge and furrow, and flat seedbed cultivation, Sujatha (1992) observed throughout the growing season, that the bulk density of 0–15 cm soil layer was significantly lower in BBF than in the narrow ridges and the flat seedbed treatments in that order. Differences in bulk density between treatments persisted at 30, 60, 90, and 145 days after sowing. During the growing season, the total porosity of the 0–15 cm soil layer was significantly greater in the BBF system than in the ridge and flat seedbed systems. Similar differences in penetration resistance were observed between the different systems. Lowest penetration resistance was recorded in the BBF system. Significantly higher pod yields were obtained in the BBF followed by ridge and flat (Table 4). This trend was observed in both varieties.

Table 3. Effect of alternative land surface configurations on crop yield, runoff, and soil loss on Alfisols at ICRISAT Asia Center, 1981–84.

	Crop yield (t ha^{-1})			
	Intercrop system			
Land treatment	Sorghum	Pigeonpea	Runoff (mm)	Soil loss (t ha^{-1})
(A) Land slope < 1.5%				
Broadbed and furrow at 0.4% slope[1]	2.74	0.83	315	3.79
Ridge and furrow at 0.4% slope[1]	2.9	0.87	282	3.02
Flat contour cultivation[1]	2.96	0.86	172	2.05
Flat-on-grade at 0.4% plus ridging up later[1]	2.88	0.84	180	2.78
SE	±0.15	±0.07	±16	±0.24
(B) Land slope > 1.5%				
Contour bund[1]	2.52	0.71	75	0.97
Modified contour bund with gated outlet[1]	3.02	0.97	160	0.92
Flat-on-grade with field bunds[1]	2.81	0.9	215	3.35
Traditional flat with field bunds[2]	0.38	0.22	256	4.79
SE	±0.18	±0.06	±23	±0.19

1. Treatment with recommended crop management practices, implying the use of acceptable or recommended variety, cropping system, chemical fertilizer, and other practices for weed, pest, and insect control.
2. Treatment with traditional management practices, implying the use of variety, cropping system, farmyard manure, implements, and other practices.

On Alfisols, crusting and sealing problems are encountered frequently during the early part of the growing season, when the crop canopy is not yet fully developed. During this period, considerable runoff has been observed even when the soils were dry. An experiment was conducted at ICRISAT Asia Center, from June 1981 to March 1983 to determine whether the excess runoff which occurred during the early part of the rainy season can be reduced by breaking the crust or the compacted top layer using various interrow tillage practices in addition to normal interrow cultivation (Pathak et. al 1994). In all 3 years, the interrow tillage, in addition to normal interrow cultivation, was effective in reducing runoff and soil loss. Except in a very high-rainfall year, crop yields were also significantly increased by additional interrow tillage during the other 2 years.

Table 4. Groundnut pod yield, as influenced by different land surface configurations on an Alfisol at ICRISAT Asia Center, 1991–92.

	Pod yield (t ha^{-1})	
Treatment	ICG(FDRS)10	ICGS 11
Flat	3.45	2.86
Ridges	3.71	3.09
BBF	4.22	3.39
SE	±0.09	±0.09
CD (0.05)	0.20	0.20

Source. Sujatha (1992).

Scoops (or Pitting)

Recently there has been an increasing interest in surface roughness as a means of improving in-situ soil and water conservation in the SAT. The main aim of producing small scoops (or pittings) is to provide more time for water that would otherwise be lost as runoff to infiltrate into the soil. Another aim is to reduce soil loss by trapping the eroded sediments that would otherwise be lost from the field.

Experiments were conducted under simulated rainfall conditions using rotating disc-type rainfall simulator to compare the performance of pitted land with flat land. The two treatments, scoops and flat land were studied under mulch (60% cover) and bare surface conditions. The average runoff measured from the pitted and flat land treatments on an Alfisol are shown in Table 5. In all conditions, runoff from scoops was significantly lower than that from the flat land. However, the comparative advantage of scoops over flat in terms of reducing runoff and soil loss varied considerably over different conditions. In terms of reducing runoff, scoops were most effective under mulch and low-rainfall intensity conditions (i.e., scoops reduced runoff by 57% compared with flat). Scoops were less effective on bare, high-rainfall intensity conditions (scoops reduced runoff by only 24% compared with flat).

The effects of rainfall intensity on runoff under bare and mulched conditions can also be seen in Table 5. Runoff from all the treatments increased with an increase in rainfall intensity. When runoff from the flat land is used as a comparison yardstick, then under bare soil conditions and at rainfall intensity of 28 mm h^{-1}, pitting reduced runoff by 40.7% compared with 23.5% reduction at rainfall intensity of 65 mm h^{-1}. Pitting under mulched conditions and rainfall intensity of 28 mm h^{-1} reduced runoff by 57.1% compared with 37.5% when rainfall intensity increased to 65 mm h^{-1}. Using the runoff from bare land as a basis of comparison, it is noted that mulching reduced runoff by 62.5% under pitting at rainfall intensity of 28 mm h^{-1} compared with 42.3% under an intensity of 65 mm h^{-1}. Under flat

Table 5. Runoff and soil loss from pits and flat treatments from an application of 46 mm rainfall on an Alfisol at ICRISAT Asia Center, 1991.

	Runoff (mm)			Soil loss (t ha^{-1})		
Treatment	Pits	Flat	SE	Pits	Flat	SE
Bare surface						
Rainfall intensity 28 mm h^{-1}	16	27	±3.1	1.8	2.9	±0.21
Rainfall intensity 65 mm h^{-1}	26	34	±4.2	5.0	8.3	±0.48
Surface with mulch (60% cover)						
Rainfall intensity 28 mm h^{-1}	6	14	±2.1	0.8	1.9	±0.14
Rainfall intensity 65 mm h^{-1}	15	24	±1.9	2.1	2.8	±0.29

land, mulching reduced runoff by 48.2% when rainfall intensity was 28 mm h^{-1} compared with a reduction of 29.4% by mulch when rainfall intensity increased to 65 mm h^{-1}. Differences in runoff between scoops and flat under bare or mulched conditions decreased with increased rainfall intensity, reflecting a decrease in the advantage of pitting over flat as rainfall intensity increased.

The soil loss data from scoops and flat showed trends similar to those for runoff. There was not much difference between the percentage reduction in soil loss due to pitting (or scoops) between the two rainfall intensities (i.e., 38.7% reduction in soil loss by pitting at 28 mm h^{-1}, compared with 40.5% reduction at rainfall intensity of 65 mm h^{-1}). Under mulched conditions, however, pitting reduced soil loss by 60.0% at rainfall intensity of 28 mm h^{-1} compared with 26.7% reduction in soil loss when rainfall intensity increased to 65 mm h^{-1}.

Mulch made less reduction in soil loss (i.e., 35.5%) over bare when applied on flat land surface with a rainfall intensity of 28 mm h^{-1}, than on the same land surface but at higher rainfall intensity of 65 mm h^{-1} (66.3%). There was little difference between the two rainfall intensities (i.e., 57.9% reduction for rainfall intensity of 28 mm h^{-1} compared with 58.5% for 65 mm h^{-1}) when scoops were mulched. All the scooped plots with the same rainfall intensity and cover conditions produced significantly lower soil loss than the plots with flat treatments. It was observed that considerable amount of eroded soil particles were deposited in the scoops. This deposition process made scoops effective in controlling soil loss. The observation on the deposition of eroded soil in scoops was confirmed by the measurements of soil surface elevations taken before and after rainfall (Fig. 1).

The effects of rainfall amount on the comparative performance of scoops over flat in terms of runoff is shown in Figure 2. We define 'scoop efficiency' as :

$$\frac{\text{Runoff from flat} - \text{Runoff from scoops}}{\text{Runoff from flat}} \times 100$$

The scoop efficiency is a measure of the percentage reduction in runoff due to pitting (or scoops) compared to flat. Figure 2 clearly shows that rainfall amount has an immense effect on scoop efficiency. For example, on bare surface and low rainfall intensity conditions, the scoop efficiency remained constant at 100% until at 28 mm rainfall when it decreased exponentially to only 16% at 76 mm rainfall. Figure 2 clearly shows that small scoops of 10 mm capacity are efficient in regulating runoff only from storms less than 55 mm. The effectiveness of this size scoops for rainfall amounts greater than 55 mm is low.

In another experiment, under natural rainfall conditions, three surface roughness treatments–pittings, tied-ridges, and flat seedbeds–were compared for their effectiveness in controlling runoff and soil loss and in increasing crop yield on Alfisols. Analysis of 4 years' (1988–91) results from this and the other experiments with and without crops indicated that :

- Surface roughness, i.e., pittings and tied-ridges, significantly reduced runoff and soil loss compared with flat seedbed cultivation. Using runoff and soil loss from the flat land as a basis for comparison in 1989–90, scoops reduced seasonal runoff by 69%, and soil loss by 53% while runoff in the tied-ridged system was reduced by 39% and soil loss by 28%.
- Pittings were more effective in reducing runoff and soil loss than tied-ridges. For example, in 1989 and 1990 rainy seasons, pittings with 40-mm storage capacity had average seasonal runoff of 81 mm and average soil loss of 2.61 t ha^{-1}, compared with 160 mm runoff and 3.9 t ha^{-1} soil loss from tied-ridges of the same storage capacity.
- Pittings were relatively more stable than tied-ridges, particularly, during high-intensity rainfall and runoff conditions. In 1989–90, there was less number of breaching in pittings than in the tied-ridges.
- In terms of controlling runoff and soil loss, the largest advantage of pittings over flat cultivation was observed during the early part of the crop-growing season. This is mainly due to the fact that problems of surface crusting and sealing were more during that period of the crop-growing season due to sparse vegetation and poor crop canopy. Consequently, in flat seedbed cultivation, a major proportion of the rains that fell during the early part of the rainy season on Alfisols was lost as runoff while in pittings, most of this runoff was stored in the depressions.
- The stability of pittings can be greatly increased by providing a graded outlet system to the field. During big storms, a graded outlet design of pittings was relatively more stable than the conventionally designed pittings. This was particularly true for small-sized pittings of 10 and 20 mm storage capacities.
- There was a significant increase ($P < 0.04$) in pearl millet grain yield in the 20-mm storage capacity pittings (2.42 t ha^{-1}) over the flat seedbed (1.79 t ha^{-1}). However, there was no significant difference in grain yield between the 10-mm storage capacity pittings (1.99 t ha^{-1}) and the flat treatment.

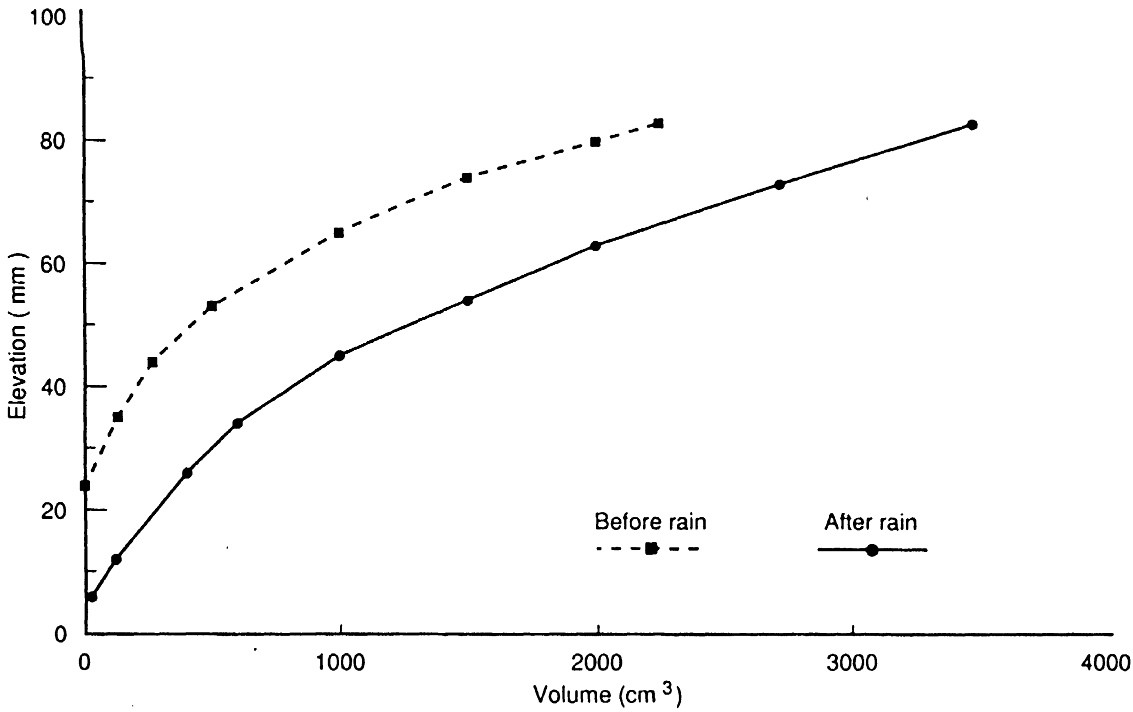

Figure 1. Elevation vs scoop storage capacity, before and after rainfall, under bare surface conditions on an Alfisol (Rainfall = 50 mm; Rainfall intensity = 28 mm h^{-1}).

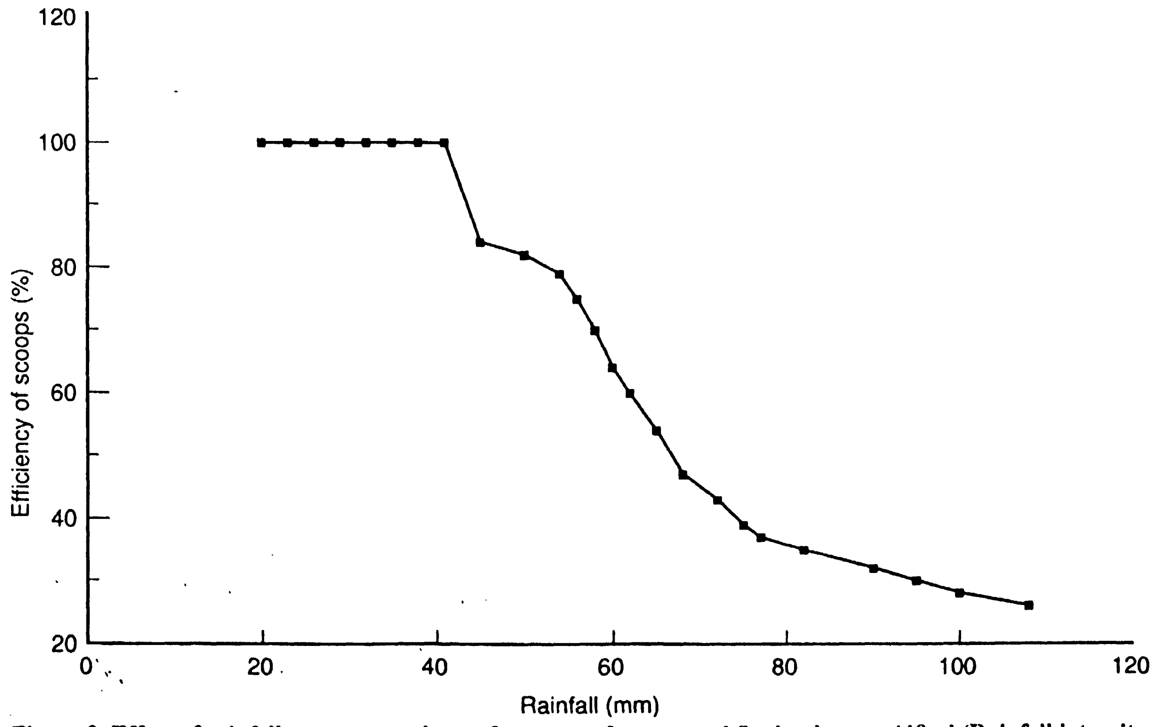

Figure 2. Effect of rainfall amounts on the performance of scoops and flat land on an Alfisol (Rainfall intensity = 40 mm h^{-1}; scoops capacity = 30 mm).

Conclusion

Results show that some of the improved land management practices can have immediate and positive benefits over the traditional management systems. These include increases in crop yields, marked reduction in soil erosion and substantially low runoff losses. For Vertisols, a system of broadbed and furrow has been found to be effective in ensuring good surface drainage of water, control of erosion and in conserving water in the soil profile. This system, together with improved cropping practices, has been found to reduce surface runoff to one third, soil loss to one seventh, and peak runoff rate to half, compared with the traditional system of farming.

On Alfisols, several soil management practices such as pits, frequent shallow interrow tillage, etc. were found to be effective in reducing runoff and soil loss and in increasing crop yields. Pits were found to be more effective than tied ridges. They were relatively more stable (i.e., do not breach easily) than tied ridges, particularly under intense rainfall and peak runoff conditions. In terms of controlling runoff and soil loss, the greatest advantage of pits over flat land cultivations occurred in the early part of the crop-growing season.

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Effect of Landforming Treatments for Water Harvesting on Soil Hydrologic Aspects

Mukki Abd Ellatif[1]

Summary

Although in north Kordofan most agricultural activities are concentrated on the 'goz sands', another type of soil, locally known as 'gardud', is also being cultivated. Gardud soils are noncracking and have a hard-compacted surface with an extremely low infiltration rate. Texturally, gardud soil is sandy clay to sandy clay loam with a depth ranging from 0.9 to 1.2 m. Gardud soils constitute about 30% of the arable land (10 million feddan) in north Kordofan. Despite good agricultural potential of gardud soils, they are usually considered to be marginal land because the hard surface is difficult to cultivate using the small, traditional hand tools available to farmers and because of the problem of reduced infiltration.

Reduced infiltration makes gardud soil well suited for natural runoff and water harvesting, without much need to change the surface configuration. Therefore, certain water-harvesting techniques such as micro and macrocatchment runoff interception, conduction, and improvement of soil physical conditions in the cultivated area could be the basis for management practices that provide better growing conditions. These water management practices are of primary importance in drought-prone areas which are characterized by erratic and unpredictable rainfall. The long-term yearly average rainfall is about 270 mm, and it is often of high intensity, resulting in considerable surface runoff and rapid evaporation.

The objectives of this study were: (1) to develop a suitable landforming technique for water harvesting on gardud soil to improve crop productivity, and (2) to determine the effectiveness of the technique on hydrological aspects of gardud soils associated with soil and water conservation.

Two landforming treatments (contour-ridge and wide flat-bed) were used with and without external macrocatchment, two levels of in-situ microcatchment contributing areas (cropped and noncropped), and three tillage treatments (chisel, harrow, and no-till). Sorghum was grown on the runoff-receiving area for two seasons to determine the effect of this water harvesting technique on hydrologic aspects of gardud soil, as they relate to soil and water conservation and crop productivity.

Gardud soil is well suited for runoff water harvesting because of its low infiltration rate in the macrocatchment, whereas chisel-tillage treatment improved infiltration capacity in the cultivated microcatchment, and hence showed greater total water profile compared with harrow and no-till cultivation. Also, soil water was increased when the microcatchment-contributing area was not cropped. The largest amount of water harvested came from the macrocatchment, which averaged 280 mm from the contour-ridge system compared with 190 mm from the wide flat-bed system. A cropped microcatchment helped to slow down the runoff compared with a noncropped microcatchment, but less runoff water was captured when the microcatchment was cropped than when it was not cropped.

Soil loss was mostly associated with the way in which the runoff area was constructed and water collected. With no crop cover in the microcatchment-contributing area, water harvesting systems were less effective in controlling sediment loss. Cropped microcatchment reduced soil loss by 50–60% over noncropped microcatchment. The least sediment loss was obtained with chisel cultivation, which reduced soil loss by 59% for the contour-ridge system and 63% for the wide flat-bed system from that lost under harrow cultivation. A system involving a contour-ridge landform, a noncropped microcatchment-contributing area, and an external macrocatchment area increased sorghum grain yields by 63% over that using wide broadbeds, 70% over that using a cropped microcatchment area, and 150% when there was no external macrocatchment area. These incremental percentages suggest that crop yield responses to the presence of an external macrocatchment water supply are significant, especially where there is limited rainfall during the growing season. Yield differences due to tillage treatments were not statistically significant, but chisel cultivation generally increased yield.

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Current Agronomic Research on Pearl Millet at El Obeid

Hassan O Elawad[1]

Abstract

*Pearl millet [*Pennisetum glaucum *(L) R. Br] is the main staple food crop in western Sudan. It is adapted to the low, erratic rainfall and poor, sandy soils that generally characterize the region. Other major constraints to production are poor varieties, poor management practices, and pests. To conduct research on production practices, several experiments pertaining to agronomic aspects were conducted at the El Obeid Research Station in 1991. Total effective rainfall was very low (184 mm), and contributed significantly to the low yields and lack of significance in many treatment effects. Intercropping pearl millet and cowpea gave greater total grain yield per unit in most combinations than in sole crops.*

Introduction

Pearl millet [*Pennisetum glaucum* (L) R. Br.] is the main staple food crop in western Sudan. It is grown traditionally and adapted to low rainfall and the poor sandy soils of western Sudan. Annual average yields dropped sharply in the last 10 years. The main production constraints are low and erratic rainfall, poor management practices, poor soil fertility, poor genetic stock, and problems of pests.

With a view to mitigate some of the above constraints, several experiments were conducted during the 1991 season at the El Obeid research farm.

Rainfall

The amount of rainfall in 1991 was very low, only 230 mm (Table 1) compared with the long term average of 359 mm. May was wet (46 mm), but June was very dry. The long dry spell in June damaged all the early plantings established by most of farmers in North Kordofan. The farmers planted again after the onset of rains in mid-July. The effective sowing date in El Obeid research farm was 22 July. The rains stopped on 21 September. The total effective rainfall was calculated to be 184 mm (Table 1).

Soil

The soils on the El Obeid research farm are mainly light textured, loamy sands, where the sand fraction represents more than 93%. These soils are also low in nitrogen (0.03%), phosphorus (4 mg kg^{-1}), organic matter (0.412%), and cation exchange capacity.

Table 1. Amount (mm) and distribution of rainfall at El Obeid Research Station, 1991 cropping season.

Month	Date	Rainfall (mm)	Total
May	10	5.8	
	11	8.8	
	15	11.0	
	21	8.5	
	22	17.0	46.1
June	0.0	0.0	
July	16	9.5	
	22	46.0	
	31	6.5	62.0
August	3	35.5	
	4	4.5	
	9	15.0	
	14	12.0	
	23	17.5	
	27	11.0	95.0
September	15	18.0	
	21	9.0	27.0
Overall total			230.1

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Experiments

Experiment 1: Effect of plant population in pearl millet cowpea intercrop

Cowpea was intercropped with millet in a 1:1 row system. Different population densities of cowpea and millet were studied, giving combined population densities of 40, 50, 70, 80, and 100 thousand plants ha^{-1} (Table 2). The design of the experiment was a randomized complete block with four replications. The experiment was sown on 22 July. Most of the population densities showed clear advantage of intercropping over sole cropping. The land equivalent ratio (LER) was highest (1.74) in the lowest population density of 40 000 plants ha^{-1}. It was also observed that with the increase in cowpea population density in the intercrop, the grain yields of cowpea gradually increased and that of millet decreased.

Table 2. Effect of plant population in a pearl millet/cowpea intercrop.

Plant population ('000 ha^{-1})				Intercrop yields (kg ha^{-1})		Sole crop yields (kg ha^{-1})	
Millet	Cowpea	Total	LER[1]	Millet	Cowpea	Millet	Cowpea
30	10	40	1.74	234	85	181	10
30	20	50	1.30	121	120	181	10
30	40	70	1.43	108	184	181	20
60	10	70	1.60	208	94	205	10
60	20	80	0.95	120	61	205	10
60	40	100	1.49	129	190	205	20

1. LER = land equivalent ratio.

Experiment 2: Effect of weeding time and frequency on grain yield, plant height, and tillering

Different weeding treatments (Table 3) were applied to study the effect of weeding time and frequency on grain yield, plant height, and tillering in pearl millet. The design of experiment was a randomized complete block with four replications. The experiment was sown on 22 July.

Table 3. Effect of weeding time and frequency on grain yield, plant height, and tillering in pearl millet.

Weeding (no. of weeks after sowing)	Grain yield (kg ha^{-1})	Tillers per plant	Plant height (cm)
6	210.0	2.50	107
4	158.0	2.50	81
2	123.0	2.75	96
2 and 4	116.0	2.50	75
2 and 6	114.0	3.00	107
4 and 6	112.5	3.50	115
2, 4, and 6	104.0	2.25	102
No weeding	64.0	2.75	102
SE	±48.25	±0.32	±9.69

The data showed no significant effect of weeding treatments on either grain yield or other characters measured. The highest grain yield (210 kg ha^{-1}) was observed when weeding was conducted once, 6 weeks after planting. The lowest yield (64 kg ha^{-1}) was observed on the treatment with no weeding.

Experiment 3: Effect of time and level of thinning on grain yields and some agronomic characters of pearl millet

Thinning was done four times, 15, 20, 25, and 30 days after planting (DAP) and four levels of thinning, 1, 2, 3, and 5 plants/hole were tested in a factorial experiment in a randomized complete block design, with four replications. The experiment was sown on 22 July. Results are shown in Tables 4 and 5.

Data show that there was a significant difference in grain yield and plant height due to time of thinning. Thinning 15 DAP gave significantly higher grain yield (191 kg ha^{-1}) than during other times (Table 4).

Table 4. Effect of time of thinning on grain yield, tillering, and plant height in pearl millet.

Time of thinning (DAP)	Grain yield (kg ha-1)	No. of productive tillers/culm	Plant height (cm)
15	191	3.2	111
120	117	2.9	110
25	112	2.8	99
30	112	2.8	92
SE	±19.7	±0.21	±3.7

Table 5. Effect of level of thinning on grain yield, tillering, and plant height in pearl millet.

Level of thinning (plant/hole)	Grain yield (kg ha-1)	No. of productive tillers/culm	Plant height (cm)
1	160	2.1	108
2	116	2.0	102
3	173	3.4	107
5	123	4.0	94
SE	±10.7	±0.21	±3.7

Grain yields were not significantly affected by the levels of thinning. However, the number of productive tillers/culm and plant height were significantly affected (Table 5).

Experiment 4: Effects of intra-row spacing and mineral fertilizer (N,P,K) on grain yield and agronomic characteristics of pearl millet

Three levels of intra-row spacing (25, 50, 100 cm), two levels of nitrogen applied as urea (0, 1N), two levels of phosphorus applied as TSP (0, 1P), and two levels of potassium applied as K_2SO (0, 1K), were tested in a factorial experiment in a randomized complete block design with four replications. The experiment was sown on 22 July.

The 100-cm intra-row spacing significantly increased the number of productive tillers per culm over the 25-cm intra-row spacing and plant height. However, grain yield and other yield components were not significantly influenced. The application of nitrogen, phosphorus, and potassium did not show any significant effect on grain yield and the other agronomic characteristics measured.

General Observations

Infestation by the millet head caterpillar [*Heliocheilus* (=*Raghuva*) *albipunctella* De Joannis] was very high in all the experiments. The damage was not significantly affected by the treatment, but contributed to the low grain yields of pearl millet in all the experiments, besides the contribution to low yields of variation in soils, erratic rainfall, and terminal drought. It is likely that these factors contributed to the low frequency of significant differences between treatments observed in the experiments.

Test of Transfer of Gambella 1107 in the Cibitoke Lowland of Burundi

Bernard Delaine, Anicet Tuyaga, and Zenon Kabiro[1]

Introduction

In order to diversify food and cash crops of Burundi, the Sorghum Breeding Program of the Institut des Sciences Agronomiques du Burundi (ISABU) recommended Gambella 1107 for release in the Imbo Region. Gambella 1107 can be used for many types of food preparations as it has white grain.

The tests for the transfer of Gambella 1107 and the appropriate production techniques were undertaken by 'L'Atelier Cibitoke' during the 1990/91 growing season. Twenty-one farmers in Rukana, Rugombo, Gasenyi, and Kagunuzi locations agreed to participate in the study in 1991. The exercise was repeated in 27 farmers fields during the 1992 season.

This paper gives the results of the study and explains the socioeconomic constraints of farmers in adopting Gambella 1107.

Goal of the Transfer Test

The atelier is a new on-farm research concept of ISABU. Its role is to fill gaps existing between researchers and farmers. Before the creation of ateliers, agronomic methods proposed by researchers were either adopted with difficulty or not at all. Such a situation was a significant problem for both researchers and extensionists. In 1989, it was decided that agronomic researchers were not actually taking into account, farmers' needs or possibilities.

Thus, the atelier was created to identify the needs of farmers to note all constraints dealing with new technologies (transfer and adoption). The atelier is to give feedback to researchers.

Before starting every growing season, the Atelier Cibitoke organizes meetings with farmers in each village to ask them what they need, to improve crop production. In 1990, improved sorghum was listed as one of the needs. In response, the Sorghum Breeding Program of ISABU proposed the use of the white-seeded variety Gambella 1107, as a suitable cultivar. Therefore, the atelier of Cibitoke tested the transferability of Gambella 1107 sorghum variety in the northern Imbo, the warmest region in Burundi.

Preparation for the Transfer Test

Before implementation of the transfer test, the atelier agronomist asked the head of the ISABU Sorghum Breeding Program to teach him and the extension team about the new sorghum variety to be tested. The seminar took a whole week in January 1991. Plots were sown 1, 2, and 3 weeks earlier, to demonstrate the different agricultural practices required in growing the crop.

Realization of the Transfer Test

The farmers who asked to participate in the transfer test had been grouped according to village by the atelier agronomist. This person explained to the farmers the recommended technology, and gave them the seeds and fertilizer needed for the area to be cultivated. Average size of plots was about 21 'ares' (1 ares = 0.01 ha) for the 21 participants in 1991 and about 24 ares for the 27 farmers in 1992. The atelier agronomist advised farmers about the best way of sowing. Most of the farmers followed the ISABU Sorghum Breeding Program proposals. Sowing took place between

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15 February and 1 March 1991, and between 15 February and 15 March 1992. Rows were spaced 75 cm apart. A basal dose of complete fertilizer (N,P,K) was applied before sowing, and urea was added after weeding as a side dressing, 3–4 weeks later. Farmers were advised to have a density of 1 50 000 sorghum plants per ha. Some of the farmers protected their fields against birds during the last month before harvesting. After harvesting, whole plot yields were determined.

The atelier agronomist recorded constraints faced by farmers and all labor used at the different steps of technology application. Before harvest, the atelier agronomist showed people how to prepare several local and exotic foods from the white sorghum. The meals of popular interest were porridge, sorghum cooked like rice, paste, chapati, and beer.

Results

The agronomic level

The yield in 1991 of 21 farms averaged 2.64 t ha^{-1} (Table 1). This yield generally corresponds to the 2.50 t ha^{-1} to 3 t ha^{-1} yields generally expected with good management.

In 1992, yield decreased to a mean of 1.95 t ha^{-1} (Tables 2 and 3). Two factors caused the decrease: bad seeds given by local extension service and political problems which made farmers run away from their homes.

The economic level

In 1991, the price of white sorghum was 30 BuFr (Burundi Franc) kg^{-1} while in 1992, it varied between 38 and 45 BuFr kg^{-1}.

Table 1. Grain yield of Gambella 1107 sorghum and net return from farmers' fields, 1991.

Farmer	Area (m^2)	Grain yield per plot (kg)	Calculated yield (t ha^{-1})	Production cost (BuFr)	Value (BuFr ha^{-1})	Net return (BuFr ha^{-1})
1	1071	332	3.10	44 100	92 969	48 869
2	582	197	3.38	65 379	105 121	36 148
3	864	257	2.98	47 807	89 236	41 429
4	3600	647	1.80	34 861	53 917	19 056
5	1701	527	3.10	44 814	92 945	48 132
6	3584	709	1.98	35 528	59 437	23 819
7	2079	563	2.71	36 136	81 241	45 106
8	1590	285	1.79	50 066	53 760	3 694
9	2033	554	2.73	35 973	81 759	45 787
10	1767	475	2.69	63 526	80 645	17 119
11	2400	547	2.28	37 396	68 375	30 979
12	2027	529	2.61	53 972	78 307	24 335
13	2022	540	2.67	45 303	80 100	34 796
14	3245	864	2.66	28 271	79 866	51 596
15	3538	680	1.92	35 695	57 660	21 965
16	1830	682	3.73	35 041	111 803	76 762
17	1880	415	2.21	58 218	66 144	7 926
18	1890	483	2.56	58 951	76 667	17 716
19	930	541	2.59	67 516	77 581	10 065
20	5110	1407	2.75	74 135	82 603	8 468
21	510	163	3.18	68 867	94 038	25 171
Mean	1071	543	2.64	48 645	79 071	30 425
SD	±1112			±3390	±15 005	±17 780
Minimum	520			2 827	53 760	3 694
Maximum	5110			74 135	111 803	76 762

Table 2. Grain yields of Gambella 1107 and net return from farmers' fields at Kagunuzi, 1992.

Farmer	Area (m^2)	Grain yield per plot (kg)	Calculated yield ($t\ ha^{-1}$)	Production cost (BrFr)	Value ($BrFr\ ha^{-1}$)	Net return ($BrFr\ ha^{-1}$)
1	500	60	1.20	48 500	4 800	-500
2	1300	212	1.63	40 515	65 231	24 715
3	2000	528	2.64	47 250	105 000	57 750
4	2000	274	1.37	43 000	54 800	11 800
5	2000	331	1.66	41 000	66 200	25 200
6	4000	445	1.11	36 625	44 500	7 875
7	1000	529	3.31	56 663	132 250	75 588
8	2600	590	2.27	47 115	90 769	43 654
9	3000	673	2.24	48 600	87 733	41 133
10	4000	620	1.55	41 750	62 000	29 250
11	1000	193	1.03	34 550	41 200	6 650
12	6000	1420	2.37	50 533	94 667	44 138
13	6000	1746	2.91	46 417	116 400	69 983
Mean	2108	579	1.94		77 750	32 941
SD	±1112				±28 007	±32 676

The farmers' point of view

Farmers had no difficulties applying the recommended agricultural practices. In fact, they were accustomed to sowing in rows and using fertilizer on cotton and tobacco.

The main agricultural practice which was not well understood by farmers was thinning. Farmers felt bad about uprooting healthy plants. They usually did it only to fill gaps. Remarkably, most of the farmers did not respect the recommended spacing between plants.

The major problem farmers faced was bird attacks. However, the farmers were convinced that if sorghum is grown in large areas (many sorghum fields grouped near each other) there would be less damage by birds than if it is only grown in isolated or widely spread fields. Another problem was an unsure market. White sorghum is a new crop and is not well known in trade, but some agricultural companies are becoming interested in it. The local brewery has requested 5000 t of Gambella 1107. What are mostly needed are middlemen to sell fertilizer and seed, and to buy the harvest.

Farmers are happy with the new variety because it yields more grain than the local variety and the seeds are inexpensive. However, fertilizer can be a constraint to adoption because it is generally not available at the farmers' level.

Table 3. Grain yields of sorghum in farmers' fields at Rukana, 1992.

Farmer	Area (m^2)	Grain yield per plot (kg)	Calculated yield ($t\ ha^{-1}$)
1	10	154	1.54
2	30	613	2.04
3	20	133	0.67
4	20	600	3.00
5	20	112	0.56
6	20	527	2.64
7	20	170	0.85
8	10	025	0.25
9	20	361	1.81
10	40	427	1.07
11	20	320	1.60
12	10	086	0.86
13	20	560	2.80
14	10	144	1.44

Average yield: 1.51 $t\ ha^{-1}$.
SD: ±0.85

Feedback to researchers

One of the purposes of atelier agronomists is to give researchers feedback regarding the new technologies. In the case of Gambella 1107, an interesting feedback to researchers was that farmers did not thin plants to meet the recommended plant population. Surprisingly enough, the farmer who had the greatest yield in 1992 did not thin. The panicles were small, but numerous. It would be interesting to study if the cost of thinning is lower than the cash added by thinning.

Conclusion

The Gambella 1107 sorghum variety has been well accepted by farmers. It's adoption by farmers will depend, however, on several factors including the availability of fertilizer at the right time (and a loan to buy it) and good prices in a sure market.

Response of Hybrid Sorghum (Hageen Durra-1) to Nitrogen and Phosphorus Under Irrigation

Saeed M Farah and Hamid H Faki[1]

Abstract

This paper presents the effects of applying different doses of nitrogen (N) and phosphorus (P) on the yields of grain and straw of Hageen Durra-1, the first sorghum hybrid in the Sudan.

It was found that the addition of 86 kg N ha^{-1} increased average grain yield by 51% and straw yield by 31%. The addition of 43 kg P_2O_5 to this treatment increased the grain yield by 11% and straw yield by 7%.

Addition of N doses higher than 2N tended to decrease yields in the absence of P. The highest net benefits (NB) were obtained from 2N. However, the optimum dose for N was 1.6N, indicating that even higher NB could have been realized with lower increments of N than the 2N dose tested in this study.

About 69 kg N ha^{-1} should be applied to obtain optimum grain and straw yields of Hageen Durra-1.

Introduction

Hageen Durra-1 is the first hybrid in the Sudan. It was officially released by the Sudan Plant Propagation and Variety Release Committee in 1983. It is early maturing and high yielding. From some 1270 ha grown to test its performance in the Gezira in 1984, the grain yield ranged between 2.83 and 6.07 t ha^{-1}, with an average of 4.35 t ha^{-1} (McDonald 1983). Compared with almost all open-pollinated cultivars grown in the Sudan, whose grain yield does not exceed 1.2 t ha^{-1}, the yield obtained from this hybrid should encourage both farmers and managers of agricultural schemes to promote production of the hybrid.

In the research plots, mineral fertilization of sorghum is seldom carried out in the commercial sector, in spite of the positive response of sorghum cultivars to nitrogen (N) and sometimes phosphorus (P).

Review of Literature

Mineral fertilization has proved to be one of the most important cultural practices which affects sorghum yields (Martin et al. 1929, Grimes and Musick 1960). Several experiments have been carried out on fertilization of sorghum in the Sudan (Ishag 1962, Ageeb 1969, El Rayah 1973, Ali 1981, Farah and Ali 1982, Farah 1984). Ishag and Babiker (1972) reported the effects of six levels of N (0, 43, 86, 129, 171, 214 kg N ha^{-1}) on sorghum variety Dwart Hegari. Application of N progressively increased grain yields compared with the nonfertilized control treatment, reaching 2.18 t ha^{-1} (increase of 202%) at the level of 129 kg N ha^{-1}. Additional levels of N over this gave slight increases ranging between 1.5 and 5.0%.

El Rayah (1973), using Dwarf White Milo, Cross 3, Dabar, and Gadam El Hamam, found highly significant ($P < 0.001$) response to N, amounting on average, to increases in grain yields of 57% by adding 43 kg N ha^{-1}, 150% by adding 86 kg N ha^{-1}, and 169% by adding 129 kg N ha^{-1}, over the control. However, these results showed a differential response of the tested cultivars to the added N, so that effects on the early-maturing cultivars were more pronounced than on late-maturing ones. The latter also showed a negative response to N at the highest dose. Such findings were also noted by Ageeb (1969) when he applied three levels of N on an early-maturing cultivar T.U.B. 7 and a late-maturing Wad Akar.

This differential response of N was also noted with plant density. For example, Farah and Ali (1982) tested three sorghum cultivars with and without 86 kg N ha^{-1} imposed on two plant densities—1 00 000 and 1 67 000 plants ha^{-1}.

1. Gezira Research Station, P.O. Box 126, Wad Medani, Sudan.

They found that although grain yields were not significantly affected by N or plant density, the absence of N decreased yields at higher plant densities.

The response of Hageen Durra-1 to levels of N and P was, for the first time, studied by Farah (1986) using five levels of N and three levels of P factorially combined. The results showed that 43 kg ha^{-1} of N increased average grain yield by 12% over the control (0 N). When 86 kg N ha^{-1} were added, grain yield was increased by 72% over the control. Yields leveled after this point, showing very slight yield increases with 129 and 172 kg N ha^{-1}. On the other hand, an addition of 43 kg P_2O_5 ha^{-1} increased grain yields over that of the control (0 P) by 5% and an addition of 86 kg P_2O_5 ha^{-1} by 19%.

Experimental Methods

The experiments were conducted on farmers' fields in the first and second seasons, and in the third season, at the Gezira Research Farm on cotton-wheat rotations. The soil is described as a heavy, deeply cracking clay of the Sulemi series and is characterized by low permeability and low N content. Planting of the hybrid during the three seasons commenced during the first half of July on ridges spaced 80 cm apart, with 30 cm between plant holes. About five seeds were planted and thinned to three plants per hole, 3–4 weeks after emergence. Nine fertilizer treatments were tested in the first season, and only the first six of these were tested in the second and third seasons. The nine fertilizer treatments were:

1. Without fertilizer control (0 N)
2. 86 kg N ha^{-1} (2N)
3. 86 kg N ha^{-1} + 43 kg P_2O_5 ha^{-1} (2N + 1P)
4. 129 kg N ha^{-1} (3N)
5. 129 kg N ha^{-1} + 43 kg P_2O_5 ha^{-1} (3N + 1P)
6. 129 kg N ha^{-1} + 86 kg P_2O_5 ha^{-1} (3N + 2P)
7. 192 kg N ha^{-1} (4N)
8. 192 kg N ha^{-1} + 43 kg P_2O_5 ha^{-1} (4N + 1P)
9. 192 kg N ha^{-1} + 86 kg P_2O_5 ha^{-1} (4N + 2P)

The N was applied in the form of urea and the phosphorus as triple super phosphate. The two fertilizers were mixed together and placed at the bottom of the ridges on one side, using a sowing stick and then covered with soil and watered in by immediate irrigation. Using plots of 10 × 9 m, the treatments were arranged in a randomized block design with six replications. Weeds were controlled by an initial application of sorghobrim at the rate of 1.43 L (a.i.) ha^{-1} followed by two hand weedings. The crops were irrigated six times following the planting irrigation at 14-day intervals, with about 850 m^3 ha^{-1} per irrigation. At harvest (26 Oct), grain and straw yields in each plot were assessed from an area of 9 m × 8 m, leaving a margin of 1 m from all sides. The analysis of variance and Duncan's Multiple Range Test were applied on the data, using the methods described by Gomez and Gomez (1983). Economic evaluation of the results was made using the partial budget analysis for the different fertilizer treatments.

Results

Effect of N and P on grain yield

Addition of 2 N increased grain yields over those of the control (0 N) by 26% in the first, by 40% in the second, and by 88% in the third season. The significance levels were $P < 0.005$ for the first, 0.01 for the second, and 0.001 for the third season. The overall increase over the three seasons was 51%. Addition of 1 P to the 2 N increased grain yields by 20% in the first, 10% in the second, and 3% in the third season, the overall increase being 11%.

Doses of N higher than 2 N tended to lower grain yields compared with 2N + P when 1 P was not applied with these doses (first and third seasons) (Table 1).

Except for treatment 4N in the first season and 2 N in the second season, the differences between the rest of the treatments, in the three seasons, did not reach the significance level.

Table 1. Grain and straw yields under various mineral fertilizer levels of the hybrid during three seasons.

Treatment	1988/89 season ($t\ ha^{-1}$)		1989/90 season ($t\ ha^{-1}$)		1990/91 season ($t\ ha^{-1}$)	
	Grain	Straw	Grain	Straw	Grain	Straw
ON	1.99 c	5.87 b	2.13 c	5.52 b	2.25 b	4.58 b
2N	2.50 a	6.80 a	2.98 b	6.96 a	4.24 a	6.89 a
2N + 1P	3.01 a	6.99 a	3.27 ab	7.85 a	4.38 a	7.22 a
3N	2.57 a	7.35 a	3.32 a	7.34 a	4.27 a	6.88 a
3N + 1P	3.47 a	7.64 a	3.42 a	7.54 a	4.43 a	7.52 a
3N + 2P	2.45 b	7.79 a	3.51 a	8.01 a	4.52 a	7.74 a
4N	3.39 a	6.95 a	–	–	–	–
4N + 1P	3.31 a	7.78 a	–	–	–	–
4N + 2P		7.51 a	–	–	–	–
Mean	2.91	7.19	3.10	7.20		
SE	±0.15	±0.31	±0.15	±0.34		

Figures in each column followed by the same letters are not significantly different, according to Duncan's Multiple Range Test (DMRT).

Effect of N and P on the straw yield

Addition of 2N significantly increased the yields over the control by 16% in the first, 26% in the second, and 50% in the third season ($P < 0.001$). The overall increase was 31% for the three seasons. An addition of 1P to the 2N increased the respective yields over 2N by 3, 13, and 5%. However, no significant differences between this treatment and the rest of the treatments with or without P, attained a level of significance in any of the three seasons.

Economic Evaluation

For the economic evaluation of the three seasons, partial budgets were estimated for their averages with respect to grain and straw yields. For sorghum prices and fertilizer costs, the 1992 prices were used, so that the results would apply to the current situation. Such levels were LS 7.511 kg^{-1} as field price of sorghum and LS 65.22 per kg of N and P. Straw was valued at LS 500 ha^{-1} for treatment without fertilizer (control). Adjustments were made for the other treatments, proportional to their straw yield (Table 2).

Table 2. Average partial budgeted estimates of fertilizer effect on Hageen Durra-1 for three seasons (1988/89/90).

Treatment	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Gross benefits ($LS\ ha^{-1}$)	Variable cost ($LS\ ha^{-1}$)	Net benefits ($LS\ ha^{-1}$)
ON	2.12	5.32	17 138	0	17 138
2N	3.24	6.88	25 873	5 588	20 286
2N + 1P	3.55	7.35	27 959	8 382	19 577
3N	3.39	7.19	26 600	8 382	18 218
3N + 1P	3.77	7.56	29 592	11 176	18 416
3N + 2P	3.83	7.85	30 026	13 970	16 057

Highest net benefits (NB) were realized with 2N, which exceeded 0 N by LS 3148 ha^{-1}. Treatments with higher fertilizer doses had lower NB since their variable costs were relatively greater than those of the 2N treatment.

Marginal analysis is shown in Table 3, in which dominated treatments, i.e., all those with fertilizer doses greater than 2N were excluded due to their lower NB and higher variable costs than 2N.

In order to determine optimum doses of N and P, regression analysis was carried out for the three seasons where the seasons were represented by dummy variables (1988/89 = 0). Results of the regression were:

$$\text{Grain yield} = 1767 + 22.7N - 0.101\ \text{sq}\ N + 0.5NP - 1050S3$$
$$(0.001)\ (0.001)\ \ (0.001)\qquad (0.001)\ \ (0.001)$$

where sq N was the square of N. S3 represents the effect of the third season. Figures in parentheses are probability levels of significance. The regression was highly significant ($P < 0.001$) and so were the individual factors. The coefficient of determination was 0.88. The interaction of N × P was significant, but with low and uneconomic effect of P on grain yield.

Table 3. Marginal analysis of fertilizer levels and sorghum yields.

Treatment	Net benefits (LS ha^{-1})	Variable costs (LS ha^{-1})	Extra net benefits (LS ha^{-1})	Extra costs (LS ha^{-1})	Marginal RR (%)
2N	20 286	5588	3184	5588	56
0N	17 138	0	NA[1]	NA	NA

1. NA = Not applicable.

Using partial derivative estimates, the economically optimum level of N was found to be 69 kg N ha^{-1}, equivalent to 80% of the dose used in this study. This dose, which is lower than 2N, is required to attain the optimum grain yield, and justifies testing N doses lower than the 2N dose used in this study.

The effect of fertilizer on straw yield was given by the following equation:

$$\text{Straw} = 5427 + 2807N - 8.0P - 0.111\ \text{sq}\ N - 327\ S3$$
$$(0.001)\ (0.001)\ \ (0.001)\ (0.001)\qquad (0.001)$$

The regression was highly significant as well as the effect of individual factors. The coefficient of determination was 0.91. The effect of P was much lower than that of N and showed an increase at a decreasing rate. Total straw yield started to decline beyond 129 kg N ha^{-1} (3N). Hence, economically it will not pay to apply fertilizers for the sake of increasing straw yields.

Finally, from the findings of this study it may be concluded that application of 69 kg N ha^{-1} would be required to obtain the optimum grain and straw yields of the hybrid Hageen Durra-1.

Discussion

The effects of N on grain and straw yields noted in this experiment conform to the previous findings of other researchers on several sorghum varieties (Ishag 1962, Ageeb 1969, El Rayah 1973, Farah and Ali 1982). However, the nonsignificant increase of grain or straw yields of Hageen Durra-1 with higher doses of N beyond 2N, particularly in the absence of P, is difficult to explain. It is possible that such higher doses of N could cause some toxicity effects on the plants during the seedling stage (Dr El Naim Ibrahim, personal communication) and hence, the observed reduction in the straw yield, as a consequence of reduced number of plants per unit area (Farah and Faki 1990, 1991). It is, however, important to note from the results of this experiment, as well as previous ones, that high yields of grain from Hageen Durra-1 could never be attained without the addition of N, particularly considering the general reluctance of farmers in carrying out the thinning operation according to the recommended plant population of about 1 25 000 plants ha^{-1}. It has been shown that grain yields were greatly reduced at higher plant densities, which are greater than the recommended, when N was not applied (Farah and Ali 1982). The high profitability associated with applying N shown in this experiment, as well as in previous studies, should encourage both farmers and the management of all the agricultural schemes in which sorghum is included in the cropping systems. For the hybrid Hageen Durra-1, addition of N at the rate of 69 kg ha^{-1} (1.6 N) should increase farmers' incomes and also self-sufficiency in sorghum, whose yields have been considerably reduced under rainfed conditions.

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Discussion Session 3: Agronomy and Resource Management

Title of Paper: Soil and Water Management Options to Increase Infiltration and Productivity on SAT soils

Name of Speaker: P Pathak

Question: *Aberra Debelo*

There are different approaches to conserving either soil moisture or soil itself. Some advocate reduced tillage whereas your findings indicated that deep plowing conserved more moisture and soil, thereby giving more grain yield. Would you comment?

Answer: *P Pathak*

The problem with no tillage or reduced tillage is that it needs herbicides and maintainance of organic material on top. These two practices are at present not acceptable to farmers. At least we believe for another 10 years or so, the possibility that farmers will agree to their use is very remote. Also, deep tillage is needed only where bulk density of the lower layer is very high, say, more than 1.6 g cm^{-3}. Until the farmer is ready to use herbicides or agrees to use organic material, we have to look for some other approach, which may be acceptable to farmers.

Question: *D E Byth*

The method of scoops is clearly very effective in reducing runoff. However, it has also been demonstrated that they can greatly aggravate runoff and soil loss where intense rainfall exceeds the surface storage capacity. This is a function of intensity/amount of rain, soil type and strength, and storage capacity of scoops. Is it too difficult a strategy for farmers in particular situations?

Answer: *P Pathak*

In the conventional design of scoops, this was one of the big problems. Even at ICRISAT Asia Center, we have observed that during big storms, scoops may breakdown which may result in excessive soil loss. At IAC, we have designed a scoop called graded type scoop which greatly reduces this problem. This newly designed scoop can withstand big storms much better than the conventionally designed scoops. In addition to this, if at a particular location, where big storms are a major problem, there are many other options available to make scoops more stable. For example, you can make deeper scoops with less density of scoops per unit area.

Question: *Mekki A Omer*

What is the optimum size of scoops that will not be topped by the sediment deposition during the season, particularly during heavy rainstorms, which reduce their storage capacity in relation to slope and soil characteristics?

Answer: *P Pathak*

The optimum size of the scoop depends upon the location, rainfall, soil strength, soil profile depth, and soil water storage capacity. At this stage, I cannot say what the optimum size of scoop would be for your Sudan location, but for our location at IAC, we have found that scoops of 7-L capacity with a density of four scoops per square meter is optimum. We have developed a small program which you can use to determine the best size of scoop for your location. But for this you need information on rainfall, soil shear strength, and the crop which you plan to grow.

Title of Paper: Effect of Landforming Treatments for Water Harvesting on Soil Hydrological Aspects.

Name of Speaker: Mukki Abd Ellatif

Question: *A B Mohamed*

What is the effect of tillage on soil conservation, especially if we know that north Kordofan is threatened by desertification?

Answer: *Mukki Abd Ellatif*

Tillage could accelerate erosion in the sandy, light soil conditions of north Kordofan. However, we have not applied our tillage practices to this kind of soil. The water-harvesting techniques and conservation measures presented in this paper were applied only to the hard compacted surface of sandy clay to clay loam soils, which are more resistant to erosion hazards such as water and wind. Additionally, the conservation measures included within the treatments are meant to conserve soil and water and to maintain sustainable production.

Title of Paper: Response of Sorghum (Hageen Durra-1) to Nitrogen and Phosphorus Under Irrigation

Name of Speaker: Saeed M. Farah

Question: *Brhane Gebrekidan*

What is the total area of Hageen Durra-1 that is currently being produced in the Sudan?

Answer: *S M Farah*

In this season, about 700 000 acres of sorghum were grown. The proportion of Hageen Durra-1 is 25–30% of this area.

Question: *A B Mohamed*

Data presented are separated for each season. Why not combine analysis to see consistency of findings.

Answer: *S M Farah*

The results of each season have been analyzed and economically evaluated separately by the prevailing prices in each season. However, for this presentation and because of nearly parallel trends in the grain and straw yields, our economist decided to use the mean yields of the three seasons with the current prices of 1992.

Question: *Zenon Kabiro*

The first table in your presentation showed increasing rates of nitrogen and phosphorus. How did you get the treatments that you get out of it? Another table showed stover yield. How did you measure it? Is it just after you harvested grains or did you oven-dry the samples.

Answer: *S M Farah*

Both grain and straw masses are those measured in the field (air-dried). Data were obtained from about 80% of the gross area.

Questions: *Adipala Ekwamu*

1. Did you determine the soil nutrient status before applying your fertilizer treatments? Based on the soils I saw, I expected more response to nitrogen.
2. Did you include straw yield when calculating your profit margin?
3. Do you think a profit of 3000 Sudanese pounds is worthwhile (meaningful) to the Sudan farmer?

Answer: *S M Farah*

1. Soil fertility status was done only once. In farmers fields it was not easy.
2. Both grain and straw were included in the analysis.
3. Perhaps it was not meaningful in 1992 because the price of sorghum went down by about half and the cost of fertilizer went up about 4-fold. In previous seasons' analyses, fertilizer application was really justifiable.

Title of Paper: Current Agronomic Research on Pearl Millet at El Obeid

Name of Speaker: Hassan O Elawad

Question: A.M. Mbwaga

1. What *Striga* spp. infect pearl millet?
2. Have you observed any effect of your intercropping pattern on *Striga* infestation?
3. Have you observed any effect of fertilizer on *Striga* infestation, especially fertilizer in the form of N?

Answer: *Hassan O Elawad*

1. *Striga hermonthica*
2. No. On our farm, we didn't observe any *Striga* infestation, we only observed *Striga* infestation in farmers' fields.
3. No. We did not observe *Striga* infestation with or without nitrogen, simply because we do not have *Striga* in our research fields.

Question: *L B Olugbemi*

In your intercropping trial with pearl millet and cowpea, you indicated that the higher the cowpea yield, the lower was the millet yield. What was your plant arrangement and plant spacing?

Answer: *Hassan O Elawad*

Plant arrangements and spacings were 1m × 1m = 10 000 plants ha^{-1}, 1m × 0.5 m = 20 000 plant ha^{-1}, and 1m × 0.25m = 40 000 plant ha^{-1}.

Title of Paper: Test of Transfer of Gambella 1107 in Cibitoke Lowland in Burundi

Name of Speaker: Anicet Tuyaga

Comment: *Adipala Ekwamu*

I am impressed by the joint approach of the researcher and extension agent to popularize the new variety. I think this supports what Dr Belum Reddy from ICRISAT said, i.e., scientists must market their products.

Question: *Adipala Ekwamu*

Clarify the method used to establish farmers' yields (kg ha^{-1}).

Answer: *Anicet Tuyaga*

The technicians of the Atelier have to weigh the whole yield obtained by farmers in a plot of known size. In this way, we can calculate the yield per ha.

Question: *L B Olugbemi*

What is the difference between your organization (Atelier) and extension workers?

Answer: *Anicet Tuyaga*

The Atelier is a workshop and works with only 60 farmers in one natural region. The Atelier carries out new technologies in those farms. If a given technology goes well in these farms, the Atelier advises the extension team to release it. If it is not adopted, the Atelier gives feedback to researchers who must make modifications according to the remarks given.

Question: *Adipala Ekwamu*

At what point does the Atelier get involved in the development of new technology? Is it only involved in letting researchers know the constraints of farmers and later in popularising the new technology?

Answer: *Anicet Tuyaga*

The Atelier doesn't intervene in technology development. It is actually involved in letting researchers know farmers' constraints. If a technology is supposed to fulfil farmers' needs, the Atelier must understand it so that it can be tested with farmers under the supervision of researchers.

Question: *C O A Oduori*

It is very common to find people prejudiced against the red-seeded sorghum compared with white-seeded sorghum. Why is it that in your country, the prejudice is against the white-seeded sorghum and not the red-seeded sorghum?

Answer: *Zenon Kabiro*

The white sorghum is a new product in Burundi, especially in the zones where sorghum is not produced. Those people like reddish opaque beer and are reluctant to make beer from white sorghum grain.

Questions: *Brhane Gebrekidan*

1. What is the total area of Gambella 1107 being produced in Burundi?
2. Is there an organized seed production scheme for Gambella 1107 in Burundi?
3. To get around the problem of no thinning by some farmers, is it possible to recommend an optimum seeding rate which will entail no thinning?

Answers: *Anicet Tuyaga*

1. We have been pushing Gambella to farmers for 2 years. The first year, more or less 20 t were produced. In the second year, more than 30 t were produced.
2. The structure of seed production is as follows: pre-basic seed from the breeder (5–10 kg), basic seed from the basic seed program in ISABU (1–5 t), which is sold to the extension service; the extension service multiplies it again and sells the product to the farmer.
3. The research team, in collaboration with the Atelier workshop at Cibitoke, will carry out tests to compare different seeding rates.

Session 4

Plant Protection

The Reaction of Cereals to *Striga asiatica* and *Striga hermonthica* in Tanzania

A M Mbwaga[1]

Abstract

Striga *species are parasitic weeds that are important as endemic pests of cereals such as maize, sorghum, rice, and millets grown in semi-arid, tropical, and subtropical regions of Tanzania. Economically important* Striga *species observed in the country include* S. asiatica *(red flowered),* S. hermonthica, *and* S. forbesii.

The yield losses caused by these parasitic weeds are estimated to range from 15 to 100% on farmers' fields. The socioeconomic implications of these weeds include the migration of farmers to Striga-*free areas, shifting cultivation, farm abandonment, and change of cropping pattern.*

A study on the reaction of cereals to S. asiatica *and* S. hermonthica *revealed that pearl millet is resistant to both* Striga *species. Maize varieties are less affected by these species than are sorghum varieties. Sorghum variety Serena shows some resistance to* Striga *species.*

Introduction

Striga species are parasitic weeds that attack and cause economically significant yield losses in cereals including maize, sorghum, pearl millet, finger millet, upland rice, and sugarcane. These weeds are particularly important as endemic pests of crops grown in the semi-arid, tropical, and subtropical regions of Tanzania.

Socioeconomic implications of *Striga* damage include the migration of family groups to *Striga*-free areas, shifting cultivation, farm abandonment, and change of cropping pattern (Riches et al. 1987). *Striga hermonthica* is reported to have directly caused depopulation of potentially useful agricultural land in Sukumaland in western Tanzania, and to also cause food shortages in some years (Dogget 1965). A recent development in this region has been that farmers now concentrate more on paddy rice than on any other cereal crop, since *Striga* does not attack paddy rice (Ramaiah 1984). Excessive watering had been reported to inhibit *Striga* germination (Sreeramulu 1959).

Striga Species

Striga species reported in Tanzania include *S. asiatica, S. hermonthica, S. forbesii, S. elegans, S. gesnerioides, S. aspera, S. euphrasioides,* and *S. fulgens* (Obilana and Ramaiah 1992). Of economic importance are *S. asiatica, S. hermonthica,* and *S. forbesii.* Hence, Tanzania lies in a unique belt of the tropics where the three most important (in damage caused to cereal crops) *Striga* species in Africa exist sympatrically.

Distribution

Striga hermonthica is the predominant species around Lake Victoria in an area extending from Mwanza to the Mara region and on to Nyanza Province in Kenya. *Striga asiatica* (red flowered) covers the largest area of the country from Lake Victoria down to Ruvuma and Coastal regions from Tanga to Mtwara region in the south of the country. *S. forbesii* has been observed only in a few areas, particularly in Morogoro region, including Ilonga research station

1. Agricultural Research and Training Institute, Private Bag, Ilonga, Kilosa, Tanzania.

(and nearby farmers' fields), Melela and Mangae villages, and the Kilombero Sugarcane Estate. The distribution of *S. forbesii* still needs to be established through a more intensive survey. The other *Striga* species are often localized and are of little or no economic importance to cereal crops.

Effect of *Striga* on crop yields

The yield losses caused by the major *Striga* species have always been significant. Estimated grain yield loss due to the parasitic weed on susceptible sorghum varieties can be up to 59% (Dogget 1965). Actual yield loss established by Obilana and Ramaiah (1992) on resistant sorghum varieties were estimated to be 5% of their potential yield, 63% of their potential yield on tolerant varieties, and 95% on susceptible varieties. On farmers' fields sown with susceptible sorghum varieties, yield losses of up to 100% can be expected.

A study was initiated at two locations, Hombolo and Ukiriguru, to investigate the reaction of cereals to *S. asiatica* (red flowered) and *S. hermonthica*.

Materials and Methods

The trial was sited at two locations, Ukiriguru in northwestern Tanzania near Lake Victoria (1100 mm annual rainfall) and Hombolo in central Tanzania (700 mm rainfall). Entries tested have all been released to farmers and included sorghum varieties Serena and Tegemeo, maize varieties Staha and TMV-1, and pearl millet varieties Serere 17 and Ukiriguru local. The six entries were sown in a randomized block design with 4-row plots of 5 m length, and three replications. The number of emerged *Striga* plants per plot and the cereal entry plant stand per plot were used to calculate average *Striga* infestation per host plant using the following formula:

$$\text{Percentage of } \textit{Striga} \text{ infestation per plant} = \frac{\text{Total } \textit{Striga} \text{ count}}{\text{Entry stand count}} \times 100$$

It is, however, important to note that the number of *Striga* plants that emerge above the ground represent an unknown and often variable percentage of the total number of *Striga* plants that actually parasitize the host's roots. The *Striga* count was taken at 50% flowering and at the time of harvesting the crop.

Results and Discussion

Differential responses were recorded among varieties of pearl millet, sorghum, and maize to *S. hermonthica* and *S. asiatica* for 3 years at the two locations. Using the percentage of infestation per plant as an index of resistance (Tables 1 and 2), the sorghum variety Tegemeo was observed to be the most susceptible to both *S. hermonthica* and *S. asiatica*; Serena had relatively low infestation by both *Striga* species. This confirms observations made by Dogget (1965) that Serena has some resistance to *S. hermonthica*. Although maize variety Staha (Table 1 and 2) had a higher *Striga* infestation than TMV-1, maize as a crop showed lower *Striga* infestation than did sorghum. One reason for this difference may be that maize matured early, and before environmental conditions were favorable for *Striga* emergence. Another reason may be because the rooting system of maize is smaller compared with that of sorghum; hence sorghum roots have a

Table 1. Mean number of *Striga hermonthica* plants associated with varieties of pearl millet, sorghum, and maize in replicated plots at two locations in Tanzania for three seasons, 1988/89 to 1990/91[1].

	No. of *S. hermonthica* plants			
Crop/varieties	1988/89	1989/90	1990/91	Mean for 3 years
Pearl millet				
Serere 17	0.0	0.0	17.0	5.7
Ukiriguru local	0.0	0.0	3.7	1.0
Sorghum				
Serena	9.3	4.0	284.0	99.1
Tegemeo	277.4	116.4	335.4	409.7
Maize				
Staha	45.0	97.0	350.7	164.2
TMV-1	102.7	5.0	259.3	122.3

1. Trials grown at Ukiriguru and Hombolo, and consisting of plots 4 rows × 5 m, replicated three times.

greater chance of coming in contact with *Striga* seeds than do roots of maize. A third possible reason could be that maize produces a lower amount of *Striga* stimulant than does sorghum.

Over a period of 3 years, very little *S. hermonthica* (Table 1) and no *S. asiatica* (Table 2) was found associated with pearl millet growing in infested soil, compared with that found on sorghum and maize in the same trials. It seems obvious, therefore, from these data that pearl millet is resistant to both *S. hermonthica* and *S. asiatica* (red flowered) in Tanzania. These results provide evidence for possible host-specific strains of *S. hermonthica* and *S. asiatica* in these cereals in Tanzania. In West Africa and Sudan, *S. hermonthica* has been reported to be of economic importance on both sorghum and pearl millet. Two strains of the parasite seem to exist, one specific to pearl millet and the other to sorghum (Ramaiah 1984). It is possible that the *Striga* species found in Tanzania are specific only to sorghum and maize. Finger millet has been observed also to be highly susceptible to *S. hermonthica* (Mbwaga and Obilana 1990). Although on rare occasions, single *Striga* plants have been observed on pearl millet at Ukiriguru, it appears that pearl millet root exudates might stimulate *Striga* seed germination at only a very low level in Tanzania.

Table 2. Mean number of *Striga asiatica* plants associated with varieties of pearl millet, sorghum, and maize at two locations in Tanzania for three seasons, 1988/89 to 1990/90[1].

	No. of *S. asiatica* plants			
Crop/varieties	1988/89	1989/90	1990/91	Mean for 3 years
Pearl millet				
Serere 17	0.0	0.0	0.0	0.0
Ukiriguru local	0.0	0.0	0.0	0.0
Sorghum				
Serena	125.7	0.0	73.3	66.3
Tegemeo	492.0	434.0	58.3	328.1
Maize				
Staha	13.0	129.0	29.0	57.0
TMV 1	4.0	93.0	6.3	34.4

1. Trials grown at Ukiriguru and Hombolo, and consisting of plots 4 rows × 5 m, replicated three times.

The implication of the occurrence of interspecific *Striga* strains is that breeding and identifying stable resistance in sorghum, maize, and millets to the two *Striga* species, especially in the region where both *Striga* species attack all cereals, may be difficult.

For a Tanzanian farmer, pearl millet can be recommended for rotation with sorghum and maize in areas highly infested with either *S. hermonthica* or *S. asiatica*, or both.

Future Research Work on *Striga*

Control practices for *Striga* on research stations have been known for many years, but there has been very little on-farm research. For this reason, our future research emphasis will be to conduct on-farm *Striga* control demonstrations with full farmer participation.

Some practices known to control *Striga* include the use of manure/nitrogen, clean weeding before *Striga* has flowered, rotation with certain crops (cotton, groundnuts, or grain legumes), trap cropping by plowing under a densely sown susceptible crop before *Striga* has flowered, and crop resistance supplemented by other cultural practices such as use of herbicides in combination with fertilizer.

We intend to conduct the following trials in farmers' fields during the next cropping seasons to suppress *Striga*: intercropping cereal and grain legumes, which is a common practice by small-scale farmers, and using fertilizers and herbicides (e.g., 2–4 D and Dicamba). Sorghum variety, SAR 29, has been found to be resistant to the three economically important *Striga* species (*S. hermonthica*, *S. asiatica*, and *S. forbesii*). This variety will be demonstrated to farmers along with other commercial varieties. Management and evaluation of suitable crop practices will be done by the collaborating farmers. The major role of researchers will be to supply them with seed, fertilizer, herbicides, and technical advice.

Small-scale farmers are likely to adopt the intercropping practices quickly as they are already familiar with them, while herbicide use might be successful, mostly on seed-producing farms. The yield performance and palatability of SAR-29 can be tested by both commercial and small farmers.

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Effects of Fertilizer in the Control of *Striga* in Bugeresa, Rwanda

Celestin Sehene[1]

Abstract

A study was initiated and conducted in Bugesera, Rwanda, during 1990 and 1991 rainy seasons to develop control measures against Striga *attack in sorghum in Rwanda. We used manure at a rate of 30 t ha^{-1} and urea at a rate of 120 kg N ha^{-1}, alone and in combination. The application of 30 t ha^{-1} of manure was the best treatment, both for* Striga *control and to increase grain yield. The use of urea alone was not significantly different from the nontreated control treatment.*

Introduction

Sorghum is a traditional crop in Rwanda. It takes first place among cereals both in area under cultivation and total production. Sorghum is cultivated in different agroecological zones from lowlands in semi-arid areas to highlands, and it is used in may ways. The average grain yield of sorghum in Rwanda is 1.1 t ha^{-1}. Constraints to yield include low soil fertility, poor agronomic practices, diseases, insect pests, and *Striga.*

Striga are obligatory parasitic plants which attack roots of legume and cereal crops in tropical areas of Africa and Asia. There are more than 50 species of *Striga*, of which 24 occur in Africa (Carson 1988, Mboob 1990). Some species are of economic importance, such as *S. hermonthica, S. asiatica, S. gesneroides, S. densiflora, S. euphrasioides*, and *S. forbesii.* These species attack many plant species and there are many wild hosts (Ramaiah et al. 1983). *Striga* causes considerable loss in production which can reach 100% in the highly infested fields. In Andhra Pradesh (India), losses in sorghum production due to *Striga* have been estimated at 25 000 t (Korwana and Friesen 1984).

In Rwanda, we have identified three species of *Striga*: *S. asiatica, S. hermonthica*, and *S. forbesii.* We do not have exact figures for Rwanda for sorghum losses due to *Striga* attack. However, *Striga* is especially severe in semi-arid zones (lowland) where some farmers are replacing sorghum with bean or cassava due to *Striga* attack.

The parasite seems to progress to intermediate zones. According to information collected from farmers, *Striga* has been known in Rwanda for about 30 years, but the effects became more serious since 1987, mainly due to the decrease in soil fertility and increased population density. About 90% of Rwanda's population is engaged in agriculture. As described by Carson (1989) for Gambia, *S. hermonthica* control in rural areas of Rwanda is very difficult. Farmers are not enthusiastic about weeding *Striga* plants, a treatment which is recommended where infestation is moderate (Ramaiah and Parker 1982).

In Institut des Sciences Agronomiques du Rwanda (ISAR) we conducted trials with trap crops such as groundnut and soybean, and the results indicate that these species are not trap crops under these conditions where sorghum is intercropped with them. After that, we decided to have an exploratory trial combining the use of farm manure and nitrogen fertilizer (urea). The main objective was to compare the effects of manure and nitrogen on sorghum production under *Striga* infestation.

Materials and Methods

The trial was conducted in 1990 and 1991 on a farmer's field identified during the previous season. We used local sorghum varieties which are usually attacked by *Striga*. The treatments were: 30 t ha^{-1} farm manure, 30 t ha^{-1} farm manure + 120 kg N (urea) ha^{-1}, 120 kg N (urea) ha^{-1}, and the control (no soil amendment).

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Farm manure was applied 2 weeks before sowing and the urea application split between time of sowing and time of ridging. For each plot emerged, *Striga* plants were counted and removed by weeding. At harvest, everything was weighed, especially fresh crop residue and grain yield. We counted the number of sorghum plants with or without panicles and grain. Sowing was in mid-January, when about 85% of the crop was sown in the country.

Results and Discussion

The results are presented in Table 1.

Table 1. Results of a fertilization trial to control *Striga* in Bugesera, Rwanda, 1990 and 1991.

	1990			1991			Mean (2 years)		
Treatment	Number of *Striga* plants m^{-2}	Fresh residue (t ha^{-1})	Grain yield (t ha^{-1})	Number of *Striga* plants m^{-2}	Fresh residue (t ha^{-1})	Grain yield (t ha^{-1})	Number of *Striga* plants m^{-2}	Fresh residue (t ha^{-1})	Grain yield (t ha^{-1})
Control	71	2.03	0.22	45	4.94	0.50	58	2.98	0.36
30 t farm manure ha^{-1}	103	5.68	0.91	38	13.57	1.96	71	9.77	1.43
30 t ha^{-1} farm manure + 120 kg N ha^{-1}	58	4.48	0.71	39	12.60	1.66	48	7.94	1.19
120 kg N ha^{-1}	86	2.23	0.41	65	6.57	0.80	75	4.16	0.60
LSD 0.05	NS[1]	1.86	0.31	NS	3.27	0.74	43	3.42	0.54
LSD 0.01	NS	2.61	0.43	NS	4.59	1.04	NS	4.63	0.73
Mean	80	3.61	0.53	40	9.21	1.23	NS	NS	NS

1. NS = Interaction between treatments and year is not significant.

Number of emerged *Striga* plants

The analysis of variance indicates that no significant differences existed among treatments for the number of *Striga* plants in each plot, when the 2 years were analyzed separately. However, analyzing the 2 years together gives a significant difference among treatments at the 5% level of probability. The 1991 season seems to have had more *Striga* than the 1990 season, but the interaction between seasons and *Striga* was not significant. This situation happens sometimes with *Striga* which may not be serious one year but may become serious the next year in the same plot. This is one of the constraints in planning field trials on *Striga* control.

Grain yield

The analysis of variance indicates significant differences among some treatments at two levels (1 and 5%) for both seasons. For both years, farm manure treatment gave four-fold more grain yield than the control. Urea, in combination with farm manure, gave somewhat less yield than farm manure only, and urea without farm manure gave significantly less yield than the combination of farm manure and urea. Grain yields in plots receiving urea only were not significantly higher than those of the nontreated control.

Fresh residue yield

The interaction between treatments and years is not significant. Application of farm manure only and farm manure with urea gave significantly higher fresh residue yields than urea by itself or the control.

These results suggest that in future, we concentrate our efforts on the use of farm manure as one of the *Striga*-control methods, after assessing the optimum level of application. The utilization of nitrogen, in combination with farm manure, is not sustainable because there is no extra yield due to the use of urea.

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Striga Infestation in Sorghum and Millets Relative to Cultivars, Trapcrop, and Hand Weeding

G O Abayo[1]

Abstract

Striga *is one of the parasistic weeds which, for many years, has threatened the economy of production of crops such as maize, sorghum, finger millet, and pearl millet. It can cause grain yield losses as high as 70–100%. In these experiments, three areas of* Striga *research were addressed: (1) the reactions of 17 sorghum, 1 finger millet, and 1 pearl millet varieties to* S. hermonthica; *(2) the effects of trap-cropping with cotton on* S. hermonthica *infestation in finger millet. The pearl millet variety was found to be resistant to strains of* S. hermonthica *at both testing sites near Alupe in western Kenya. All the sorghum entries and the one finger millet entry were, however, susceptible to* Striga *infestation. Seredo, Framida, ICSV 1018BF, ICSV 10068F, ICSV 1112BF, and N 13 were found to be tolerant to* Striga *as they maintained high grain yields under high* Striga *infestation.*

Cotton, intercropped at the same time with sorghum or relayed 1 month later, significantly suppressed emerged Striga *number. Cotton relayed in sorghum 2 or 3 months later had no significant effect on* Striga *suppression. The mean grain yield of sorghum inter- or relay-cropped with cotton 0 or 1 month later, were significantly less than those where cotton was relay-cropped 2 or 3 months later.*

Both local Ikhulule and P-224 finger millet varieties were susceptible to Striga *attack under all the five weed control treatments. But Ikhulule exhibited more tolerance to* Striga, *by maintaining high mean grain yields, under two or three consecutive hand weedings than the pre-released P-224 variety.*

Introduction

Striga is one of the several parasitic angiosperm plants of the Scrophulariacea family, which has, for many years, threatened the economy of production of agronomic crops such as maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench.], finger millet [*Eleusine coracana* (L.) Gaertn.], pearl millet [*Pennisetum glaucum* (L.) R. Br.], and sugarcane (*Saccharum officinarum* L.) in Kenya (Mumera 1983).

The most serious *Striga* species on sorghum and millets are *S. hermonthica* (Del.) Benth. and *S. asiatica* (L.) Kuntze, with the former being the most damaging in eastern Africa (Khidir 1983). He further observed that, with the exception of birds, *S. hermonthica* may be the most important cause of yield reduction in sorghum and millets in Africa, with yield losses as high as 70–100%.

In Kenya, *S. hermonthica* is predominant in the Lake (Victoria) Region, covering the whole of Nyanza Province and most of Western Province in western Kenya. Here the *Striga* problem is aggravated by the fact that *Striga* limits sorghum and millets production in the areas which are marginal for other crops due to low and/or unreliable rainfall, low soil fertility (especially low nitrates), continuous cultivation of the same land to sorghum and millets without rotation due to land limitation, and the ability of these obligate root parasites to remain viable in the soil for at least 20–30 years (Mumera 1983).

The general requirements for the germination of the most important *Striga* spp. include an 'after-ripening' period of at least 6 months, a 1–4 week moisture imbibition 'pre-conditioning' period, and natural germination stimulants originating from the roots of a range of host and trap crops called Strigol or Strigol Acetate or their synthetic analogues, for example, ethylene, GR7, and GR24 (Johnson et al. 1976, Ramaiah and Parker 1982, Reid and Parker 1979).

Furthermore, an ideal condition of moist well-drained soil with a temperature range of 23–33°C sustained for about 2 weeks is required for *S. hermonthica* germination (Mumera 1983). He further observed that after attaining

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germination, the *Striga* seedlings will attach to the host roots by a haustorium through which water, minerals, sugars and such growth hormones as cytokinnins and gibberrellins are transferred. Consequent to parasitism, the host plant exhibits stress symptoms such as leaf curl and chlorosis, generalized stunting, and wilting culminating in necrosis if the infestation is severe, as is common in *Striga* 'hot spots'.

Because these parasites are obligate to their hosts, conventional weed control methods such as cultivation, hand pulling, and herbicide use have not been particularly successful (Khidir 1983).

Different crops or crop varieties have been known to illicit a range of responses to *Striga* infestation. Mumera (1983) observed that maize was highly susceptible to *Striga* under controlled environment. But sorghum varieties exhibited resistance (Serena and Serenex), tolerance (MY146), or susceptibility (2KX-17). Similar responses on different sorghum varieties have also been made by other scientists (Dogget 1965, Parker et al. 1977, Babiker and Hamdoun 1990). Saunders (1933) came to the conclusion that resistance in sorghum is due to low production of the stimulant required for *Striga* seed germination and/or inhibition of haustorial attachment to the host's roots, because of the development of a thick-walled silicate endodermis, pericycle, and/or stele.

Many scientists have reported that different strains of *S. hermonthica* and *S. asiatica* exist and are specific in their virulence to different agronomic crops (Reid and Parker 1979, Obilana et al. 1991, Parker 1983).

Due to land limitations, mixed cropping is a common farming practice by most subsistence farmers in western Kenya. I have observed inter- or relay-cropping of cereals with legumes such as cowpea (*Vigna unguiculata* L.), field bean (*Phaseolus vulgaris* L.), and green gram (*Vigna radiata* L.); with oil crops such as groundnut (*Arachis hypogea* L.) and sunflower (*Helianthus annus* L.); and with fiber crops such as cotton (*Gossypium hirsutum* L.). In some fields, an all cereal mixture such as maize and sorghum also exist. Some of these crops have been reported to stimulate suicidal germination in *Striga* because their root exudates stimulate germination of nearby *Striga* seed, but they are not a host to parasitism, and thus the term trap crops (Andrews 1947, Dogget 1965, Parker 1976, Visser and Botha 1974, Babiker and Hamdoun 1990, Bebawi 1988).

It is therefore, our conviction that the use of resistant crop varieties, together with effective agronomic packages such as proper cropping systems, would be more easily adopted by these resource-poor farmers. In order to determine some of the components that could be used in future, in an integrated manner to control *Striga hermonthica* in sorghum and millets in western Kenya, the following experiments were conducted and are reported here: (1) to determine *Striga*-resistant or tolerant sorghum and millets varieties with high, stable yield potentials for the farmers or for future use in breeding programs; (2) to determine the trap cropping effect of cotton on *S. hermonthica* when either inter- or relay-cropped with sorghum; and (3) to determine whether intensifying mechanical weed control appreciably reduces *S. hermonthica* infestation in finger millet.

Materials and Methods

General information about ARSC-Alupe

Agricultural Research Sub-Centre (ARSC) Alupe, at an altitude of 1189 m asl, is in a warm, humid to dry subhumid zone of equatorial climate, and it is situated at latitude 0° 28'N and longitude 34° 07'E (Braun 1980).

The ARSC-Alupe and its surroundings have a bimodal type of rainfall, with the long rains between March and July, and the short rains between August and November. While there is an almost equal amount of rainfall (about 1000 mm each) in the two seasons, the long rains are more uniformly distributed than the short rains, with a peak between April and May. The mean annual temperature ranges are, 34.3° to 28.6°C maximum and 13.6° to 9.3°C minimum.

The soils of the ARSC-Alupe, as is dominant in most of the Lake (Victoria) Region, are very heterogeneous. They are generally light, and commonly range between very shallow (10–50 cm deep) to moderately deep (50–80 cm deep), underlain with a massive sheet of hardened 'Plinthite', also called 'Murram' or 'Laterite', resulting in limited water-holding capacity. The pH range is 5.0–5.5.

The heterogeneity of these soils is further pronounced by the existence of randomly situated anthills and *Striga* in the fields. These factors enhance the plot by replication interactions, resulting in high coefficients of variation in experimental areas.

Experiments

Three separate experiments were set up adjacent to each other in a known *Striga* 'hot-spot' at ARSC-Alupe, during the 1992 long rains growing season.

Reaction of the EARSAM Sorghum and Millets *Striga*-Resistant Nursery. Seventeen early-maturing sorghum varieties, one finger millet variety, and one pearl millet variety collected from national agricultural programs in the region, ICRISAT, and other international and regional organizations, were sown on 27 and 28 March at two sites, the ARSC-Alupe and at a farmer's field adjacent to the ARSC. This was a one-factor experiment sown in a randomized complete block design (RCBD) with three replications. Experimental units were 4 rows of 3 m length with interrow spacing of 0.75 m.

Locally recommended cultural practices in growing these crops in western Kenya were used, i.e., thinning to 0.15 m within row 2 weeks after sowing, sowing with 20 kg N ha^{-1} and 20 kg P_2O_5 ha^{-1} fertilizers applied at the time of sowing, using 20:20:0 compound, two hand weedings at 3 and 6 weeks after sowing, and harvesting at physiological maturity.

The data were collected from the two middle rows excluding 0.5 m border ends of each row. Five counts of *S. hermonthica* plants were taken at 2-week intervals, beginning from the 5th week after sowing. *S. hermonthica* plants were pulled out by hand with every count. The last count coincided with physiological maturity of most of the cultivars used in this experiment. Subsequently, panicles were harvested, dried, threshed, and weighed at 12.5% moisture content.

Sorghum-cotton inter-and relay-cropping trial. Sorghum variety, Seredo, and cotton variety BPA-75, were used in this trial. Sorghum was the main crop and cotton was either inter- or relay-cropped in sorghum plots at 0, 1, 2, and 3 months after sowing sorghum. Pure stands of sorghum at the onset of rains, and cotton at those different mixed cropping times were also sown, making a total of nine treatments. Sown on 4 April, this trial was an RCBD with three replications, sown in plots 5.4 m × 6 m long with an inter-row spacing of 0.9 m, later to be thinned to within-row spacing of 0.15 m (sorghum) and 0.30 m (cotton), one plant per hill for sorghum, and two plants per hill for cotton.

Other cultural practices for sorghum were as in the above trial for varietal reaction. Only rates and sources of fertilizer were varied for cotton: 69 kg P_2O_5 ha^{-1} using triple super phosphate (TSP) at sowing and top dressing with calcium ammonium nitrate (CAN) at a rate of 150 kg N ha^{-1}, 4 weeks after sowing.

Data were collected in the 18 m^2 net plot. *Striga* count was done as in the above experiment. At maturity, sorghum was harvested, dried, and threshed before weighing at 12.5% moisture content.

Cotton was picked as and when bolls opened. This exercise was ongoing at the time of writing this report.

Effect of crop-weed competition on the yield of finger millet. This experiment was sown on 13 April in a 2 × 5 factorial arrangement of treatments, using two finger millet varieties and five mechanical weed-control treatments, with three replications. The two finger millet varieties were P-224 and Ikhulule, a farmer's local, both medium maturing, while the weeding regimes applied to each plot were 0 weedings (control), 1 weeding early (3–4 weeks after sowing), 2 weedings (3 and 6 weeks after sowing), 1 weeding late (8 weeks after sowing), and 3 weedings (3, 6, and 9 weeks after sowing). Each plot measured 1.2 m × 4 m with an inter-row spacing of 0.30 m. Seed was drilled and plants were later thinned to 0.15 m between plants, one plant per hill. Fertilizer was applied at a rate of 20 kg N ha^{-1} and 20 kg P_2O_5 ha^{-1} using compound 20:20:0.

Data were collected in the 2.7 m^2 plots. Five counts of *S. hermonthica* were taken as was done for cereals variety experiments above. Harvesting of finger millet was done at physiological maturity. Subsequently, drying, threshing, and winnowing were carried out before taking the final grain yield.

Results and Discussion

Rainfall and temperature

Table 1 shows the rainfall and mean temperature ranges (maximum and minimum) between January and August 1992. Long rains were late this year, starting in late March, becoming regular in April with a peak in May. June, which

Table 1. Climatic factors at the Agricultural Research Sub-Centre (ARSC) Alupe, Kenya, Jan to Aug 1992.[1]

Month	Rainfall Amount (mm)	Rainfall No. of days	Mean temperature (°C) Maximum	Mean temperature (°C) Minimum
Jan	22.6	3	32.4	17.9
Feb	20.0	5	32.3	18.2
Mar	106.6	7	30.4	18.0
Apr	164.0	16	29.3	17.1
May	346.5	22	29.6	17.3
Jun	114.2	13	29.3	17.1
Jul	143.1	12	28.3	16.1
Aug	117.1	12	28.1	16.8
Total	1034.1	107		

1. Source: Meteorological Weather Station, ARSC-Alupe.

usually experiences dry spells, was sufficiently moist this year to sustain the crops through July and August when harvesting occurred.

Monthly mean temperature ranges from January through August were 32.4°C to 28.1°C maximum and 18.2°C to 16.1°C minimum. The high temperature ranges caused high rates of evapotranspiration. Crops usually experience drought stress in these soils, which are also shallow and light (Braun 1980). Such drought stress symptoms as wilting and leaf curling have been associated with *Striga* infestation (Ramaiah and Parker 1982). They observed that under the two environmental vagaries, the sorghum plant usually has low amounts of growth-promoting hormones such as cytokinnins and gibberrellins, while abscisic acid (ABA) and Fernesal, growth inhibitors, generally increase.

Reaction of sorghum, finger millet, and pearl millet to *S. hermonthica*

The results of this experiment are shown in Table 2 for the ARSC-Alupe site 1 and in Table 3 for the farmer's field nearby. For mean grain yields among the entries there were significant differences ($P \leq 0.05$), at the ARSC-Alupe

Table 2. Mean grain yield and *Striga* count in the EARSAM Sorghum *Striga*-Resistant Nursery at ARSC-Alupe, Kenya, long rains 1992.

Entry	Mean yield (g per plot)[1]	Mean number of *Striga* plants per plot
Seredo	1115 a[2]	339 abcd
Framida	1030 ab	318 abcd
ICSV 1018BF	725 abc	182 d
ICSV 1164BF	675 abcd	454 abcd
ICSV 1156BF	605 bcde	347 abcd
ICSV 1021BF	475 cdef	618 a
MEDPMCOM 1 (pearl millet)	470 cdef	9 e
ICSV 1006BF	415 cdef	185 cd
ICSV 1007BF	395 cdef	647 a
ICSV 1112BF	365 cdef	543 abcd
ICSV 1098BF	340 cdef	477 abcd
SAR 24	295 cdef	485 abcd
ICSV 1017BF	255 def	437 abcd
P-224 (finger millet)	250 def	543 ab
SRN 39	195 ef	456 abcd
N 13	130 f	248 bcd
ICSV 1078 BF	110 f	337 abcd
IS9830	85 f	271 bcd
CK 608 (Susceptable control)	45 f	423 abcd
CV (%)	65.5	51.3
LSD (0.05)	457.5	340.3

1. Plot size = 3 m²
2. Numbers followed by the same letter are not significantly different.

Table 3. Mean grain yield and *Striga* count for the EARSAM Sorghum *Striga*-Resistant Nursery at a farmer's field, Alupe, Kenya, long rains 1992.

Entry	Grain yield (g per plot)[1]	Number of *Striga* plants per plot
Seredo	890 a[2]	421 a
ICSC 1018BF	725 ab	304 abc
ICSV 1156BF	705 abc	237 bcd
ICSV 1006BF	540 bcd	137 cde
ICSV 1112BF	520 bcde	94 de
SAR 24	520 bcde	70 de
Framida	455 bcdef	392 ab
N 13	425 cdef	32 de
ICSV 1021BF	385 def	88 de
P-224 (Finger millet)	340 def	134 cde
SRN 39	290 defg	64 de
ICSV 1078BF	285 defg	119 de
MEDPMCOM 1 (pearl millet)	265 defg	9 e
ICSV 1017BF	260 defg	149 cde
ICSV 1007BF	260 efg	12 e
ICSV 1164BF	250 efg	148 cde
ICSV 1098BF	235 fg	335 ab
CK60B (Susceptible control)	180 fg	342 ab
IS 9830	55 g	54 e
CV (%)	42.7	63.6
LSD (0.05)	281.9	174.2

1. Plot size = 3 m².
2. Numbers followed by the same letter are not significantly different

site. Seredo and Framida varieties of sorghum gave the highest grain yields with 1115 g per plot for Seredo, and 1030 g per plot for Framida. The lowest yields, on the other hand, were observed for sorghum varieties N13 (130 g per plot), ICSV 1078 BF (110 g per plot), IS 9830 (85 g per plot), and CK 60B (45 g per plot). The remaining eight entries of sorghum, MEDPMCOMP 1 (pearl millet) and P-224 (finger millet), had yields between these two groups.

There were also significant differences for numbers of *S. hermonthica* plants among entries ($P < 0.05$) at the ARSC-Alupe site (Table 2). The lowest number of *S. hermonthica* plants (nine per plot) were found in the pearl millet entry, MDEPMCOMP 1. The lowest group of sorghums included ICSV 1006BF with 185 *S. hermonthica* plants per plot, N13 with 248, IS 9830 with 271, and Framida with 318 *S. hermonthica* plants per plot. The highest mean *S. hermonthica* populations were obtained in plots sown to ICSV 1007BF (647), ICSV 1021BF (618), and P-224 (finger millet—543).

Significant differences ($P \leq 0.01$) for mean grain yields were also found among entries in the farmers' fields (Table 3). Seredo sorghum still outyielded all the entries (880 g per plot) followed closely by ICSV 1018BF (725 g per plot), ICSV 1115BF (705 g per plot), and ICSV 1006BF (540 g per plot). The lowest yields were obtained from plots sown to IS 9830 (55 g per plot) and CK 60B (180 g per plot). The remaining sorghum entries, P-224 (finger millet), and MEDPMCOMP 1 (pearl millet) had yields ranging between these two groups.

Significant differences ($P \leq 0.05$) were also found among entries for *S. hermonthica* populations in the farmers' fields. Once again, MEDPMCOMP 1 (pearl millet) supported the lowest number of *S. hermonthica* plants (9 per plot) (Table 3). However, this number was at par with those found in plots sown to ICSV 1007BF (12), N13 (32), IS 9830 (54), and SRN 39 (64). Seredo sorghum, on the other hand, supported the highest number of *Striga* plants at this site (421). This number, however, did not differ significantly from numbers of *S. hermonthica* plants associated with the sorghum varieties Framida (393), CK 60B (342), and ICSV 1098BF (333). The other entries of sorghum and P-224 (finger millet) supported populations of *S. hermonthica* in between these two groups.

A combined analysis was not performed because of lack of variance (S^2) uniformity for the two sites. It was observed, however, that both sites had a lot of heterogeneity with respect to soil depth and fertility, and *Striga* populations (Braun 1980). This resulted not only in inconsistent *Striga* × variety/crop interaction across replications, but also within replications. This was one of the causes of the high coefficient of variation observed for the two sites. The low rate of N applied (20 kg N ha^{-1}) could also have influenced the high number of emerged *Striga* plants associated with most of the entries. Obilana (1983) observed that low rates of nitrogen (33 kg N ha^{-1}) stimulated *Striga* populations and decreased grain yields of sorghum while high rates (100–200 kg N ha^{-1}) suppressed *Striga* populations significantly and increased mean sorghum grain yields.

Seredo sorghum had the highest yield at both sites, although it also supported a moderate-to-high *Striga* population. Seredo is a progeny of the variety Dobbs, a local sorghum from western Kenya, which was found to be resistant to *Striga* (Dogget 1965, Mumera 1983). Seredo can therefore be described as highly tolerant to *Striga* infestation, under the conditions of these experiments. This tolerance was also observed for Framida, ICSV 1018BF, ICSV 1006BF, ICSV 1112 BF, and N 13. SAR 24 and SRN 39 could be described as moderately tolerant, while P-224 (finger millet) and CK 60B (sorghum) were the most susceptible entries. These observations are generally similar to those made previously by other scientists.

Saunders (1933) concluded that *Striga* resistance in sorghum was probably due to low stimulant production and/or resistance to parasitic attachment to the roots of the crop. Parker et al. (1977) reported that SRN 4841 and N 13 showed stable field resistance/tolerance to *Striga*, by producing high yields under a '*Striga*-sick' plot. Babiker and Hamdoun (1990) observed that SRN 39 and IS 9830, which produce low amounts of the germination stimulants, were more resistant to *Striga* infestation than a Sudan sorghum hybrid called Hageen Durra-1. They, however, reported that this resistance was seasonal, depending on the interaction of the host, parasite, and the environment.

The susceptibility of finger millet to *Striga* in this study could be because of continuous cultivation of the crop in association with *Striga* in the Alupe area. Similar observations were made by Parker (1983) on strains of *Striga* virulent to sorghum and maize. There was clear evidence in this research that the pearl millet entry, MEDPMCOMP 1, was the least attacked by *Striga*. In fact, the few plants found in some plots could have been parasitizing some grass weeds (e.g., *Cynodon dactylon* L.) rather than pearl millet. These results confirm the existence of different strains of *S. hermonthica* which are host-specific in their attack, as was observed by Reid and Parker (1979) and Obilana et al. (1991).

IS 9830 was observed to be an early-maturing variety. When *Striga* counts were started, it was flowering and it reached maturity between 85 and 90 days after sowing. It could, therefore, be described as a '*Striga*-escaper'. Because of its earliness and white grain, it was highly susceptible to bird damage. This was also the case for the pearl millet entry. Data on bird damage is not reported here, but it was scored at about 90% for the two entries. This could explain their low yields at both sites.

Table 4. Mean sorghum grain yield and *Striga* counts of sorghum and cotton cropping trial, Alupe, Kenya, long rains 1992.

Treatment	Grain yield (kg per 18 m^2)	*Striga* count (Number per 18 m^2)
Sorghum only	3.38 a[1]	1596.7 a
Sorghum + Cotton[2]	3.31 a	1359.7 a
Sorghum + Cotton[3]	2.90 ab	1418.7 a
Sorghum + Cotton[4]	2.47 b	896.0 b
Sorghum + Cotton[5]	2.47 b	586.3 b
Cotton only[6]	-[7]	0.0
CV (%)	10.9	17.5
LSD (0.05)	0.59	463.6

1. Numbers followed by the same letter are not significantly different at $P < 0.05$.
2. Cotton planted 3 months after sorghum.
3. Cotton planted 2 months after sorghum.
4. Cotton planted 1 month after sorghum.
5. Cotton intercropped with sorghum.
6. Pure stand cotton planted at 0, 1, 2, and 3 months after sorghum.
7. Cotton still being harvested, sorghum yield data were not available at the time of writing this report.

Trap-cropping effect of cotton on the *Striga* counts and grain yield in sorghum

The results of these investigations are shown in Table 4. The grain yields of Seredo sorghum were significantly different ($P \leq 0.01$). The mean grain yields of sorghum, when intercropped with cotton (2.42 kg per 18 m^2) and cotton relayed 1 month after sowing sorghum (2.47 kg per 18 m^2) were similar but significantly lower than grain yield of sole-cropped sorghum sown at the onset of rains. Yields of sole-cropped sorghum (3.38 kg per 18 m^2) were not significantly different from yields of sorghum relayed with cotton 2 months (2.90 kg per 18 m^2) and 3 months (3.31 kg per 18 m^2) after sorghum.

Mean *Striga* numbers, on the other hand, were significantly ($P \leq 0.05$) greater in treatments sown to pure stand sorghum (1597 plants per 18 m^2, and cotton relayed in sorghum 3 months (1360 plants per 18 m^2 and 2 months (1419 plants per 18 m^2) after sowing sorghum, than when cotton was relayed in sorghum 1 month after sowing sorghum (896 plants per 18 m^2) or intercropped with sorghum at the same time 896 and 586 plants per 18 m^2 plot.

One important point shown by these results (Table 4) is that the Seredo sorghum is tolerant of *Striga*. Its yield of about 2000 kg ha^{-1} in a pure stand *Striga*-sick plot was not drastically lower than the yields of 3–3.5 t ha^{-1} usually realized in *Striga*-free areas.

Seredo sorghum has Dobbs, a farmer's local variety from western Kenya, as one of its progenitors. Dogget (1965) observed that Dobbs and one of its progenies, Serena, exhibit some resistance to *Striga*. Serena was also reported to be resistant to *Striga*, as was the variety Serenex, since they maintain yields at above 3 t ha^{-1}, which is always the case, also under *Striga*-free conditions, and supported low populations of the parasite under *Striga*-sick plot conditions (Mumera 1983). The tolerant nature of Seredo sorghum could therefore be attributed to its Dobbs origin.

Cotton, as an intercrop or relay crop, suppressed sorghum yields. This could be attributed to competition for soil nutrients, water, and space. Cotton has a deep tap root and its foliage covers the ground early in the seedling stage. However, this negative interspecific relationship could be offset by the trap cropping nature of cotton on *Striga*, as was evident in pure stands of cotton and cotton sown early (0 and 1 months) in sorghum plots. The trap cropping nature of cotton could be attributed to *Striga*'s inability to attach to cotton roots and to lowering of soil temperature due to shading (Andrews 1947, Bebawi 1988). Babiker and Hamdoun (1990), while working with Dolichos bean (*Dolichos lablab* L.) and groundnut as trap crops, observed that Dolichos bean (which grows faster, is more leafy, and covers the ground early in the season) intercropped with sorghum, suppressed a higher number of *Striga* plants than did groundnut. The evident lowering of the soil temperature, besides resistance to the attachment of the parasite's haustoria, is supported by these observations. These results concur well with those for cotton in this study.

After harvesting the cotton in this experiment, land equivalent ratio (LER) will be calculated and a comprehensive efficient use of land assessed, before giving a complete report. This experiment will be repeated in the next 2 years before a final conclusion is made.

Effect of hand weeding on *Striga* count and grain yield of finger millet

The results of these investigations are shown in Tables 5 and 6. There was a significant interaction difference ($P < 0.05$) between varieties of finger millet and the weeding operations on the mean population of *Striga*. The highest mean number of *Striga* plants was observed in the variety P-224 (186 plants per plot) under the no-weed control

Table 5. Two-way table of weed-control methods × variety on the mean *Striga* count (number per plot[1]) on finger millet, Alupe, Kenya, long rains 1992.

Variety	Weed-control methods					Variety means
	W_0[2]	W_1	W_2	W_3	W_4	
P-224	186a[3]	162ab	141ab	164ab	118b	154.2
Ikhulule	142ab	153ab	147ab	132ab	116b	138.0
Weed control means	164	159	144	148	117	
CV (%) 24.5						
LSD 61.4 (0.05)						

1. Plot size = 2.7 m².
2. W_0 = No weeding (control).
   W_1 = 1 early hand weeding, 1 month after planting.
   W_2 = 2 hand weedings, 1 and 2 months after planting (recommended).
   W_3 = 3 hand weeding, 1, 2, and 3 months after planting.
3. Numbers followed by the same letter are not significantly different at $P < 0.05$.

Table 6. Two-way table of weed control methods × variety on the mean grain yield (g per plot[1]) of finger millet, Alupe, Kenya, long rains 1992.

Variety	Weed-control methods					Variety means
	W_0[2]	W_1	W_2	W_3	W_4	
P-224	235 d[3]	255 cd	325 bcd	295 bcd	295 bcd	290.0
Ikhulule (local)	245 d	370 b	360 bc	350 bcd	495 a	360.0
Weed control means	240.0	312.5	342.5	322.5	415.0	
CV (%) 20.3						
LSD 113.7 (0.05)						

1. Plot size = 2.72 m².
2. W_0 = No weeding (control).
   W_1 = 1 early hand weeding, 1 month after planting.
   W_2 = 2 hand weedings, 1 and 2 months after planting (recommended).
   W_3 = 1 late hand weedings, 2 months after planting.
   W_4 = 3 hand weeding, 1, 2, and 3 months after planting.
3. Numbers followed by the same letter are not significantly different at P>0.01.

treatment. This was significantly higher than the no-weed control with Ikhulule (142 plants per plot), the two hand weedings, and the one late hand weeding for both varieties of the crop (Table 5). The lowest mean population of *Striga* was observed in both varieties when they were weeded three times, 118 plants per plot for P-224 and 116 plants per plot for Ikhulule.

There was also a significant difference in the mean grain yields of finger millet, given the various hand-weeding treatments (Table 6). Ikhulule gave the highest grain yield when weeded three times. This was followed by one (early) and two weedings of the same variety. The latter two methods gave significantly higher mean yields than one late weeding for Ikhulule. The yield at this latter treatment was similar to those of P-224 under two weedings, three weedings, and one late weeding, but significantly better than under one early weeding for P-224 and the control for both finger millet varieties.

Ikhulule finger millet, with a little hand weed control, clearly resulted in better performance, and thus higher grain yield than the introduced P-224 cultivar (prereleased), in a *Striga*-infested field. This tolerance response could be attributed to variety × environment interaction. Babiker and Hamdoun (1990), while working with different sorghum varieties observed similar variety × environment interaction as a manifestation of *Striga* resistance or tolerance. The former variety, having been grown in these areas for a longer time, may have become better adapted over the years, than the P-224 which is being introduced. Under *Striga*-free conditions, every other factor being constant, P-224 has been observed to outyield Ikhulule by about 1.5–2 times (personal observation).

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Sorghum Seed Dressing against Smuts and Pythium Seedling Disease

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Abstract

This paper summarizes recent results of seed dressings screened for the control of covered kernel smut, loose smut, and Pythium*-caused damping-off of sorghum. Both in vivo and in vitro evaluation results are considered. Until now, only one product, Fernasan-D, has been recommended for sorghum seed dressing in the Sudan. Five products were compared with the standard in the field for the control of smut and* Pythium *damping-off. The effect of seed dressings on crop establishment was also assessed in the field. Tecto Tm and Captan gave the best results in controlling covered smut. Monceren Combi was as good as the standard. Loose kernel smut incidence was generally very low, and differences between test products were nonsignificant. All fungicides reduced pre- and post-emergence seedling loss, but Apron mix was the best against* Pythium.

Introduction

Smuts on sorghum are very widespread in the Sudan. Because of their effects on yield and quality of grain, they are considered to be the most serious diseases affecting sorghum production in the country. The four known smuts–covered kernel smut (*Sporisorium sorghi*), loose smut (*Sphacelotheca cruenta*), head smut (*Sporisorium reilianum*), and long smut (*Tolyposporium ehrenbergii*), occur in the Sudan. Incidence of these smuts varies from one location to another, and varies with the season, but covered kernel smut and long smut are of wide distribution, especially in traditional small farming. In 1991, both were predominant in Gash, where infection by covered kernel smut exceeded 30% and long smut was up to 10%. A similarly high incidence of covered smut was recorded in the mechanized schemes of the eastern region. Loose smut is of particular importance in ratoon fodder sorghum. Long smut is sporadic and its incidence is increasing from one season to the next in areas where sorghum is grown after sorghum. Though seed contamination is the source of infection for covered kernel smut and loose kernel smut, soil contamination, wind, and rain splash play a major role in the dispersal of the other organisms.

Pythium-caused damping-off is generally considered a cold-temperature, high-soil moisture disease. However, in the Sudan, virulent *Pythium* has frequently been isolated from root and mesocotyl lesions of sorghum seedlings in the central clay lands. The symptoms are characterized by grey water-soaked lesions on the roots and mesocotyl. Affected plants succumb and wilt rapidly.

Research Objective

There is only one product, Fernasan-D, recommended in the Sudan for sorghum seed protection. Many farmers complain that the protective dust is not available in production areas. This paper summarizes recent results of newly tested products against covered kernel smut, loose kernel smut, and *Pythium*-caused damping-off of seedlings.

Materials and Methods

Laboratory test

Sporidial cultures were prepared from teliospores of covered kernel smut (*S. sorghi*). Test products were evaluated for their in vitro activity using spot application of increasing concentrations on the sporidial-seeded agar plates. Activity was based on visual rating of inhibition zones of sporidial germination.

1. Agricultural Research Corporation, Gezira Research Station, P.O. Box 126, Wad Medani, Sudan.

Greenhouse test

The top soil of pots was contaminated with a pathogenic isolate of *Pythium* produced on agar medium. An equal number of seeds treated with seed protectants were sown in each pot. A nontreated control was included in the trial. Each treatment was replicated four times.

Field test

To screen products against covered and loose kernel smuts, seed of sorghum variety Gadam Hamam was surface-contaminated artificially with the respective teliospores collected from the previous season. Spore-dusted seeds were then treated with the prescribed dose of test products before sowing.

Results and Discussion

Laboratory screening of test products showed that all seed dressings were active against the covered smut organism, *S. sorghi*. However, Apron Mix was relatively poor at the 10 and 25 mg kg^{-1} rates compared with the other products (Table 1).

Table 1. In vitro test of seed dressings on *S. sorghi*.

	Concentration (mg kg^{-1})			
Fungicide	10	25	50	100
Tecto TM	+[1]	++[2]	+++[3]	+++
Monceren Combi	+	++	+++	+++
Thiram/Lindane	+	++	+++	+++
Apron Mix	–	+	+++	+++

1. + = Small inhibition zone.
2. ++ = 3–5 mm inhibition zone.
3. +++ = >5 mm inhibition zone.

At the two tested levels, all products except Thiram reduced *Pythium* damping-off significantly. Tecto TM at the higher concentration and Monceren Combi and Apron Mix at both levels tested, were the best treatments in experiment 1. In experiment 2, Apron Mix at both levels rated best. Monceren Combi and Thiram/Lindane gave inconsistent results between experiments 1 and 2 (Table 2).

Table 2. Effect of seed dressings against *Pythium* damping-off.

		Experiment 1		Expteriment 2	
Product	gP per kg[1]	Healthy plants (%)	Arcsin	Healthy plants (%)	Arcsin
Tecto TM	2	97	75.7 bc[2]	94	76.8 bc
Tecto TM	4	100	90.0 a	92	73.8 bc
Monceren Combi	1.5	100	90.0 a	97	82.3 ab
Monceren Combi	3	99	86.7 a	92	73.8 c
Thiram/Lindane	1.5	94	76:4 bc	84	66.8 d
Thiram/Lindane	3	91	73.4 c	100	90.0 a
Apron Mix	2	86	84.5 ab	100	90.0 a
Apron Mix	4	97	83.9 ab	100	90.0 a
Control	0	77	68.1 c	69	56.2 e

1. gP per kg = Grams of product per kg of sorghum seed.
2. Numbers followed by the same letter are not significantly different (P >0.05).

Table 3. Effect of seed dressings on covered kernel smut.

Seed dressing	gP per kg[1]	Disease incidence 1990: Plants with covered kernel smut (%)	1990: Arcsin	1991: Plants with covered kernel smut (%)	1991: Arcsin
Tecto TM	2	3.4	10.1 b[2]	1.5	5.4 abc
Tecto TM	4	1.1	3.1 a	0.4	1.2 a
Monceren Combi	1.5	4.2	10.4 b	4.0	11.4 bc
Monceren Combi	3	1.1	5.3 a	1.6	4.5 ab
Thiram/Lindane	1.5	10.7	18.0 c	3.1	10.1 bc
Thiram/Lindane	3	6.7	14.4 c	1.1	4.6 ab
Apron Mix	2	25.4	30.1 e	3.3	10.2 bc
Apron Mix	4	19.7	26.3 de	5.8	12.3 c
Control	0	19.6	25.9 d	10.7	18.8 d
SE			±1.34		±2.16

1. gP per kg = Grams of product per kg of sorghum seed.
2. Numbers followed by the same letter are not significantly different ($P > 0.05$).

In the 1990 season, all products except Apron Mix significantly reduced incidence of covered kernel smut compared with the nontreated control. Tecto TM and Monceren Combi at the higher concentrations were the best treatments. The results of 1991 were consistent with those of 1990 (Table 3).

Loose kernel smut incidence was very low. Maximum infection level in chemical treatments was 1.3%. This was significantly lower than the 6.2% infection in the control (Table 4).

Table 4. Effect of seed dressings on loose kernel smut.

Seed dressing	gP per kg[1]	Disease incidence: Plants with loose smut (%)	Arcsin
Tecto TM	2	0	0.57
Tecto TM	4	1.3	2.07
Monceren Combi	1.5	0	0.57
Monceren Combi	3	1.0	2.31
Thiram/Lindane	1.5	0.5	1.44
Thiram/Lindane	3	0.5	1.44
Apron Mix	2	0.2	1.40
Apron Mix	4	0.5	1.44
Captan	2	0.5	1.44
Captan	4	0.5	1.44
Control	0	6.2	6.79
SE			±1.11

1. gP per kg = Grams of product per kg of sorghum seed.

Testing of Inoculation Techniques to Screen Sorghum Lines for Resistance to Anthracnose in Ethiopia

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Abstract

Tests on inoculation methods and screening for resistance to anthracnose (Colletotrichum graminicola) *were carried out at Bako and Pawe during the 1989 and 1990 rainy seasons. Inoculum was produced of the sorghum anthracnose pathogen using Sorghum Green Leaf Medium (SGLM). Results showed that inoculum suspension, prepared from isolates of* C. graminicola *from Bako and Pawe, produced maximum infection and provided high disease pressure when plants were inoculated at the 5–7 leaf stage. Systematic screening of 110 sorghum accessions led to the identification of 25 anthracnose-resistant lines. This study showed that sorghum germplasm can be screened in the field using artificial inoculation to reduce the confounding effect of other diseases. Resistant sorghum accessions have valuable genes for resistance, which can be used to breed stable resistance to anthracnose.*

Introduction

Anthracnose, caused by *Colletotricum graminicola* (Ces.) G.W. Wilson, often damages leaves, stalks, and grain of sorghum (*Sorghum bicolor* (L.) Moench) (Harris et al. 1964, Harris and Stowell 1970). The leaf blight, stalk rot, and head blight phases of anthracnose limit sorghum production in most regions of Ethiopia (Mengistu Hulluka 1982). Grain yield is reduced by 50% or more on cultivars susceptible to anthracnose under severe epidemics (Mashilla Dejene 1988). The disease has been reported in Ethiopia, especially in Alemaya, Jimma, Bako, and recently at Pawe, where high rainfall, hot, and humid conditions prevail. Considering the importance of sorghum anthracnose disease in eastern Africa, the Advisory Committee of the Eastern Africa Regional Sorghum and Millet Network (EARSAM) recommended that the national sorghum program of Ethiopia should conduct research on the control of sorghum anthracnose.

Earlier, the Ethiopian Sorghum Improvement Program identified five sorghum cultivars resistant to *C. graminicola* in the field at Alemaya. These lines were not tested across the region where different physiological races are supposed to occur. Recently, the presence of more than one pathotype was confirmed in Ethiopia.

The virulence study made with isolates of *C. graminicola* from Jimma, Bako, and Alemaya using a set of sorghum lines showed pathogenic variation among the three isolates. The study indicated that the Alemaya isolate is less pathogenic than the Jimma and Bako isolates. At Alemaya, the anthracnose disease syndrome was complex because bacteria associated with lesions seemed to reduce sporulation by *C. graminicola*. The lines tested in this region were therefore screened against an isolate with low virulence. The field evaluation of cultivars for anthracnose reaction, both at Bako and Pawe in 1981 using natural infection, failed to identify any cultivars with significant resistance to anthracnose, because other leaf diseases confounded the results. Therefore, the study reported here was conducted to evaluate sorghum cultivars for resistance to anthracnose using artificial inoculation.

Materials and Methods

Screening for anthracnose resistance was carried out at Bako and Pawe in 1989 and 1990, using 150–200 Ethiopian sorghum germplasm accessions obtained from the Ethiopian Sorghum Improvement Program and 84 accessions from ICRISAT.

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Test materials were sown in single rows, 3 m long, with 75 cm between rows, in a nonreplicated nursery. Susceptible and resistant controls, identified from the 1988 variety trials, were sown after every five rows. Surrounding the trial field and perpendicular to the test entries, a mixture of susceptible controls were sown at least 20 days before sowing the test entries. This served as a spreader of inoculum during both years. In 1990, however, test materials were also artificially inoculated with *C. graminicola* conidia.

Pathogen: *C. graminicola* was isolated at Melkassa laboratory from infected leaves collected at Bako and Pawe. The fungus was cultured on potato dextrose agar (PDA) and V-8 juice agar using standard methods (Johnston and Booth 1983). The isolates were reinoculated and reisolated until pure cultures were obtained. Isolates were then cultured on Green Sorghum Leaf Medium (GSLM) for the production of conidial inoculum because conidial production on PDA and V-8 juice agar was not satisfactory. GSLM was produced by cutting washed green sorghum leaves into small pieces of about 2 × 3 cm. Leaf pieces were moistened and placed in 100 mL Erlenmeyer flasks until full. The flasks were then autoclaved at 121°C for 25 min. Flasks were seeded with 3-mm diameter discs of the isolates cut from petridish cultures with a sterile cork borer. The flasks were subsequently incubated at 30°C.

Inoculation of plants: To obtain conidial inoculum, the GLSM cultures of *C. graminicola* were washed with 1 L tap water and filtered with doubled cheese cloth. This stock solution and 9 L tap water were added to a knapsack sprayer, and test plants were inoculated at about the 5–7 leaf stage at both testing sites.

Evaluation: The disease was assessed three times. The first assessment was at boot stage, the second at flowering, and the third at dough stage. Severity was estimated using a 1–9 scale, where 1=<1% leaf area covered with lesions; 5=30–40% leaf area covered with lesions; 9=80–100% leaf area covered with lesions. For final tabulation, the degree severity of each tested entry was transformed into apparent infection rate according to Van der Plank's formula (Van der Plank 1963). The apparent infection rate was calculated using the Mstat-C program to determine the apparent infection rate of the mean, range, and individual test entries.

Results

Artificial inoculation technique: The artificial inoculation technique was used at both sites in 1990. We observed that application of inoculum at the 5–7 leaf stage provided maximum infection and produced high disease severity at both test sites. Development of the disease at the early boot stage made it possible to differentiate the extent of host-pathogen interactions among test entries and reduce the confounding effects of other diseases.

Table 1. Apparent infection rate of some Ethiopian sorghum accessions found resistant to anthracnose, under artificial screening, Bako and Pawe, 1990.

Genotypes[1]	Apparent infection[2] rate
ETS 4544	0.01
ETS 3530	0.01
ETS 3135	0.02
ETS 3286	0.02
87 HL 4016	0.02
Susceptible controls	
ETS 2113	0.05
ETS 3753	0.04
No. of entries	27
Mean	0.028
SE	±0.002

1. Only entries with the highest level of resistance are shown.
2. Van der Plank (1963).

Screening for anthracnose resistance: Out of 120 Ethiopian sorghum accessions screened in 1989 in the preliminary screening trial, 27 were selected and retested in 1990 in the advanced screening trial. From these, 7 entries were selected as those with the highest resistance to anthracnose (Table 1). The mean apparent infection rate among the 27 entries was r=0.028 and the range was r=0.01–0.05. The apparent infection rates of the susceptible controls were r=0.04–0.05.

Out of the 76 ICRISAT entries tested in 1990, 18 were selected for further testing. The mean apparent infection rate was r = 0.035 and the range was r = 0.01–0.14. The apparent infection rates of the resistant entries were r = 0.01–0.02, while those of the susceptible entries were r = 0.05–0.14 (Table 2). During selection of the resistant lines, disease severity was also considered.

Discussion

Apparently, the inoculation technique produced high disease pressure for screening. Clear differences were observed among the test entries 10 days after inoculation. In addition, no other diseases confounded anthracnose scoring at early stages, and so the difficulties we experienced in the first preliminary screening in 1989 were avoided.

One advantage of the GSLM inoculum production technique was its transportability. This was very useful for the Pawe location which has no laboratory facilities and is 750 kms northwest of the laboratory of Melkassa. Inoculum was prepared at Melkassa and transferred to Pawe at the time of inoculation, and infection was obtained. However, more testing is required to establish the optimum frequency of inoculation. It would also be useful to know more about the relationship of the amount of inoculum to the amount of infection which develops. We also observed variability in germination among the tested materials and hence not all test materials reached the 5–7 leaf stage simultaneously. However, the screening technique can be used for rapid field testing.

Table 2. The apparent infection rate of some ICRISAT sorghum accessions found resistant to anthracnose, following artificial inoculation, Bako and Pawe, 1990.

Genotypes[1]	Apparent infection[2] rate
M 82637	0.01
A 2267-2	0.01
ICSV 108	0.02
Susceptible controls	
A 1395	0.09
SPV 104	0.14
No. of entries	76
Mean	0.035
SE	±0.001

1. Only entries with the highest level of resistance are shown.
2. Van der Plank (1963).

The identification of resistant entries at both sites was significant, because some materials showed similar responses at both sites to both isolate populations. The apparent infection rate of the resistant entries was low — r=0.02, compared with the rate r=0.09 on susceptible entries. The apparent infection rate should be considered along with the degree of severity in resistant entries during selection, because the apparent infection rate of resistant and susceptible entries produced similar results, r=0.02, in our observations. The selected entries also showed resistance to other diseases. Probably these entries may have horizontal resistance against populations of the anthracnose pathogen.

Much of the information obtained in this study will be useful in developing a future control strategy. Further, initial contact of the pathogen to the host and penetration and establishment of the pathogen in the host need further investigation to develop varieties with effective resistance.

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Effect of Head Blast Severity on Finger Millet Yield

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Abstract

Breeding finger millet with resistance to Pyricularia grisea *(Cooke) Sacc., causal agent of blast, is difficult because resistance is expressed quantitatively, and the relationship between symptom expression and grain yield losses due to disease is not clear. Sixteen elite finger millet accessions supplied by the Eastern Africa Regional Sorghum and Millets Network (EARSAM) were evaluated under natural inoculum in replicated field trials at the Makerere University Agricultural Research Institute, Kabanyolo (MUARIK), Uganda. Severity of blast was visually estimated as percentage of spikelet area affected, number of blasted spikelets, and number of blasted necks. Except for the lines ACC/100007, ACC/100008, and ACC/100057, the other 13 lines had low blast infections, and showed no significant relationship between blast and yield.*

Introduction

Blast of finger millet (*Eleusine coracana* L. Gaertn), caused by *Pyricularia grisea* (Cooke) Sacc., is a serious disease in many areas of the world where finger millet is grown (Adipala 1980). Although the disease is often more severe under warm (20–25°C), humid (> 80% RH), and wet conditions, considerable losses occur even in semi-arid areas.

Epidemics of blast are usually of long duration. *Pyricularia grisea* oversummers as conidia or mycelia on infested residue, or on infected seed. Under favorable conditions, sporulation occurs, seedlings become infected, and are sometimes killed. Losses also result from reduced yields due to infection of leaves, nodes, and heads; however, the most significant losses result from neck infections (Adipala 1980, Ekwamu 1991).

Literature on genetic variability of the fungus is limited, but it is most likely that physiological races do exist (Emechebe 1975, Seetharam and Ravikumar 1991). Variations in response of finger millet germplasm to the blast fungus have been reported, and in many cases, early-maturing genotypes appear most susceptible (Adipala 1980).

In Uganda, yield reductions of up to 50% have been attributed to blast (Adipala 1980, Emechebe 1975). Although similar estimates have been given for India (Govindu and Shivanandappa 1967, McRae 1922, Rath and Mishra 1975) and the importance of blast is recognized, little information is available on the disease-yield relationship. In order to reduce yield losses to acceptable levels, we must first know how much loss occurs. This information is not available for blast, or any other pest of finger millet in Uganda. Such information would be useful for policymakers and for setting research priorities. This paper reports on a preliminary study to evaluate different Eastern Africa Regional Sorghum and Millets Network (EARSAM) finger millet lines for resistance to blast, and to quantify the relationship between blast severity and yield of finger millet.

Materials and Methods

Sixteen elite finger millet lines supplied by the ICRISAT/EARSAM Program, Nairobi, were evaluated during April-June 1992 (Table 1). Field plots were established in land previously under soybean at the Makerere University Agricultural Research Institute, Kabanyolo. The experimental design, replicated three times, was a split-plot with finger millet lines as the main plots and chemical treatments as subplots. Each main plot measured 5 × 5 m, and consisted of 12 rows of finger millet planted at a spacing of 40 × 10 cm. The main plots were divided into four subplots (chemical treatments), each consisting of three rows. The four chemical treatments studied were: (i) carbofuran (3 G) applied at a rate of 30 g per 0.4 m^2; (ii) mancozeb applied at a rate of 3 g per 0.4 m^2; (iii) application of both mancozeb and carbofuran; and (iv) nontreated control. Carbofuran was applied in furrows at planting, while mancozeb was

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Table 1. Codes, names, origin, and time to 50% flowering of 16 elite finger millet lines evaluated for resistance to blast (*Pyricularia grisea*) at Kabanyolo, Uganda, 1992.

Codes	Line	Origin	Time to 50% flowering (days)
1	ACC/100007	Ethiopia	58
2	ACC/100008	Ethiopia	61
3	ACC/100057	Ethiopia	70
4	KAT/FM-1	Kenya	62
5	IKHULULE	Kenya	76
6	P227	Uganda	75
7	SERERE 1	Uganda	73
8	ENGENY	Uganda	74
9	GULU E	Uganda	75
10	P224	Uganda	75
11	U10	Uganda	76
12	SC/18-44	Uganda	73
13	SC/10	Uganda	74
14	EDING	Uganda	70
15	SC/14-C	Uganda	75
16	SC/25-8	Uganda	75

Table 2. Main effect of finger millet genotype on number of spikelets per plant, and yields of 16 elite finger millet lines grown at Kabanyolo, Uganda, 1992[1].

Finger millet line	No. of spikelets per plant	Yield (t ha^{-1})
ACC/100007	22.8	1.97
ACC/100008	20.5	2.63
ACC/100057	31.8	2.68
KAT/FM-1	17.0	2.44
Ikhulule	25.3	4.08
P227	22.0	3.50
Serere 1	27.1	4.62
Engeny	24.0	3.98
Gulu E	26.3	4.44
P224	26.9	3.72
U10	18.4	4.04
SC/18-44	23.4	4.30
SC/10	21.7	3.17
Eding	20.3	3.57
SC/14-C	20.3	2.98
SC/25-8	23.6	3.58
Mean	23.2	3.48
$LSD_{0.05}$	NS[2]	0.49
CV (%)	26.0	23.0

1. Data are means of three replicates.
2. NS = not significant.

applied at 2-week intervals from germination to flowering four times. Agronomic practices necessary for the production of finger millet were followed (Dunbar 1969).

Disease and Yield Evaluation

Disease level, under natural inoculum, was quantified three times: 86, 100, and 114 days after planting (DAP). Plants in the middle row of each subplot were used for disease and yield assessments. The total number of plants, total number of finger millet heads, and the total number of blast-free and blasted spikelets were determined for all plants in the middle row, 100 DAP. Percentages of spikelet areas blasted were rated on 10 tagged plants 86, 100, and 100 DAP. Data for percentages of spikelet areas blasted were used to compute area under disease progress curve (Campell and Madden 1990). At maturity, the number of plants in the inner row were determined, plants harvested, and grain yield (kg ha^{-1}) determined.

Analysis of variance (ANOVA) was used to test the effects of finger millet genotype and chemical treatments. Regressions of yield (kg ha^{-1}) on severity of blast provided an estimate of maximum yield in the absence of disease (y–intercept, i.e., b_o) and the slope of the regression equation (b_i) indicated the yield loss (kg ha^{-1}) per unit increase in disease. Aptness of the regression equation models was assessed by an F-test for significance of b_o and b_i, and the coefficient of determination (R^2); comparisons of parameter estimates for different regression models and treatment means were made at $P < 0.05$, using MSTAT-C computer programs.

Results

The level of head blast infection was significantly affected by finger millet genotype and chemical application (Tables 2 and 3). In the case of Ethiopian lines (ACC/100007, ACC/100008, and ACC/100057) genotype × chemical interactions were significant ($P = 0.01$) for AUDPC and for number of infected spikelets per plant, and number of plants with neck blast (data not shown). Generally, there was low incidence of neck blast on all the finger millet lines studied, and there was no head blast infection on the Uganda line Engeny. Application of mancozeb reduced blast infection, but this varied with the finger millet line and did not result in significant yield increase (Table 3). However, application of carbofuran stimulated spikelet production, and higher yields were obtained when accompanied by mancozeb application.

Correlations among yield and blast assessment indices were low and nonsignificant (Table 4). However, the relationships among the number of blasted spikelets per plant, number of blasted necks, and percentage of spikelet area blasted were highly significant. Similarly, disease assessments 86, 100, and 114 DAP were highly correlated amongst themselves and with the area under disease progress curve (AUDPC) (Table 5).

Yield was related to blast severity by ANOVA and regression analysis. There were no significant relationships ($P < 0.1$) between blast severity and yield for the majority of finger millet lines except for ACC/100007, ACC/100008, and ACC/100057. Lines with no significant blast-yield relationships were excluded from subsequent data analysis. Overall, the relationship between blast severity and yield was best described by relating yield to the number of blasted spikelets, and to a lesser extent, AUDPC and percentage of spikelet area blasted (Table 6). Therefore, subsequent analyses of the blast-yield relationships were made using only the three most susceptible lines, i.e., ACC/100007, ACC/100008, and ACC/100057, and the number of blasted spikelets or percentage of spikelet area blasted (Tables 7 and 8).

Table 3. Main effect of treatments on number of spikelets per plant and grain yields of 16 finger millet lines grown at Kabanyolo, Uganda, 1992[1].

Chemical type	No. of spikelets per plant	Yield (t ha^{-1})
Carbofuran	25.0	3.35
Mancozeb	22.1	3.34
Carbofuran + Mancozeb	25.1	3.56
Control	20.7	3.37
Mean	23.2	3.48
$LSD_{0.05}$	2.1	NS[2]

1. Data are means of three replicates.
2. NS = Not significant.

Table 4. Pearson's correlation coefficients, describing the relationships among blast severity indices and yield of 16 finger millet lines grown at Kabanyolo, Uganda, 1992.

	No. of spikelets per plant	No. of infected spikelets	No. of heads with neck blast	Spikelet area affected (%)
Infected spikelets per plant	0.069			
Number of heads with neck blast	0.036	0.674**		
Spikelet area affected (%)	0.026	0.746**	0.797**	
Yield	0.257	-0.326	-0.391	-0.362

**Significant at $P < 0.01$.

The regression statistics between yield and blast severity were highly significant for ACC/100007 ($P = 0.01$, $R^2 = 0.47$) and ACC/100008 ($P = 0.19$, $R^2 = 16.8$), but not for ACC/100057 (Table 7). Similarly, when critical point models (Campbell and Madden 1990) were fitted to the yield and blast data assessed 86, 100, and 114 DAP, R^2 values were only slightly high for ACC/100007 and almost nil for ACC/100008 and ACC/100057. These results (Tables 7 and 8) did not correspond well with the resultant yield loss (Table 9).

Table 5. Pearson's correlation coefficients describing the relationships between yield (kg ha^{-1}) and percentage of spikelet area affected by blast (*Pyricularia grisea*), assessed at different growth stages of 16 elite finger millet lines grown at Kabanyolo, Uganda, 1992.

	Days after planting			
	86	100	114	AUDPC[1]
Days after planting:				
96	0.96*[2]			
114	0.99*	0.99*		
AUDPC[1]	0.98*	0.99*	0.99*	
Yield	−0.36	−0.37	−0.38	−0.36

1. Area under disease progress curve (Campell and Madden 1990).
2. Significant at $P < 0.001$.

Discussion

Although high yield losses were recorded on ACC/100007, ACC/100008, and ACC/100057, the effect of head blast was not significant on the other 13 finger millet lines. Yield losses recorded in this study were higher than those reported by Talengyere (1990), where 2.80% yield losses were recorded for ACC/100007, 0.14% for ACC/100008, and 0.02% for ACC/100057. These are, however, similar to previous estimates of 50%, suggested by Adipala (1980) and Emechebe (1975). During this study, there was comparatively low intensity of blast compared with that often observed in Uganda. This probably accounted for the lack of blast infection on Engeny, and the low R^2 values obtained.

Table 6. Coefficient of determination (R^2) describing the relationship between yield (kg ha^{-1}) and indices used to assess head blast severity on three elite finger millet lines grown at Kabanyolo, Uganda, 1992.

	Head blast severity indices			
Finger millet line	Severity (%)[1]	AUDPC[2]	No. of infected spikelets per plant	No. of infected necks per plant
ACC/100007	0.12	0.16	46.7	0.00
ACC/100008	0.3	0.01	0.16	0.12
ACC/100057	0.3	0.06	0.00	0.01
Pooled[3]	0.2	0.02	0.10	0.00

1. Percentage of spikelet area affected assessed 114 days after planting.
2. Area under disease progress curve (Campbell and Madden 1980).
3. Based on data for all the three finger millet lines.

Table 7. Regression statistics describing the relationship between yield (kg ha^{-1}) and average number of blast-infected spikelets for three elite finger millet lines grown at Kabanyolo, Uganda, 1992.

	Statistics[1]				
Finger millet line	b_o	b_i	MSE	*P*	R^2
ACC/100007	4495	74.6	2 45 599	0.01	46.7
ACC/100008	3117	43.2	3 88 690	0.19	16.8
ACC/100057	3367	1.0	7 56 498	0.071	0.0
Pooled[2]	3751	26.4	5 50 445	0.06	9.5

1. b_o is the intercept and b_i is the slope; MSE is the mean square error; *P* = probability level; R^2 is the coefficient of determination (%).
2. Based on data for the three varieties.

Table 8. Coefficients of determination (R^2) describing the relationship between yield (kg ha^{-1}) and percentage of spikelet area affected by blast on three finger millet lines grown at Kabanyolo, Uganda, 1992.

	Days after planting		
Finger millet lines	86	100	114
ACC/100007	0.11	0.11	0.12
ACC/100008	0.02	0.02	0.03
ACC/100057	0.01	0.03	0.04
Pooled[1]	0.13	0.13	0.12

1. Based on data for all three finger millet lines.

Table 9. Relationship between percentage of spikelet area affected by *Pyricularia grisea* and yield loss assessed on 16 elite finger millet lines grown at Kabanyolo, Uganda, 1992.

Variety	Severity[1]	Yield loss (%)[2]
ACC/100007	18.5	56.0
ACC/100008	23.4	15.6
ACC/100057	5.7	6.4
KAT/FM-1	2.0	5.8
SC/18-14	0.9	0.4
SC/14-4	0.3	0.2

1. Blast severity assessed 114 days after planting.
2. Difference between yield in absence of disease (Y-intercept) and actual yield obtained and expressed as percentage of the Y-intercept.

Good blast-yield models were obtained only for the highly susceptible genotype ACC/100007. The best model was obtained using numbers of blast infected spikelets. In rice, critical point models using the number of blasted nodes (L=0.57X, where L is percentage yield loss and X is the percentage of blasted nodes, 30 days after heading) usually provide good estimates of yield loss (Katsube and Koshimizi 1970). In this study, the number of blasted necks were considered, but it provided poor fit and low R^2, even for the susceptible ACC/100007. The low R^2 values were most likely due to the low incidence of neck blast because neck blast infections usually lead to significant yield reductions (Ekwamu 1991). For ACC/100007, critical point blast-yield models for disease assessment at 86, 100, and 144 DAP resulted in similar R^2 values. This suggests that any of the three disease assessment periods would be suitable for assessing blast-yield relationships. However, future studies should include more and earlier disease assessments.

The primary objective of our study was to develop a blast severity-yield model that can adequately predict yield loss. Although our results are preliminary, use of both critical point models based on number of blast-infected spikelets, and AUDPC models based on percentage of spikelet area affected, appear promising. Our study used natural inoculum and probably higher disease levels could have been achieved by imposing artificial inocula.

This will be done in subsequent studies. Effect of leaf blast infection on yield will also be considered in future studies.

Acknowledgements

Field-plots for this study were established by Dr M.W. Ogenga-Latigo and Mr E. Ouma of Makerere University. Funding for the research was provided by USAID/Uganda Manpower for Agricultural Development (MFAD). We also acknowledge the research support given by OAU/SAFGRAD/ICRISAT Regional office, Nairobi.

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Insect Pests of Sorghum in Eastern Africa: Utilization of Host-Plant Resistance in Pest Management

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Abstract

Sorghum shoot fly (Atherigona soccata *Rond.), stem borers (*Chilo partellus *Swin. and* Busseola fusca *Fuller), aphids* (Melanaphis sacchari *Zehnt.*), midge (Contarinia sorghicola *Coq.), head bugs (*Taylorilygus *sp.), and birds are the major pests of grain sorghum in eastern Africa. In a survey of the farmers' fields in the Bay region in Somalia during the 1989 short rainy season, 69% of the plants showed stem borer leaf feeding and 27% showed deadhearts. Sorghum midge and borers (*Chilo *and* Semamia*) are major pests in Tanzania, while midge and* Busseola *are the most important pests in Ethiopia. Shoot fly, stem borers, midge, bugs, and aphids are present on sorghum in Kenya, of which stem borers are more serious in drier regions, and midge in wetter western Kenya. More than 80% of the fields surveyed in 1991 were infested by these pests, and nearly 20% grain loss was attributed to midge damage.*

Several sorghum breeding trials and international pest nurseries have been evaluated for resistance to shoot fly, stem borers, midge, and aphids in Kenya, Tanzania, and Somalia. A number of germplasm and breeding lines have shown good levels of resistance to shoot fly at Ilonga, Tanzania, in the 1990 rainy season. Marimanti collections 2, 9, and 10, F6 Y.Q. 353, PB 12874, PS 35853, ICSV 714, ICSV 708, PS 35832, and IS 22144 showed resistance to C. partellus *under natural infestation at Kiboko, Kenya during the 1991 long rainy season. Nine sorghum genotypes (IS Nos. 2168, 2205, 2263, 2291, 5566, 5619, 8320, 18677, and ICSV 700) showed very low incidence of spotted stem borer (*C. partellus*) under natural infestations at the Bonka Dryland Agricultural Research Station (BDARS), Baidoa, in Somalia during the 1989 long and short rainy seasons. PM 12699-2, PM 15836-1, PM 15908-3, A 16638-1, PM 14383, and A 16637-1-2 were resistant to midge at Alupe, Kenya, during the 1990 short rainy season. PGRCE Nos. 69442, 222878, 69474, F6 Y.Q. 353, WM 177, ENT SADCC 177 and 62, IS 12601C, and TAM 428 showed high levels of resistance to* M. sacchari *(damage rating <1.5 compared with 9.0 in the susceptible control, White Dwarf Milo). Hybrids A 807 × TAM 2566, AT 636 × DT No.043, A 36257 × PGRCE 20079, A 36287A × F6 Y.G. 353, and A 36251 × WM 177 were resistant to the aphid. These lines can be used per se or involved in breeding programs to develop cultivars resistant to the major pests.*

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the major cereal crops in eastern Africa. Insect pests, drought stress, *Striga*, birds, and diseases are the major constraints to sorghum production. Several insects have been reported to cause damage to sorghum in eastern Africa (Jepson 1954, Ingram 1958, Schmutterer 1969, Starks 1969, Bohlen 1973, Gebrikadan 1982, Seshu Reddy and Omolo 1985, Sharma 1992), of which sorghum shoot fly (*Atherigona soccata* Rond.), stem borers (*Chilo partellus* Swin., *Busseola fusca* Fuller, *Eldana saccharina* Wlk., and *Sesamia* spp.), armyworm (*Spodoptera exempta* Wlk.), aphids (*Rhopalosiphum maidis* Fitch. and *Melanaphis sacchari* Zehnt.), midge (*Contarinia sorghicola* Coq.), bugs (*Taylorilygus* sp., *Creontiades pallidus* Ramb., *Campylomma* sp. and *Agonoscelis* spp.), and head caterpillars (*Helicoverpa*, *Cryptoblabes*, *Celama*, *Eublemma*, and *Sitotroga*) are the major pests in different agroecosystems (Table 1). Shoot fly is a major problem in late-sown crops, when the sowings are staggered in Tanzania, Kenya, and Uganda. Stem borers are a serious problem in low and dry areas of Kenya, Tanzania, Somalia,

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ICRISAT Conference Paper no. CP 1033.

Table 1. Insect pest problems on sorghum in eastern Africa[1].

Insect	Burundi	Ethiopia	Kenya	Rwanda	Somalia	Sudan	Tanzania	Uganda	Yemen
Shoot fly									
Atherigona soccata	*[2]	*	***	*	*	**	**	***	-
Stem borer									
Chilo partellus	-	*	***	*	***	**	***	**	*
Busseola fusca	*	**	**	*	-	-	*	**	-
Chilo orichalcociliellus	-	-	-	-	-	-	*	-	-
Eldana saccharina	*	-	*	*	-	-	*	*	-
Sesamia spp.	*	*	*	*	*	*	*	*	-
Armyworm									
Spodoptera exampta	-	*	**	*	*	*	**	-	*
Aphid									
Melanaphis sacchari	-	*	**	-	-	*	*	*	-
Rhopalosiphum maidis	*	*	*	*	*	*	*	*	*
Shoot bug									
Peregrinus maidis	-	-	*	-	-	-	*	*	-
Spittle bug									
Poophilus costalis	-	-	*	-	-	-	*	*	-
Midge									
Contarinia sorghicola	***	***	*	*	*	*	***	**	***
Shield bugs									
Agonoscelis spp.	-	-	**	-	-	**	**	*	-
Mirid bug	-	**	**	-	-	**	*	**	*
Creontiades pallidus									
Campylomma spp.									
Taylorilygus sp.									
Head caterpillars	*	**	**	*	-	*	*	*	-
Celama sp.									
Eublemma spp.									
Helicoverpa armigera									
Sitotroga sp.									

1. Based on Seshu Reddy and Omolo (1985), Sharma (1992), and information provided by National Agricultural Research Systems (NARS).
2. - = No damage, * = slight damage, ** = moderate damage, *** = severe damage.

and Sudan. Aphids, particularly *M. sacchari*, becomes serious during the long rainy season. Armyworm outbreaks are sporadic in Tanzania and Kenya. The larvae cause extensive defoliation of crops during outbreaks. Sorghum midge is a major problem when sowings are staggered in Tanzania, Kenya, Uganda, Sudan, and Ethiopia. Head bugs are extensively distributed, although populations are presently low, largely due to the loose- panicled and colored sorghums grown by farmers in these regions.

Pest Incidence and Extent of Losses

Jepson (1954) reported 40–100% plants infested by *B. fusca* in Tanzania. In Uganda, up to 56% loss in grain yield has been reported due to *C. partellus* (Starks 1969). Losses due to midge (*C. sorghicola*) often reach 25% in the Sudan (Schmutterer 1969). During the 1989–91 crop seasons, we carried out surveys on pest incidence in Tanzania, Kenya, Ethiopia, and Somalia. The results of these surveys are summarized below.

Kenya. Farmers' fields along Kisumu-Kakamega-Busia-Kisumu-Ahero-Mbita Point-Rongo route were surveyed for pest incidence at the milk to hard-dough stages during the 1991 long rainy season. Shoot fly, stem borer,

Table 2. Pest incidence and severity of damage to sorghum in farmers' fields in Kenya during July 1991.

Location	No. of fields sampled	Short fly incidence (%)	Stem borer incidence (%)	Midge		Headbugs	
				Incidence[1] (%)	(DR)[2]	Incidence (%)	Bugs per 5 panicles
Kisumu-Kakamega	6	100	100	100	2.3	83	46
Busia-Kisumu	12	83	91	83	3.6	83	24
Kisumu-Ahero	14	93	93	100	3.3	100	53
Kendu Bay	5	80	80	100	1.6	69	11
Homa Bay	4	100	100	100	1.5	100	26
Mbita	8	63	63	100	4.4	75	33
Rusinga Island	11	82	100	100	2.3	100	43
Rongo	11	82	100	100	2.3	100	43
Kiboko	4	0	100	100	3.7	100	55
Mean	-	78	90	98	2.8	89	35

1. Incidence = Percentage of fields infested.
2. DR = damage rating on a 1–9 scale, where 1 = <10% grain damage, and 9 = 80% grain damage.

midge, bugs (*Creontiades pallidus* Ramb., *Campylomma* spp., and *Taylorilygus* sp.), and sugarcane aphid (*M. sacchari*) are the major pests of sorghum in western Kenya (along the coast of lake Victoria) (Table 2). As a result of infestations by sorghum midge, there was nearly 20% grain loss. In late-flowering crops, loss in grain yield exceeded 60%. Stem borer damage was quite severe (up to 77%) at Kiboko during the long rainy season.

Ethiopia. Farmers' fields were surveyed for insect pest incidence in the Wallon-Chiti area in Nazret Province during 1990. Stem borer (*B. fusca*) and midge (*C. sorghicola*) were the major pests in the region. Midge has been reported to be an endemic pest in the Gambella region. Late-flowering sorghums also showed head bug damage. Birds caused by far the greatest damage to sorghum. Farmers explained that they generally grew red-grained sorghums and that it was difficult to grow white-grained sorghums because of extensive damage by birds.

Somalia. A survey was undertaken to estimate insect damage in the Bay Region of Somalia during the 1989 short rainy (Deyr) season (Oct-Feb). Twelve fields were sampled on the Baidoa-Mogadishu Road, and 10 along the Baidoa-Dinsoor Road. Each field was sampled at three points marked at random (3 × 3 m). The number of plant hills, number of plants, and the number of plants showing insect damage were recorded. Spotted stem borer was the major insect damaging the sorghum crop in all the fields surveyed. *C. partellus* leaf feeding was found in 91.8% of the hills and 68.7% of the plants (Table 3). Deadhearts were found in 53.4% of the hills and 27.0% of the plants. Ratooning of sorghum was generally practised during the short rainy season in the Bay Region. Stem borer infestation was higher on the ratoon crop compared with the planted one, both at the Research Station and in the farmers' fields (Table 4). The ratooned crop had more stem borer larvae, and these larvae were in advanced stages of development, compared with larvae in the planted crop.

In an experiment on the yield loss assessment due to spotted stem borer at BDARS using partial chemical control, significantly lower leaf damage/deadhearts and higher grain yields were recorded in treatments where the chemical was applied 15 days after crop emergence.

Table 3. Insect pest survey on sorghum in the Bay Region of Somalia, short rainy season, 1989.

District	No. of fields sampled	Hills with borer (%)		Plants with borer (%)	
		Leaf feeding	Dead hearts	Leaf feeding	Deadhearts
Bur Hakaba (Baidoa-Mogadishu)	12	91.5	46.1	64.6	20.1
Baidoa (Baidoa-Qansa Dheere)	6	91.8	59.0	72.6	33.9
Qansa Dheere and Dinsoor	4	92.6	66.8	72.0	37.4
Mean		91.8	53.4	68.1	27.1
SE		±3.51	±7.02	±5.03	±4.81
CV (%)		9	22	14	25

Table 4. Spotted stem borer infestation on ratoon and planted sorghum crop at Bonka Dryland Agricultural Research Station (BDARS), Baidoa, and in the farmers' fields in Somalia, short rainy season, 1989.

Observation	BDARS		Farmers' fields		SE	CV (%)
	Ratoon	Planted	Ratoon	Planted		
Plant height (cm)	88	73	60	74	±1.9	5
Leaf feeding (% hills)	100	100	100	90	-[1]	-
Deadhearts (% hills)	68	35	78	60	-	-
Leaf feeding (% plants)	79	73	92	71	±3.4	10
Deadhearts (% plants)	23	16	54	32	±5.4	27
Leaf feeding score	6	3	5	2	±0.2	14

1. - = SE and CV not computed.
The percentages are based on total plants examined.

Tanzania. Surveys were conducted in Morogoro and Dodama regions during the 1990 rainy season. *Chilo*, *Sesamia*, and *Contarinia* were the most damaging pests at the research stations as well as on farmers' fields. *Atherigona* and *Calidea* infestations were also recorded.

Host-Plant Resistance in Pest Management in Eastern Africa

Host-plant resistance to insects, in conjunction with cultural practices, natural enemies, and a need-based application of pesticides, constitutes a robust combination for a sustainable pest management strategy. Adequate levels of resistance are available against sorghum midge and sugarcane aphid, *M. sacchari*, while moderate levels of resistance are available against shoot fly and stem borers. The useful effects of resistant genotypes are continuous, cumulative, and without cost to the farmers. Reduction in pest density through plant resistance also makes the control operations easier through natural enemies, and reduces the number of pesticide applications.

The severity of infestation of shoot fly, stem borer, midge, aphids, and head bugs differs in different countries. Armyworms and locusts are sporadic, while head bug populations may increase on late-flowering crops. Resistance or at least some degree of tolerance to shoot fly and stem borers is essential in the drier lowland areas of Somalia, Kenya, Ethiopia, Uganda, Tanzania, and the Sudan. Resistance to aphids is also essential in some regions. Resistance to midge is desirable in areas where sowings are staggered or where genotypes with different maturities are grown. Mixed cropping of cowpeas with sorghum has been shown to reduce stem borer damage, while uniform and timely planting of the same cultivar over large areas reduces the losses by shoot fly and midge (Jotwani 1982). This practice also reduces grain damage by birds.

Shoot fly (*Atherigona soccata*)

Considerable effort has been made to screen for resistance to shoot fly in the Sudan (Zien El Abdin 1981). Results indicated that Combine Kafir 60, Abu Sabien, Feterita Gardif, and Dwarf Gassarbi are tolerant of shoot fly damage (Mowafi 1967, Abdel Rahman 1971). Several sorghum genotypes, identified to be resistant to shoot fly at ICRISAT Asia Center (IAC), showed good levels of resistance in Tanzania and Kenya (Raina et al. 1984, Unnithan and Seshu Reddy 1985) (Tables 5 and 6). Tillering response to shoot fly damage is a form of recovery resistance. The cultivars Namatare and Serena have shown good recovery resistance in Uganda and the heritability of recovery resistance was fairly high (Doggett et al. 1970, Starks et al. 1970).

Stem borers (*Chilo, Busseola*)

In eastern Africa, resistance to *Chilo* has been reported by Starks and Doggett (1970). Extensive screening for stem borer resistance has been carried out under natural and artificial infestation in Kenya (Dabrowski and Kidiavai 1983, Seshu Reddy 1983, 1985, Alghali and Sexana 1988) and several lines resistant to stem borers were identified (Table 6).

Table 5. Incidence of shoot fly on sorghum trials using delayed sowing, infestor rows, and fishmeal technique, Agricultural Research and Training Institute, Ilonga, Tanzania, rainy season, 1990.

		Shoot fly incidence (% deadhearts)				
Trial[1]	No. of genotypes	Trial mean	Mean susceptible excluding control	Susceptable control	Local control	Range
1987 ISSFN	25	29.0	23.2	79.7	74.6	12.1–79.7
1988 ISSFN	25	28.5	23.7	83.9	83.5	14.6–83.9
1988 ISSBN	25	42.0	39.1	73.8	72.6	16.9–83.9
TEVT	110	81.4	-[2]	-	86.8	54.0–96.7

1. ISSFN: International Sorghum Shoot Fly Nursery; ISSBN: International Sorghum Stem Borer Nursery; TEVT: Tanzania Elite Variety Trial.
2. - = Damage not recorded.

LC 119/83-3, LC 119/80-2, and P 101 were tolerant of borer damage because of production of more tillers which, in some cases, resulted in higher grain yield (Alghali 1985, 1987). Screening for spotted stem borer resistance has also been carried out at BDARS, Baidoa, in Somalia during the 1989 long (Gu) and short (Deyr) rainy seasons, and at Kiboko in Kenya during the 1991 long rainy season (Table 6).

Sorghum midge (*Contarinia sorghicola*)

Several midge resistance nurseries and other sorghum trials have been evaluated for resistance to sorghum midge at Alupe, Busia in Kenya (a hot-spot location for this insect) during 1990–91. During the 1990 short rainy season, several lines were found to be resistant to midge damage (Table 6). These lines have earlier been identified to be resistant at IAC in India. However, these results are based on one season's data. Our recent experience with breeding lines derived from DJ 6514 (e.g., ICSV 197, ICSV 745, ICSV 88013, and ICSV 88032) have shown that these lines become susceptibile across planting dates at Alupe, Kenya. A similar trend may be expected with the above-mentioned lines. Our current emphasis is focused on the identification of stable sources of resistance to midge for the eastern Africa region, and determination of the factors responsible for the breakdown of midge resistance in the Busia region of Kenya.

Sugarcane aphid (*Melanaphis sacchari*)

Heavy incidence of *M. sacchari* was recorded during the long rains of 1991 at Kiboko, Kenya. Several lines showing low aphid damage during 1990 were tested in a 8 × 8 triple lattice design. Aphid damage in this trial was quite high. The entries were rated for aphid damage on a 1–9 scale, where 1 = plants with a few aphids on 1–3rd leaf, and a few aphid feeding spots, and 9 = aphids infesting all the leaves, and the leaves showing extensive yellowing, wilting, and covered with sooty molds. The susceptible control, White Dwarf Milo, was completely damaged (DR 9). Most hybrids with aphid-resistant pollinators were less damaged (rating <2), even though their female parents were susceptible. This indicated that resistance to aphids is probably controlled by dominant genes. TAM 428, PGRC/E Nos.69442, 222880, 69442, and 69419 showed high levels of resistance to the aphid (rating <2), compared with the susceptible control White Dwarf Milo (DR = 9). Resistance to aphid is dominant and several aphid-resistant hybrids were obtained with aphid-resistant pollinators.

Research on Host-Plant Resistance at IAC and its Relevance to Eastern Africa

Shoot fly

Screening for resistance to shoot fly can be carried out under late plantings, and by increasing the shoot fly infestation using the interlard-fishmeal technique (Taneja and Leuschner 1985a). Entries selected as less susceptible under field conditions can be further tested under a multi- or no-choice cage technique. Shoot flies can be collected in a fish meal trap and after conditioning with sorghum seedlings for 1–2 days, can be released (about 40

Table 6. Sorghum gentoypes indentified to be tolerant or resistant to insect pests in eastern Africa.

Insect	Genotype	Remarks/Reference
Shoot fly		
Khartoum, Sudan	Combine Kafir 60, Abu Sabien, Feterita Gardif, Dwarf Gassarbi	Mowafi (1967) and Abdel Rahman (1971)
Serere, Uganda	Namatare, Serena	Tolerant (Dogget et al. 1970)
Mbita Pt., Kenya	IS nos. 2122, 2123, 2146, 2205, 2291, 39622, 4660, 5092, 5480, 5613, 18551	Resistant (Raina et al. 1984; Unnithan and Seshu Reddy 1985)
Ilonga, Tanzania	IS nos. 2146, 2205, 5480, 5604, 18551, 18585, 22121, 22148, 22196, 24357, PS nos. 28060-3, 30715-2, 31888-2, 31405-3, 31408-2, ICSV nos. 680, 711, 712, 713, 714	Resistant (Taneja, S.L., unpublished)
Stem borers		
Mbita Pt., Kenya	E 302, E 303, IS nos. 1044, 1151, 2162, 4660 17739, 18328, 18349, 18749, 18849	Resistant (Dabrowski and Kidiavai 1983, Seshu Reddy 1983)
	LC 119/83-3	Yield not reduced (Alghali 1985)
	LC 119/80-2, P 101	Tolerant (Alghali 1987)
	L1, L2, IS nos. 1044, 1151, 3962, 4213, 4405, 4481, 5613, 10364, 10370, 10711, 12497, 18323, 18326, 18427, 18479, 18517, 18676	Resistant to borer complex (Seshu Reddy 1985)
Baidoa, Somalia	IS nos. 2168, 2205, 2263, 2291, 5566, 5619, 8320, 18677, ICSV 700	Resistant to *Chilo* (Taneja and Mohammed 1990)
Kiboko, Kenya	Marimanti collections 2, 9, 10, F6YQ 353, PB 12874, PS 35832, PS 35853, ICSV 708, ICSV 714, IS 22144	Less damaged (Sharma, H.C., unpublished)
Sorghum midge		
Alupe, Kenya	IS nos. 2290, 8671, 18658, 19476, 21879, 22464, 22471, 22806, ICSV nos. 386, 387, 388, 389, 391, 393, 564, PM nos. 12652, 13520, 14414-2-4, 15908-3, 15926, 15929-2, 15933-2, 15936, 15936-1, 15908-1	Damage rating[1] <3 (Sharma, H.C., unpublished)
Sugarcane aphid		
Kiboko, Kenya	TAM 428, PGRC/E nos. 69419, 69442, 222880, F6YQ 353, WM 177, ENT SADCC 177, IS 12601C	Damage rating[1] <2 (Sharma, H.C., unpublished)

1. Damage rating on a 1-9 scale, where 1 = highly resistant, and 9 = highly susceptible.

flies per 100 plants) inside cages (1 × 1 × 1 m) or plastic trays (40 × 30 × 14 cm) (Sharma et al. 1992). Over 25 000 germplasm accessions have been screened for resistance to shoot fly. Two-hundred-and-thirty-nine lines have been screened for more than two seasons each in the rainy and postrainy seasons. In the postrainy season, 188 lines have shown good levels of resistance, while only 19 lines showed resistance in the rainy season. IS 2146, IS 2205, IS 4646, IS 5604, and IS 18551 are good sources of shoot fly resistance. ICSV 705, ICSV 708, and ICSV 717 are improved breeding lines with resistance levels comparable to original sources of resistance.

Spotted stem borer

Screening for stem borer resistance can be carried out at the hot-spot locations (Kiboko in Kenya, Baidoa in Somalia, Zwei in Ethiopia, Serere in Uganda, Wad Medani in the Sudan, and Ilonga in Tanzania), and under artificial infestation using whorl application of larvae (about 5–7 larvae per plant) with a bazooka on 15–20 day old plants (Taneja and Leuschner 1985b). A rapid screening technique using microplots or trays has also been developed (Nwanze and Reddy 1991). Genotypic resistance can also be studied using a stem cage. Different numbers of larvae can be released inside the stem cage on plants 35 or 45 days after seedling emergence. Infestation with four larvae per plant gives 100% infestation. Length of the stem tunnel increases with an increase in the number of larvae or number of infestations. Nearly 20 000 germplasm accessions have been screened for resistance. IS 2205, IS 5470, IS 5604, IS 8320, IS 18573, IS 18577, IS 18579, and IS 18581 are stable sources of resistance. ICSV 443, ICSV 700, and PB 12779-1 are improved sources of resistance.

Midge

Screening for midge resistance can be carried out by delayed plantings at hot-spot locations and by using infester row technique (Sharma et al. 1988a). Resistance of field-selected materials can be tested under no-choice head-cage technique (40 midges per panicle for 2 days at half-anthesis) (Sharma et al. 1988b). Nearly 15 000 germplasm accessions have been screened for midge resistance. DJ 6514, TAM 2566, AF 28, IS 8918, and IS 7005 are stable and diverse sources of resistance. ICSV 197, ICSV 745, ICSV 88013, and ICSV 88032 are improved cultivars with high levels of midge resistance, and their yield potential is comparable with commercially released cultivars.

Head bug

Screening for head bug resistance can be carried out under field conditions using late plantings and infester rows. Cultivars showing less damage under field conditions can be tested under no-choice conditions in the headcage (5 or 10 pairs of bugs per panicle at the half-anthesis stage) (Sharma and Lopez 1992). IS 17610, IS 17645, IS 20740, IS 21444, and IS 20664 are resistant to head bugs. Resistance to head bugs is being transferred into improved breeding lines. Malisor 84-7 and CSM 388 are good sources of resistance to *Eurystylus immaculatus* Odh.

Current emphasis in the sorghum improvement program has been placed on tranferring resistance to individual pests into high-yielding varieties and hybrid parents. Efforts are also being made to improve the levels of resistance to shoot fly and stem borer. Midge resistance is being diversified, involving various sources of resistance. Resistance to head bugs is being transferred from *guinense* sorghums into agronomically acceptable cultivars. Both pedigree and population breeding procedures are being used to achieve these objectives.

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Discussion Session 4: Plant Protection

Title of Paper: The Reaction of Cereals to *Striga asiatica* and *Striga hermonthica* in Tanzania

Name of Speaker: A M Mbwaga

Question: *A M Yassin*

Have you observed any association or antagonism between *S. asiatica* and *S. hermonthica*?

Answer: *A M Mbwaga*

We have observed *S. asiatica* and *S. hermonthica* infesting the same host plant and the same was observed with *S. asiatica* and *S. forbesii*. *Striga hermonthica* and *S. forbesii* do not occur in the same geographical zone. We need detailed studies in the laboratory on the association observed in the field.

Title of Paper: *Striga* Infestation in Sorghum and Millets Relative to Cultivars, Trapcrop, and Hand Weeding

Name of Speaker: G O Abayo

Question: *A M Yassin*

Since there was an indication of reduction of sorghum yield, especially when simultaneously planted with cotton, why did you not include a legume in the experiment?

Answer: *G O Abayo*

1. Cotton being a major cash crop in western Kenya, was deliberately chosen in this first year trial to address both the problem of yield and control of *Striga*. It was recommended that cotton be planted at the onset of long rains to realize high yield, but farmers did not adopt this practice because they gave priority to food crops. If high yield is coupled with 'suicidal' germination of *Striga*, the adoption rate by the farmers would increase.
2. We completely ignored the use of legumes in the control of *Striga*. In fact, in the future research plan, we intend to use cowpea, green gram, field bean, and even peanut as *Striga* trap crops in sorghum plots.

Question: *Sit Elnafar M Badi*

You showed that the number of *Striga* plants is high while the grain yield is high too, and at one time both are low. Would you elaborate on why you did not want high *Striga* counts although it did not affect the yield.

Answer: *G O Abeyo*

I accept that high grain yield of sorghum and high *Striga* population occurred. But at that time, the high yield could be attributed to lack of competition between cotton and sorghum, since cotton, planted in these plots 2 and 3 months after sorghum was planted, had adequately been established. Inclusion of cotton in sorghum plots early in sorghum planting (0 and 1) reduced the number of *Striga* plants appreciably, and this was a major objective as we not only want to reduce attack at that time, but also reduce future attacks by reducing *Striga* seed populations in the soil.

Question: *S B King*

Please clarify what you mean by the word "tolerance" while referring to reaction to *Striga*?

Answer:

"Tolerant" means that the *Striga* will germinate and attack the crop, but the crop will tolerate the attack and produce relatively good yield.

Question: *A Ekwamu*

Your data showed increased sorghum yields and at the same time, high *Striga* populations. Do you think that there is possibly a threshold *Striga* population at which significant yield losses begin to occur? I suggest that you carry out an experiment to vary *Striga* population and establish the threshold population.

Answer: *G O Abayo*

It would be both interesting and useful to detect the threshold number of *Striga* which would significantly reduce the grain yield of sorghum. We do hope to set such a trial in future so as to determine this turning point.

Title of Paper: Effect of Head Blast Severity on Finger Millet Yield

Name of Speaker: Adipala Ekwamu

Question: *A B Mohamed*

The low R^2 value suggests that other important parameters need to be incorporated. Also what assumptions did you impose in trying to formulate the model?

Answer: *A Ekwamu*

Yield is certainly determined by variables other than head blast. I did not include these variables in formulating the models. I think low blast levels may also have contributed to the low R^2 values.

Question: *A M Mbwaga*

When you applied a mixture of carbofuran and mancozeb, the number of spikelets per plant increased. What do you think is the biology behind it?

Answer: *A Ekwamu*

I do not know. Our results are preliminary and we are repeating the experiment to see if the same phenomenon occurs again. Then we will make more detailed physio-chemical studies. There could be a hormonal effect.

Question: *Aberra Debello*

If you have variety by chemical interaction, don't you think it is difficult to interpret your data from the main effect table, as seen from your chemical effect table, because of the confounding effect of chemicals with variety?

Answer: *A Ekwamu*

I agree. I only wanted to show the trends; in fact, I did not calculate LSD for main effects means when the interactions were significant.

Title of Paper: Testing of Inoculation Techniques to Screen Sorghum Lines for Resistance to Anthracnose in Ethiopia

Name of Speaker: Girma Tegegne

Question: *A M Yassin*

In the Sudan, we always note infection of anthracnose with that of leaf blight due to *Helminthosporium*. Have you ever noted such association in Ethiopia?

Answer: *G Tegegne*

In our country, especially in humid regions, we have a combination of different diseases in sorghum and that was the reason that we established inoculation techniques to avoid the interference of other diseases in the screening procedure. Otherwise, we have both diseases at the same time but with distinguishable characteristics.

Question: *J W Stenhouse*

Can you tell me, please, whether the anthracnose-resistant lines identified in your paper—those with ETS numbers—are germplasm lines or improved lines?

Answer: *G Tegene*

The materials we used are indigenous germplasm. They are not improved lines.

Question: *A Ekwamu*

Your data indicated, at least for the Ethiopian lines, that lines with higher severity of anthracnose had similar or lower apparent infection rates than lines with lower severity. Are you using severity or apparent infection rates to classify varieties as resistant or susceptible? Since Ethiopian lines had lower apparent infection rates than the susceptible controls, do you think you have partial or rate-reducing resistance?

Answer: *G Tegene*

We used both parameters for selection. But the apparent infection rate was calculated using the severity level. The apparent infection rate is used here for further study to see the performance of lines for partial resistance.

Question: *P Esele*

I know in Ethiopia you have been doing some work on anthracnose for quite a while. Considering that you grow sorghum under a wide range of environments and the disease appears in all of them, are you doing any work on race differentiation of the pathogen? The pathogen is likely to be variable under such a wide range of environments and sorghum cultivars.

Answer: *G Tegene*

We have not started race identification yet. We have a virulence study in collaboration with ICRISAT. Maybe in future we will concentrate on this issue once we differentiate between the variability and pathogenicity of the pathogen.

Title of Paper: Sorghum Seed Dressing Against Smuts and Pythium Seedling Disease

Name of Speaker: M El Hilu Omer

Question: *A M Mbwaga*

You suggest that the residual effect of your test chemicals be analyzed at a stage when you want to recommend them to farmers. At this stage if you find that your chemicals have some residual effect, don't you think that you would have lost both your money and time? I suggest you include residual testing right from the beginning.

Answer: *El Hilu Omer*

This is the usual practice with all chemical screening. You have to prove the effectiveness of the chemical, then the best ones are subjected to analysis. If a chemical is to be eliminated on health basis then it will not be recommended and may be the choice would be for the safe competitors.

Question: *A Ekwamu*

You said you contaminated soil with *Pythium* during inoculation. Give more details on the inoculation technique: what was the inoculum, mycelium or oospores?

Answer: Different species of Pythium exist in the central clays of the Sudan. The one pathogenic on sorghum was isolated from the eastern region; it was purified and multiplied in petri dishes. The fungus is fast growing.

Session 5

Utilization and Socioeconomics

Nonwheat Bread Research and Development

P L Bureng, L Y Monawar, and S M Badi[1]

Abstract

Traditionally, bread is produced from wheat flour. In the past three decades, research and development have been geared towards inclusion of other cereals and legumes for the production of bread. Composite flour bread is now an accepted phenomenon.

In developing countries, shortage of wheat and hard currency to import adequate quantities of wheat have resulted in the use of sorghum, pearl millet, and other cereals to make baked products. Sorghum and pearl millet have been used successfully to the level of 20–30% in bread-making. For biscuits and pasta products, higher percentages (up to 75%) of nonwheat flours have been used commercially.

This study investigated the development of bread from sorghum and pearl millet. With the addition of starches, emulsifiers (Glycerol monostearate, GMS), and gums (Guar and xanthan), an acceptable bread has been produced.

Results and development on nonwheat bread at the Food Research Centre in the Sudan (FRC) have shown that quality bread can be produced from sorghum, pearl millet, and other tropical cereals. This could be a breakthrough on the monopoly of wheat bread production.

Introduction

The idea of nonwheat bread development seems simple: total substitution of wheat in the bakery by domestically grown cereals or other starch and protein sources, thereby contributing to reducing wheat imports by developing countries and improving the nutritional status of the population.

Despite persistent efforts by development agencies, notably the Food and Agriculture Organisation of the United Nations (FAO), and policymakers in developing countries alike, the composite flour concept, started in 1964, cannot be said to have made much headway. The initial enthusiasm cooled down markedly after the first, primarily experimental stage, and although there have been, and still are, several composite flour projects in developing countries, run either under technical assistance schemes or independently by governments or nongovernmental organizations (NGOs), the composite flour concept has not yielded the results it originally promised.

Initial activities in nonwheat bread development, however, gave high expectations. These expectations would have been shortlived in Sudan, if the pitfalls which seriously retarded or completely derailed the progress of the composite flour projects, had not been carefully avoided.

Nonwheat bread research and development has been going on in many laboratories, at almost the same time as when the composite flour program was announced by FAO in 1964. But in 1988, a breakthrough was reported that bread without wheat can be made commercially or at home from tropical staple crops. If this technology is proved, the implications for developing countries could be profound. Unfortunately, the existence of a simple technology of this kind is never enough by itself to change government policies or the business approach of local entrepreneurs. An appropriate government policy should be that, if people want to eat bread, then let them, but it should be bread free of imported wheat, since this crop has damaged the agricultural base of many African countries.

Result of research and development showed the possibility of using nonwheat flour (sorghum, maize, cassava) to bake bread, provided cassava starch is included. The FAO cassava formula awas developed from cassava flour and gelatinized cassava starch, with the addition of such ingredients as xanthan gum, and glycerol monostearate (GMS) to strengthen and improve the rheological properties of the batter. The other normal bread ingredients (e.g., yeast, sugar, fat, and salt) were also applied.

1. Food Research Centre, P.O. Box 213, Khartoum North, Sudan.

FAO recipe for bread using cassava

Ingredients	Mass (g)
Cassava flour	250
Cassava starch[1]	50
Sugar	12.5
Salt	5
Yeast[2]	3
Oil/Magarine	3.5
Xanthan	1
Water	275

1. Gelatinized starch: Mix 50 g cassava starch with 275 mL water, weigh, then gelantinize, cool, weigh, and adjust with water to original mass, then mix with dry ingredients.
2. Yeast—mix with 20 mL water and add.

Another formula which was developed at the International Institute for Tropical Agriculture (IITA) at Ibadan, Nigeria, for nonwheat bread under the heading 'Alternative breads from cassava flour' was developed from cassava flour, roasted soy flour, whisked egg white, xanthan, margarine or fat, and other ingredients used in normal wheat bread.

In the Food Research Centre (FRC), Khartoum North, the Sudan, nonwheat bread has been developed using sorghum flour, gelatinized sorghum starch, GMS, guar, gum, and the usual bread ingredients.

International Institute of Tropical Agriculture recipe for bread using cassava

(All ingredients are expressed as percentages of the sum of flour and starch)

Flour and starch		
Cassava flour		80
Roasted soy flour		20
Sum		100
Ingredients		
Whisked egg white		48 on 12% dry matter
Xanthan		1
Margarine		4–10
Sugar		6–10
Yeast		1
Water	Variable	70–100

Food Research Centre (FRC) recipe for bread using sorghum
(All ingredients are expressed as percentages of the sum of flour and starch)

Flour and starch	
Sorghum flour	70
Sorghum starch (raw)	10
Sorghum starch (gelatinized)	20
Sum	100
Ingredients	
Sugar	10
Fat	5
Yeast	1
GMS	0.5
Guar gum	1–2
Water	100–116

The wheatless bread formulae developed by the Federal Institute of Industrial Research, Oshodi (FIIRO), were more feasible for commercial interest, but the bread produced was of very poor quality. There were innumerable problems and the bakers were discouraged.

Federal Institute of Industrial Research, Oshodi (FIIRO) recipe for bread
(All ingredients are expressed as percentages of the sum of flour and starch)

Flour and starch		
Sorghum flour	70	-
Cassava flour	-	70
Cassava starch	30	30
Sum	100	100
Ingredients		
Yeast	1	1
Margarine	2	2
Sugar	10	10
Amylase/malted sorghum	0.48	0.48
Water	80–100	80–100

The challenges of developing and extending wheatless bread on a commercial scale was taken up by FAO in 1991; three projects were formulated to be executed in Nigeria, Zambia, and Sri Lanka under the title 'Wheatless Bread Development and Extension'.

Sorghum Bread Development

Raw materials

1. **Sorghum flour.** Sorghum flour was prepared by dehulling the grain and pulverising (or grinding) to fine particle size (<200 microns). The color of the grain plays an important role as observed in the *Kisra* and *Asida* quality and acceptability in the Sudan. Therefore, a new technology of milling sorghum was recommended.

2. **Sorghum starch.** This starch is being produced on a commercial scale in the Sudan. Sorghum starch and glucose are now being exported to international markets.
3. **Cassava starch.** Cassava starch was produced on a laboratory scale some 2 years back. The lack of raw materials made it difficult to carry on this experiment in the Sudan. The FAO project TCP/NIR/0052 in Nigeria made use of cassava starch and cassava flour in the pilot plant of FIIRO. Nigeria is a large producer of cassava, and starch and flour industries have been established there.
4. **Emulsifiers.** Glycerol monostearate (GMS), monoglycerol palmitate (MGP), guar gum, and xanthan gum were found suitable for nonwheat bread development. The recommended levels range from 0.01–0.5% for GMS and MGP, and 0.5–5.0% for the gums.
5. **Normal bread ingredients.** These include salt, sugar, fat, and yeast.

Bread making

1. **Preparation of gelatinized starch.** Sorghum starch/cassava starch was weighed into a stainless steel pot and water added at the ratio of 1:4. The suspension was heated gently with constant stirring until a clear translucent mash was produced. After cooling the gelatinized starch, water was added to replace the water lost during evaporation.
2. **GMS or MGP emulsion preparation.** The quality of GMS and MGP must be Food Grade and should not exceed 1%.
   The emulsion was prepared by weighing GMS or MGP and adding boiling water at the ratio of 1:8. The suspension was stirred until a white cream emulsion paste was produced.
3. **Preparation of batter.** All ingredients were weighed or transferred into a mixing bowl (Hobart or Kenwood Mixer).
   i. First mix — speed no. 1. Time 3–5 min. All ingredients were mixed at slow speed until a dough was formed, followed by softening and finally a sticky batter.
   ii. Second mix — speed no. 2. Time 15—20 min. The sticky batter was mixed until a smooth batter was formed.
   iii. Batter resting — Time 10-30 min at room temperature, although 10–15 min have been generally found suitable.
   iv. Third mix — speed no. 2. Time 5—10 min. This was done to drive out the gases formed.
   v. Panning — the batter was scooped into baking pans, the volume or mass depending on the size of the pan.
4. **Proofing.** The proofing conditions were the same as for normal bread, with a few modifications. The room or cabinet should be humidified (80% humidity) at a temperature range 40–48°C and for 20–40 min.
5. **Baking.** The baking oven temperature was optimum at 230°C for a baking time of 20–30 min, depending on the size of pan.

Discussion

Sorghum bread produced at the laboratory level at FRC and FAO project in Nigeria could be classified as very poor, satisfactory, and good. The nonwheat bread development was investigated under the following categories:
1. Sorghum flour/sorghum starch (raw)
2. Sorghum flour/sorghum starch (gelatinized)
3. Sorghum flour/sorghum starch (raw)/sorghum starch (gelatinized)
4. Sorghum flour/cassava starch (raw)/cassava starch (gelatinized).
5. Sorghum flour/cassava flour/cassava starch (raw)/cassava starch (gelatinized).

The nonwheat breads produced which were based on sorghum flour and sorghum starch (1, 2, and 3), were found to be very poor. Several combinations of sorghum flour and sorghum starch, raw and gelatinized, gave good rheological properties of batter during proofing. In the oven, there was significant oven spring; but the top crust collapsed or cracked at the centers when browning stage was reached, resulting in poor quality.

When the same formula was developed with cassava starch raw and gelatinized, good quality bread was produced with all properties of wheat bread. The great quality contrast could be attributed to the role played by the constituents of starches, protein, fat, and enzymes of sorghum and cassava starch. The formula for this bread follows:

Project TCP/NIR/0052/Nigeria
Sorghum flour-based formula for bread
(All ingredients are expressed as percentages of the sum of flour and starch)

Flour and starch	
Sorghum flour	70
Cassava starch (raw)	10
Cassava starch (gelatinized)	20
Sum	100
Ingredients	
Yeast (Instant)	1.5
Salt	1.2
Fat	1.0
Sugar	10
GMS/MGP	0.5/0.6
Water	100–106
Bread Specific Volume (Average mL g^{-1})	2.2–2.9

The bread developed with equal ratios of sorghum and cassava flours plus raw and gelatinized cassava starch resulted in better bread quality (FAO Project TCP/NIR/0052). The formula for this bread follows:

Project ICP/NIR/0052/Nigeria
Sorghum/cassava flour-based formula for bread
(All ingredients are expressed as percentages of the sum of flour and starch)

Flour and starch	
Cassava flour	35
Cassava starch (raw)	10
Cassava starch (gelatinized)	20
Sorghum flour	35
Sum	100
Ingredients	
Yeast (Instant)	1.5
Salt	1.2
Fat	1.0
Sugar	10
GMS/MGP	0.5/0.6
Water	102–120
Bread Specific Volume (Average mL g^{-1})	2.1–2.7

Although starch is the major constituent of flours, other constituents of the grain are also present in smaller amounts, which enhances its use for some purposes. Sorghum flour, with which this discussion is chiefly concerned, contains about 72–75% starch, 7–13% protein, 0.4–0.7% ash, and small amounts of natural sugars, fats, enzymes, and other organic components. Although the amount of protein present is relatively small compared with that in starch, it exerts a very pronounced influence on the character of products made from flour.

The constituents of sorghum grain are similar to those found in wheat except for the type of protein in the two cereals. But the role of sorghum flour in combination with cassava starch or cassava flour, was vital in the development of wheatless bread. When maize was used in place of sorghum, a lower quality bread resulted.

The nonwheat bread development depends on complex characteristics of the constituents involved in bread making. The presence of cassava starch (raw or natural) and cassava starch (gelatinized) are very important. The types of cassava starches complement each other by association and water absorption during batter development. During baking, these starches, in the presence of cereal protein and other constituents such as emulsifiers and fats, form the matrix which traps the gas and hence facilitates the formation of good crumb.

For increased utilization of sorghum, it is imperative to produce improved cultivars which have the same functional properties of starch granules found in cassava and have increased protein constituent, enzymes, and fat which are vital constituents for good quality bread-making.

There is a concerted effort from FAO, international institutions, and developing countries' governments to develop bread or bread-like products from tropical grains, roots, and tubers. This is running parallel with agricultural trials of growing wheat in the tropics or other cereal crops such as rye and triticate.

Studies on Methods to Improve *Injera*-Making Qualities of Two Brown Sorghum Varieties

Senayit Yetneberk and Tiruset Haile[1]

Abstract

Two brown sorghum varieties, Seredo and IS 2284, were evaluated for their injera-*making qualities.* Injera *from whole grain was poor and unacceptable. In order to remove the seed coat to reduce the tannin, dehulling of grain by hand pounding and Tangential Abrasive Dehulling Device (TAAD) was done. As these varieties possess soft endosperm, these procedures resulted in the loss of endosperm. For IS 2284, hand pounding for 6 min and dehulling for 4 min in the TADD gave good* injera. *Seredo resulted in poor* injera *with hand pounding, but dehulling for 5 min with TADD gave better quality* injera. *Differences in dehulling characteristics of the grain were observed between the two varieties. In a subsequent experiment, Seredo was further tested with teff in composite flour mixed in different proportions. Mixing at 1:1 ratio was found optimum and increasing the proportion of teff improved the quality. The results indicated that removing the seed coat and mixing with teff is a possible means of improving* injera-*making qualities of brown sorghum varieties.*

Introduction

Tannin is normally associated with brown sorghum varieties. Tannin in sorghum seed is concentrated in the pericarp and removal of pericarp significantly reduces the tannin content (Jambunathan and Mertz 1973). Tannins apparently do not occur in the endosperm (Hahn and Rooney 1986). Sorghum tannin can bind digestive enzymes, hence reducing digestibility of both dietary proteins and carbohydrates. Actual binding with dietary proteins also reduces their digestibility (Butler et al. 1984).

Many researchers studied the possible means of limiting interaction of dietary proteins with tannin. Treatment of high-tannin sorghum grain with moist alkaline conditions was shown to substantially reduce the amount of tannin (Price et al. 1979). Formaldehyde was reported to reduce tannin (McGrath et al 1982). However, these measures are not suitable for adoption at the farmer's level.

Mechanical abrasion is an extension of traditional processing techniques to overcome the anti-nutritional effect of sorghum tannin. In this process the tannins and fibre are largely removed to yield a product with improved nutritional and sensory qualities. However, high-tannin sorghum varieties have been observed to give low yields when subjected to abrasive dehulling due to the predominantly floury nature of their endosperms.

At the Institute of Agricultural Research (IAR), Addis Ababa, Ethiopia, a survey was carried out on food uses of sorghum in the major sorghum-growing areas of the country. *Injera* (a fermented staple food which is a fluffy pancake-like product made from cereals) was found to be the major food made from sorghum in the surveyed areas. Further, the effect of processing on the quality of sorghum *injera* was used to standardize laboratory methods of *injera* preparation. With this standard procedure, a set of seven varieties of sorghum were evaluated for their *injera*-making qualities. Among the set were two brown sorghum varieties. These were poor *injera* makers when used undehulled, and hence required further investigation of processing methods to make acceptable *injera*. That formed the basis for this investigation, whose objectives are to:

1. Evaluate dehulling quality of brown sorghum varieties with hand pounding and with a mechanical dehulling device.
2. Determine the level of mixing brown sorghum with teff in composite flour.
3. Evaluate the *injera*-making quality from the two treatments.

1. Institute of Agricultural Research (IAR), P.O. Box 2003, Addis Ababa, Ethiopia.

Materials and Methods

Sorghum sample

Two high-tannin sorghum varieties, Seredo and IS 2284, were obtained as pure inbred lines from the Ethiopian Sorghum Improvement Program (ESIP), Melkassa. The seeds were cleaned by winnowing and hand removal of foreign materials (straws and glumes).

Dehulling quality

Dehulling was done using two methods: (1) traditional hand pounding, and (2) mechanical dehulling with Tangential Abrasive Dehulling Device (TADD).

Traditional method of dehulling (hand pounding). This was a manual process where a wooden mortar and pestle was used. A kilogram of sorghum sample was washed in a bowl containing tap water. The cleaned kernels were poured into a wooden mortar, and pounded with a wooden pestle for 3, 6, and 10 min. The number of strokes was counted each time. After pounding, the kernels were allowed to dry in the sun and when dry, the bran was removed by winnowing. Three determinations were made for each sample and mean values were calculated and tabulated.

Mechanical method of dehulling (TADD mill). One-hundred grams of the grain were poured into five cups of the sample plate of TADD and dehulled at four levels corresponding to 1, 2, 3, and 4 min retention times. Each time the dehulled grain was removed from the sample cups with a vacuum-aspirating device and deposited into a plastic container. The broken kernels and the bran were separated by winnowing. The mass of the dehulled grain and the brokens were measured using a triple beam balance. Three determinations were made for each sample being tested and mean values calculated.

Composite flour

The brown sorghum variety, Seredo, and teff were used for this experiment. *Injera* was prepared with either whole (undehulled), dehulled, or composite flour (Seredo sorghum mixed with teff) at 5:1, 2:1, 1:1, 1:2, and 1:5 proportions of Seredo to teff. Whole and dehulled (4 min) Seredo were included as controls.

Injera preparation

Each variety from each treatment was milled separately using an Udy mill with a screen aperture of 0.5 mm. After obtaining the flour, four major steps were involved in *injera* preparation.

Preparation of ersho. Ersho is a semi-liquid starter culture saved from the previous fermentation. During the period of testing, 50 g of sorghum flour was mixed with 130 mL of water to make a batter. Ten milliliters of starter culture from the previous fermented batter was inoculated. This mix was allowed to ferment for 24 h. The fermented product was used as a starter culture for further experimentation.

Preparation of dough. Two hundred grams of the flour sample was taken and mixed with about 180 mL of water. Kneading was done in a bowl for about 5 min. The dough was transferred into a 1000-mL capacity polypropylene beaker. Ten milliliters of starter culture was poured on top of the dough. It was left to stand for 48 h. This was designated as first fermentation time.

Preparation of absit. Absit is a gruel made from fermented dough to initiate second fermentation and to improve the texture of the end product. After the dough was fermented for 48 h, about 80 g was taken and made to a batter consistency by adding 30 mL of water. The mix was added to 200 mL of boiling water. It was cooked for about 2 min with constant stirring. The absit was mixed with the fermented dough at a temperature of 45°C. Simultaneously, about 150 mL of water was added to convert the dough to a batter consistency. These steps initiated the second fermentation.

Baking the *injera*. Second fermentation takes 2–3 h after the addition of absit. This was manifested by the production of carbondioxide gas as a fermentation byproduct. Immediately thereafter, *injera* was baked on an electrically heated clay griddle by pouring the batter carefully in a circular manner starting from the circumference of the griddle towards the center, using a beaker with a spout. The clay griddle was covered with an aluminium lid and baked for 2–3 min.

Sensory evaluation of *injera*

A score sheet entitled 'Taste panel evaluation of '*injera*' was used (see Annex 1). A three-digit code number was assigned to each sample. The *injera* was cut into eight pieces at each serving. The taste panels were requested to rate each sample separately and assign their rating by ticking against each quality description.

There were six parameters involved: color, eye quality, texture, underside appearance, taste, after-taste, and final remark of general acceptance. Under each parameter, there were five description names. For example, color as a parameter had five descriptions: white, creamy-white, reddish, light-brown, and brown. These descriptions were given score values. A 1–5 rating scale was used, where 5 was the best and 1 the poorest. For each parameter at each determination, the number of responses against each description was multiplied by the value attached and mean value was calculated. Three determinations were made for each sample being tested.

Results and Discussion

Dehulling quality

Traditional dehulling. The results of the two varieties dehulled using the traditional dehulling method indicated that as the number of strokes and time for dehulling increased, total recovery percentage decreased and the percentage of brokens increased (Table 1). This could be associated with the loss of endosperm along with the seed coat. However, the polishing quality was poor. The grain broke easily before proper polishing took place, due to the floury nature of the endosperm. No significant difference in total recovery was observed between the two varieties.

Table 1. Evaluation of sorghum for dehulling quality (traditional method)[1].

Cultivar	Water used (mL kg^{-1})	No. of strokes to dehull	Time for dehulling (min kg^{-1})	Recovery percentage (%) Dehulled	Brokens	Total
Seredo	200	157	3	71.7	12.3	84.0
Seredo	200	320	6	64.0	13.6	77.6
Seredo	200	455	10	40.0	24.3	64.3
IS 2284	250	160	3	69.0	15.5	84.5
IS 2284	250	302	6	52.8	23.9	76.7
IS 2284	250	500	10	38.6	29.7	68.3

1. Values are means of three determinations.

Mechanical dehulling. In this method, the same trend as in the traditional method was observed. With increased retention time, dehulled grain mass decreased while mass of brokens increased (Table 2). Initially the extent of breakage was less with the TADD compared with the traditional method. This could be due to differences in the applied forces. Hand pounding gives an impact force which leads to more broken grain at early stages of dehulling, while the TADD applies an abrasive action, which favors seed coat removal with less broken grains. However, as retention time increased, the extent of breakage increased, due to more exposure of the floury endosperm. The percentage of brokens was significantly higher with IS 2284 than with Seredo at 4 min retention time. This indicates differences in dehulling quality between the two varieties.

Sensory evaluation of *injera*

Traditional dehulling. Undehulled grain gave poor *injera* for both varieties tested. The sensory quality of *injera* for the variety IS 2284 improved as the level of pounding increased. Six minutes of hand pounding was found optimum to

Table 2. Evaluation of sorghum dehulling quality (TADD)[1].

Cultivar	Time for dehulling (min)	Recovery (%) Dehulled grain	Brokens	Total
Seredo	1	89.5	–	89.5
Seredo	2	79.2	3.8	83.0
Seredo	2	62.0	13.3	75.3
Seredo	4	40.0	26.8	66.8
Seredo	5	21.0	33.0	54.0
IS 2284	1	86.2	5.6	91.8
IS 2284	2	67.3	16.0	83.3
IS 2284	3	51.1	25.6	76.7
IS 2284	4	34.6	36.6	71.2

1. Values are means of three determinations, based on 100 g samples each.

produce good *injera* (Table 3). On the other hand, Seredo did not make good *injera* at any level of dehulling (3, 6, and 10 min). The color remained brown, the bitterness persisted, and the general rating was poor at all polishing levels. This result indicated that dehulling quality differences existed among the brown sorghum varieties.

Mechanical dehulling. The *injera* quality from IS 2284 improved with increased retention time (Table 4). At 4 min of dehulling, the *injera* was rated as very good. This quality was obtained at 71% total recovery. The optimum dehulling to obtain good *injera* was 2–3 min of retention time with 83–75% recovery. Dehulling Seredo with a mechanical dehulling device up to 4 min of retention time did not improve the quality of *injera*. Good *injera* was produced at 5 min of retention time, with a total recovery of 54%.

Table 3. Sensory evaluation of *injera* from TADD dehulled sorghum[1].

Variety	Pounding time (min)	*Injera* quality characteristics Color	Eye quality	Underside appearance	Texture	Taste	Aftertaste	General acceptance
IS 2284	0	Reddish	Large scattered	Reddish	Crumby	Sour	Slightly sweet	Poor
IS 2284	3	Reddish	Large scattered	Creamy white	Dry	Sour		Fair
IS 2284	6	Reddish	Small scattered	Creamy white	Dry	Sour	Slightly sour	Good
IS 2284	10	Reddish	Even interlocked	Creamy white	Dry	Sour	Slightly sour	Very good
Seredo	0	Brown	Flat (no pore)	Brown	Sticky	Bitter	Bitter	Poor
Seredo	3	Brown	Flat (no pore)	Brown	Sticky	Bitter	Bitter	Poor
Seredo	6	Brown	Very few	Brown	Sticky	Bitter	Bitter	Poor
Seredo	10	Brown	Very few	Brown	Sticky	Bitter	Slightly bitter	Poor

1. All values are means of three independent determinations.

Table 4. Sensory evaluation of *injera* from TADD dehulled sorghum[1].

Variety	Retention time (min)	*Injera* quality characteristics Color	Eye quality	Underside appearance	Texture	Taste	Aftertaste	General acceptance
IS 2284	0	Light brown	Light scattered	Light brown	Crumby	Slightly sweet	Slightly bitter	Poor
IS 2284	1	Reddish	Light scattered	Reddish	Crumby	Slightly sweet	Slightly bitter	Fair
IS 2284	2	Creamy white	Small scattered	Creamy white	Dry	Sour	Slightly sweet	Good
IS 2284	3	White	Small scattered	White	Soft	Sour	Slightly sweet	Good
IS 2284	4	White	Even interlocked	White	Soft	Slightly sour	Bland	V. good
Seredo	0	Brown	Flat (no pore)	Brown	Sticky	Bitter	Bitter	Poor
Seredo	1	Brown	Flat (no pore)	Brown	Sticky	Bitter	Bitter	Poor
Seredo	2	Brown	Very few	Light	Sticky	Bitter	Bitter	Poor
Seredo	3	Light brown	Very few	Reddish	Sticky	Slightly bitter	Slightly bitter	Poor
Seredo	4	Reddish	Very few	Reddish		Slightly bitter	Slightly bitter	Poor
Seredo	5	Creamy white	Small scattered	White	Soft	Slightly sour	Bland	Good

1. All values are mean of three independent determination.

Composite flour

As indicated above, when Seredo was dehulled for 5 min, the quality of *injera* improved. However, 46% of the grain was lost during dehulling. Composite flour was the other alternative tried. The *injera* prepared from different proportions of composite flour (Seredo mixed with teff) was evaluated by panelists. The results suggested that with high proportion of sorghum, *injera* quality remained poor. However, a 1:1 proportion of Seredo to teff mixture gave acceptable *injera* (Table 5). Nevertheless, as the proportion of teff increased, the *injera* quality improved.

Table 5. Quality assessment of *injera*, prepared from different proportions of Seredo and teff mixtures, as evaluated by different panelists.

Treatment[1]	Color	Eye quality	Texture	Underside appearance	Taste	Aftertaste	General acceptance
T1	Brown	Flat	Sticky	Brown	Bitter	Slightly bitter	Poor
T2	Brown	Very few	Crumby	Brown	Slightly bitter	Slightly bitter	Poor
T3	Light brown	Large scat.	Soft	Light brown	Slightly sour	Slightly sour	Good
T4	Creamy white	Even interlocked	Soft	Creamy	Slightly sour	Bland	Very good
T5	Creamy white	Even interlocked	Soft	Creamy	Slightly sour	Bland	Very good
T6	Brown	Very few	Sticky	Brown	Bitter	Slightly bitter	Poor
T7	Creamy white	Very few	Sticky	Creamy white	Slightly sour	Bland	Fair

1. Key: T1 = Seredo:teff, 5:1; T2 = Seredo:teff, 2:1; T3 = Seredo:teff, 1:1, T4 = Seredo:teff, 1:2; T5 = Seredo:teff,1:5; T6 = 100% whole grain Seredo; and T7 = 100% 4 min dehulled Seredo.

Conclusion

In many cultures, processing sorghum for food begins with the removal of the seed coat, often with laborious pounding by hand. However, high-tannin sorghum varieties have been observed to give low yields when subjected to dehulling due to the predominantly floury nature of their endosperm. There is a tendency of greater kernel breakage and loss of endosperm with time. Alternatively, mixing the undehulled grain with other cereals to make composite flour required a high proportion of the complementing cereal to give a good quality product. Although the product was found to be organoleptically acceptable, the level of tannin present in it needs further investigation.

Future Research Areas

Brown sorghum will continue to be grown in areas where bird and grain molds limit production or reduce quality. Processing techniques to convert these high-tannin sorghum varieties into useful food products will be required. The following research areas are worth looking into:

1. Develop brown sorghum varieties with a sufficiently vitreous endosperm to withstand the mechanical abrasion imparted during manual or mechanical dehulling.
2. Simultaneously study the relationship between the nature of endosperm and chemical composition to processing quality of high-tannin sorghum varieties.
3. Introduce mechanical dehulling devices into brown sorghum-growing areas as a possible step towards better utilization.
4. Further investigation of industrial uses of brown sorghum varieties.

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Annex 1

Taste Panel Evaluation of *injera*

Name ____________________ Date: ____________________ Time: ____________________

Please evaluate the *injera* supplied for the following. Rate each sample separately and assign your rating by making a tick (✓).

Description	1	2	3	4	5
1. *Colour*					
White					
Creamy white					
Reddish					
Light brown					
Brown					
2. *Eye quality*					
Even interlocked					
Small scattered					
Large scattered					
Very few					
Flat (no pore)					
3. *Texture*					
Soft					
Elastic					
Dry					
Crumby					
Sticky					
4. *Underside appearance*					
White					
Creamy white					
Reddish					
Light brown					
Brown					
5. *Taste*					
Slightly sour					
Sour					
Slightly sweet					
Slightly bitter					
Bitter					
6. *Aftertaste*					
Bland					
Slightly sour					
Slightly sweet					
Slightly bitter					
Bitter					
7. *General acceptance*					
Excellent					
Very good					
Good					
Fair					
Poor					

Code (1 = poorest; 5 = best)

General comments, if any.

Sorghum Grain Utilization in Western Africa

L B Olugbemi[1]

Abstract

Sorghum is one of the most important and widely grown cereal crops in western Africa, stretching from the southern Guinea savanna to Sudan savanna zones. Traditionally, it is used for human consumption and livestock feed, but today it is additionally used in the malting, brewing, and baking industries. Some of the local foods made from sorghum grain are described. Suitability and defects of sorghum for industrial uses are highlighted, with particular reference to the baking industry.

Introduction

Cereals are the most widely cultivated crops, consumed in large amounts worldwide. Sorghum and pearl millet, because of their wide adaptation, are the most widely cultivated and consumed cereals in western Africa. In Nigeria, for example, sorghum occupies over 25% of the total land area under cereals, and together with pearl millet, accounts for over 60% of cereal grain production in the country (Nwasike and Aba 1986). Sorghum, which is less drought tolerant than pearl millet, is grown extensively in the Sudan and northern Guinea zones.

Utilization

Sorghum grain, as with other cereals, is predominantly carbohydrate and generally low in protein. Apart from wheat, the protein content of most cereals are below 10%, but they are over 70% carbohydrate (Table 1). Generally, the higher their carbohydrate content, the lower are their proteins. Thus, rice grain with the highest carbohydrate content of 80%, is the lowest, 7.2%, in protein while wheat, with the least carbohydrate content (69.1%), is highest in protein (14.0%). It is worth noting that sorghum with a protein content of 8.8% and carbohydrate content of 76.0% occupies a medium position nutritionally. Wheat and pearl millet are superior to sorghum, but rice and maize are poorer.

Cereals are generally deficient in some important amino acids, including lysine and tryptophan, which are required by humans. That is why it is important to supplement cereal-based foods with legumes which, in addition to their high protein content, are good sources of minerals such as calcium and iron, as well as vitamins.

Until recently, almost all the sorghum produced in western Africa, like in other developing countries, was being used for human consumption and livestock feed. Traditional sorghum foods and drinks include *tuwo*, *injera*, various types of porridges and different alcoholic brews. As the developing countries can no longer afford the rising import bills, the young industries must be supplied locally. Consequently, many of our cereals, especially sorghum and maize, have now assumed greater importance in the industrial sector. These cereals are now used for a wide range of products including baby foods, edible oils, syrups, sugars, industrial starch, corn flakes, biscuits, beverages, and a range of baked products. By far, the most important industrial uses of sorghum are brewing and baking.

In this paper, work carried out by the Food Science and Technology Research Programme of the Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria, on sorghum utilization in baking is discussed, following a brief review of the uses of sorghum for traditional foods, baby foods, and in the brewing industry.

Traditional Sorghum-Based Foods

In a recent survey carried out in the northern part of Nigeria by the above research program, it was found that several traditional foods are produced from sorghum. These foods are essentially carbohydrate with a small fraction of

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Table 1. Comparative nutritional values of cereal grains per 100 g.

Cereals	Calories	Protein	Fat	Carbohydrates
Wheat	330	14.0	2.16	9.1
Pearl millet	327	9.9	2.97	2.9
Sorghum	342	8.8	3.37	6.0
Maize	360	8.0	1.07	6.0
Rice	360	7.2	0.48	0.0

Source: Avima Ruder (1985).

proteinaceous legume sometimes added. These include *yarsala* – sorghum pancake (sorghum), benniseed paste (sorghum and benniseed), *miyan karkachi* (karkachi and sorghum), *tuwo-dawa* (sorghum), *rodaleyi* (sorghum, pearl millet, and maize), *kunu zaki* (sorghum, maize, millet or rice), *ngabai kubwa* (sorghum, maize or pearl millet), *burabusco* (sorghum, rice, maize or wheat), and *kunun gaido* (sorghum, rice or pearl millet/groundnut).

Many traditional foods are little known outside their local areas of origin, and there is little effort to promote them. Several reasons can be advanced for this lack of popularity. These include:

(i) **Nonacceptability.** For various reasons, e.g., taste, color, and most importantly, lack of public education and awareness of their nutritive values, some traditional foods are not acceptable to some people.

(ii) **Lack of preservative systems.** Most African traditional foods do not keep well. They are usually meant for consumption within a day or two of preparation. Since most people do not have access to refrigeration, it is highly desirable to develop some preservative methods.

(iii) **Traditional beliefs.** Certain crops are regarded by some African tribes as sacred and must only be eaten during ceremonial functions. Such beliefs limit the spread and usage of the crop, even though the product is highly nutritious.

Weaning Foods

The primary components of infant foods should consist of carbohydrates 43–81%, protein 5.5–36.1%, fat 2.9–7.1%, and fibre 0.3–2.5% (Olugbemi and Aluko 1989). The nutrient compositions of some selected commercial infant foods are shown in Table 2.

The main source of carbohydrate used for this purpose in most tropical and subtropical countries are sorghum, maize, and millets. The carbohydrate component may originate from a single cereal or from a mixture of cereals.

Sorghum is considered a coarse grain due to the presence of an outer layer of fibrous bran or seed coat. During the process of dry milling, the bran usually gets mixed with flour, thus reducing the palatability of the product. Improvement in palatability involves the removal of the outer layers to reduce the coarse feeling to the taste. It is, therefore, considered necessary to remove the outer layers by a separate decortication process before milling.

Table 2. Average composition of selected infant foods (per 100 g powder).

	Name of product		
Component	Lactogen	Similac	Cerelac
Protein	21.6	11.4	15.5
Fat	19.0	27.6	9.0
Carbohydrates	51.6	55.8	67.4
Ash	4.8	3.0	3.3
Moisture	3.0	2.2	2.5

Source: Olugbemi and Aluko (1989).

The low nutritional quality of sorghum is a product of several parameters such as: low levels of lysine, threonine, and tryptophan; higher levels of prolamin and leucine; the positive correlation between protein or prolamin and leucine; inverse correlation between protein and lysine; and presence of phenolic compounds and the coarse nature of the grain. The high prolamin content decreases the level of lysine in the protein. The nutritional value of sorghum-based foods can be improved by supplementing with lysine-rich foods such as grain legumes and oilseeds. The nutritive quality of sorghum grains can also be improved by malting as noted by Wu and Wall (1980), who reported an increase in the protein content of the grain from the 3rd to the 10th day of germination.

Porridge in its different forms is a very popular African diet. In Nigeria, a form of porridge, prepared from wet-milled fermented cereals, is referred to as *ogi*. The most commonly prepared *ogi* are those made from maize or sorghum. As noted with sorghum-*ogi*, the starch, protein, fat, ash, and soluble sugar contents vary with the type of sorghum cultivar used (Akingbala et al. 1981). In order to improve the protein content and amino acid composition of cereal-based *ogi*, a composite *ogi*, comprising a mixture of cereal and legume, has been developed (Akinrele et al. 1970, Oniwinde and Ankinrele 1973). An example is soy-*ogi* comprising 70 parts of cereal grain and 30 parts of soya. The resulting *ogi* has been reported to contain up to 20% protein compared with a low level of 6–12% contained by unblended cereal *ogi*.

Sorghum in Brewing Industry

In western Africa, maize and sorghum are both used for the production of malt for the brewing industry, but sorghum has proved more successful. In Nigeria, the success with sorghum was a result of the release of sorghum variety SK 5912 (SAMSORG-17) by the Institute for Agricultural Research, Ahmadu Bello University, Zaria. In terms of the important malt characteristics such as diastatic activity, sorghum malt compared very favorably with barley malt. In addition to SK 5912, the white-grained sorghum variety *farafara* has been found suitable. According to Ogundiwin et al. (1989), sorghum malt could be used for 100% production of acceptable commercial beer. There are, however, several problems associated with the production of beer from sorghum. These include low level of B-amylase, low extract yield and soluble proteins, high polyphenols, long mashing process, and high malting losses. In order to overcome some of these problems, concerted efforts must be made by researchers to produce suitable cultivars for brewing.

Sorghum in Baking Industry

In order to reduce wheat importation bills of the developing western and central African countries, the Food Science and Technology Research Programme of IAR/A.B.U., Zaria, Nigeria, in collaboration with the West and Central African Sorghum Research Network, has carried out extensive studies on the development of technology for the production of acceptable wheat/sorghum composite bread and confectioneries.

Formulation of wheat/sorghum flour

After milling and sieving (about 120 mesh), three levels of substitutions by sorghum were formulated for composite bread productions as follows:
(i) 70% wheat + 30% sorghum.
(ii) 60% wheat + 40% sorghum.
(iii) 50% wheat + 50% sorghum.

Formula and procedure

Flour - 100%
Sugar - 10%
Fat - 1.6%
Salt - 1.1%
Water - Variable

In order to produce a loaf of bread of comparable size to one made with 100% wheat flour, it was necessary to increase the quantity of wheat/sorghum composite flour, depending upon the level of substitution by the nonwheat flour, as shown below:

100% wheat flour	- 170 g
70/30% wheat/sorghum	- 230 g
60/40 wheat/sorghum	- 240 g
50/50 wheat/sorghum	- 250 g

Procedure

Each mixture was made into dough by the bulk fermentation method. All the ingredients were added together at once and mixed at high speed in a Kenwood Mixer for 15–20 min. The dough was left to ferment in the mixer until it almost doubled its initial volume. This was followed by 'knocking back' of the dough, scaling, and moulding. The moulded doughs were then put in oiled baking pans and allowed to proof to maximum volume. The doughs were then baked in an electric oven at temperatures ranging from 230–250°C. After the loaves had cooled, their volumes were determined by amaranthus seed displacement and expressed as a ratio of the mass of the loaf, i.e., Specific Loaf Volume (SLV).

Table 3. Effects of sorghum varieties and levels of substitution with sorghum on quality of wheat composite flour bread.

Flour	Specific Loaf Volume (cm^3g^{-1})	Drop in Specific Loaf Volume (%)	Appearance	Texture
Control (100% wheat flour)	3.10	-	Very smooth golden brown crust. No cracks.	Fine
30% substitution with sorghum				
Wheat + FFBL	2.32	30.1	Smooth golden brown crust. No cracks.	Fine
Wheat + L 533	2.16	34.7	Smooth golden brown crust. Crack along one side.	Fine
Wheat + L 181	2.22	32.9	Smooth golden brown crust. Crack along one side.	Contained one large hole
Wheat + L 1499	2.33	29.6	Smooth golden brown crust. No cracks.	Fine
Wheat + SK 5912	2.05	38.1	Slightly rough and golden brown crust. No cracks.	Open with large holes.
Wheat + Mori	2.19	33.8	Smooth golden brown crust. No cracks.	Fine
Mean		33.2		
40% substitution with sorghum				
Wheat + FFBL	1.92	42.0	Dull brown and slightly rough crust. No cracks.	Fine
Wheat + L 533	2.00	39.6	Dull brown and slightly rough crust. Few cracks along one side.	Fine
Wheat + L 181	2.30	30.5	Dull brown and slightly rough crusts. Few cracks along one side	Fine
Wheat + L 1499	1.95	41.1	Dull brown and slightly rough crust. Few cracks along one side.	Fine
Wheat + SK 5912	2.25	32.3	Dull brown and slightly rough crusts. Few cracks along one side	Fine
Wheat + Mori	2.00	39.6	Brown and slightly rough crust. No cracks.	Fine
Mean		37.5		
50% substitution with sorghum				
Wheat + FFBL	2.23	32.6	Rough, pale crust. Few cracks on the surface.	Fine
Wheat + L 533	2.17	34.4	Rough, pale crust. Few cracks on the surface.	Fine
Wheat + L 181	2.15	35.0	Smooth, pale crust. No cracks.	Fine
Wheat + L 1499	2.15	35.0	Smooth pale crust. Few cracks on one side.	Open with small holes
Wheat + SK 5912	2.18	34.1	Very rough, pale crust. Lots of cracks on the surface.	Open with small holes
Wheat + Mori	NA[1]	NA	Very rough, pale crust but no cracks.	Open with large holes
Mean		34.2		

1. NA = Not available.

Baking quality of composite bread

The results generally showed that the higher the level of substitution by sorghum, the lower the SLV of the resulting bread. Thus, the mean reduction in SLV at 30% substitution level was 33.2%, at 40% it was 37.5%, and at 50% substitution level it was 34.2% (Table 3). At 50% level of substitution by sorghum, the bread produced was still acceptable, although it was generally of a lower quality.

In another study, the effect of wheat varieties on wheat-sorghum composite bread was investigated. Three wheat varieties, Florence Aurore 8193, Pitic × GB Yarta, and Sonora 63, which are adapted to Nigerian conditions, were compared with a commercial wheat flour, Golden Penny. Parameters measured included water absorption, time of final proof, yield of dough, SLV, and Total Bread Scores (TBS).

The SLV of the 100% commercial flour was 3.77 $cm^3 g^{-1}$ and the highest, followed by F. Aurore 8193/sorghum composite bread (70/30%) which gave an SLV of 3.21 $cm^3 g^{-1}$ (Table 4). The least was Sonora 63/sorghum composite bread with SLV of 2.81 $cm^3 g^{-1}$. Consequently, the TBS of the bread from commercial flour was the highest (90%), followed by F. Aurore 8193/sorghum composite bread (81%) and least by Sonora 63/sorghum bread (70%).

Absence of gluten in nonwheat flour, such as sorghum flour, is responsible for lowering the quality of wheat/sorghum composite bread. Addition of gluten extract would improve the quality of composite bread, but this is uneconomical. Another study was therefore undertaken to investigate the effect of pentosans on the quality of wheat/sorghum composite bread.

The high concentration (up to 12%) of pentosans in the endosperm cell walls of rye grain makes it one of the important sources for industrial extraction of pentosans. Breads baked from sorghum substitution varying from 30–100%, to which 2 or 4% pentosans had been added were compared with those to which no pentosans had been added. At 30% sorghum substitution, addition of pentosans had little or no effect (compare SLV of 3.39 $cm^3 g^{-1}$ for no addition to 3.46 $cm\ g^{-1}$ for addition of 2%), but at 50% sorghum substitution, addition of pentosans gave good and acceptable bread (Table 5).

In a recent study, the economics of wheat/sorghum composite bread was assessed. Wheat variety Sitte Cerros (SAMWHIT-5) and sorghum variety *farafara* at 30% level of substitution were used. The formula used is as follows:

Flour - 100%
Sugar - 10.0%
Salt - 1.0%
Fat - 1.0%
Dried yeast - 1.5%
Water - Variable, usually 65–70%

Table 4. Effect of wheat varieties on the quality of wheat/sorghum composite bread.

Flour composition	Absorption of water (%)	Final proof (min)	Yield of dough (%)	Specific loaf volume ($cm^3 g^{-1}$)	Total Bread score (TBS) (%)	Reduction in TBS (%)
100% Golden Penny (wheat)	70	38	167.3	3.77	90	-
70% Golden Penny + 30% sorghum	70	30	170.2	2.96	74	18
70% F. Aurore 8193 + 30% sorghum	75	35	180.5	3.21	81	10
70% Pitic × GB Yarta + 30% sorghum	74	30	179.4	2.96	74	18
70% Sonora 63 + 30% sorghum	73	30	177.3	2.81	70	22

Table 5. Influence of pentosans on the quality of wheat/sorghum composite bread.

	Level of sorghum substitution					100% commercial wheat flour (control)
	-------- 30% --------		50%	70%	100%	
Addition of pentosans	0%	2%	4%	4%	4%	
Absorption of water (%)	72	75	75	85	85	70
First fermentation (min)	30	30	30	20	20	100
Final proof (min)	42	33	32	25	41	66
Specific volume (cm^3 g flour^{-1})	5.45	5.60	4.85	4.00	Not acceptable	4.87
(cm^3 × g loaf^{-1})	5.39	3.56	2.85	2.38	Not acceptable	3.21
Total Bread Score (Max 100)	86	89	70	50	-	87
Remarks	Good	Very good	Good	Hard texture	Very hard texture	Good

Production Cost

(i) 70/30% wheat/sorghum flour:

Quantity (kg):
- Wheat flour - 35
- Sorghum - 15

Cost (Naira):

Wheat flour	- 385.00
Sorghum flour	- 96.00
Ingredients	- 88.00
Labour	- 100.00
Miscellaneous	- - 10.00
Total cost:	Naira 679.00

Loaves of bread produced - 150

Revenue from bread produced - Naira 750.00

Profit: 750–679 = Naira 71 per bag (50 kg) flour

(ii) 100% wheat flour

Quantity of wheat flour - 50 kg

Cost (Naira):

Wheat flour	- 550.00
Ingredients	- 80.00
Labour	- 100.00
Miscellaneous	- 10.00
Total cost:	Naira 740.00

Loaves of bread produced - 170

Revenue from bread produced - Naira 850.00

Profit: 850–740 = Naira 110 per bag (50 kg) flour

Owing to the need to increase the quantity of the wheat/sorghum composite flour in order to produce loaf sizes comparable with the control, fewer loaves of bread (150) were produced from composite flour than from pure wheat flour (170). Consequently, the profit margin from wheat/sorghum composite bread seems less than that of pure wheat. This, of course, depends upon the relative costs of wheat and sorghum which change from one time of the year to another.

One of the major shortcomings of bread made from wheat/sorghum composite flour is increased crumbling. The bread 'breaks' easily, especially after the first day of its baking. In order to improve its binding characteristics, a small fraction, 0.5%, of cassava starch flour is incorporated. This makes the composite bread more spongy, with a closer texture, and less vulnerable to crumbling. It, however, further reduces the loaf volume and profit margin of the composite bread, and slightly shortens its shelf life.

Nutritional studies of wheat/sorghum composite flour

Owing to the lower level of sorghum grain protein content compared with that of wheat, the total crude protein content of wheat/sorghum composite bread is lower than that of pure wheat bread. For example, the crude protein contents of wheat/sorghum composite bread at 30% level of sorghum dilution is 11.50% and at 40% level of dilution is 11.15%, compared with 12.71% by pure wheat bread (Table 6). These figures are, however, slightly higher than those of wheat/maize composite bread at 30% level of maize, which contains 10.55% protein and at 40% level of maize which contains 10.19% protein. It is noteworthy that the protein content at 40% substitution by sorghum is higher (11.15%) than 30% substitution by maize (10.55%).

Wheat/sorghum composite flour for snacks

The work in our laboratory has shown that snacks, including puff-puff, rolls, cookies, and biscuits can be produced from wheat/sorghum composite flour with sorghum substitution varying from 30–80%. The formulae used are as follows:

Puff-puff

Composite flour—100%, Sugar—20%, Yeast—3%, and Water—variable and increases with increasing level of sorghum substitution.

Bread rolls

Composite flour—100%, Sugar—16%, Yeast—3%, Salt—1.5%, Fat—3.5%, and Water—variable.

Cookies

Composite flour—100%, Sugar—30%, Fat—37.5–60.5%, and Water—variable.

Biscuits

Composite flour—100%, Sugar—20%, Salt—3.5–7.0%, Fat—35–67%, and Water—variable.

In general, substitution with sorghum up to 50–60% gives good and acceptable snack foods, but at substitution levels higher than 60%, some of the products tend to exhibit a raw sorghum taste with rough, hard, and broken surfaces. In the case of biscuits, sorghum substitution higher than 70% usually produces biscuits which crumble easily, thus creating packaging and transportation problems.

As with composite bread, there are varietal differences among the sorghum types used. The local white grain variety, *farafara*, usually gives better results than the other varieties tested.

Table 6. Crude protein content of wheat and composite flour bread.

Bread sample	Dry matter crude protein (%)
Control (wheat)	12.7
70% wheat + 30% sorghum	11.5
70% wheat + 30% maize	10.6
60% wheat + 40% sorghum	11.2
60% wheat + 40% maize	10.2

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Acknowledgement

I am grateful to the West and Central African Sorghum Research Network for providing funds for parts of this project and for my participation at this workshop.

Highland Forage Sorghum in Kenya: What Prospects?

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Abstract

The role of forage sorghum silage as a basal diet in beef feedlots is well documented in Kenya. Large-scale utilization of sorghum silage in milk production is practised by a few farmers.

An on-going study in Nakuru District, Rift Valley Province of Kenya, has indicated a new potential use for forage sorghum as silage in small-scale dairy production. The study involved farmers with a minimum of 1 ha of land, in agroecological zone 4 and transitional zone 3. The main enterprise on the farms was crop-dairy, using cross-bred cattle for milk production.

Preliminary results indicate that poor awareness about sorghum, lack of cold-tolerant varieties, bird damage, and an uncertain marketing situation were factors that contributed to low adoption of grain sorghum in the past. However, farmers in the study had no previous experience with forage sorghum.

The main feed resource is natural pastures. Attempts to introduce Napier grass failed due to prolonged dry periods. Sorghum efficiently utilizes available moisture during the rainy season and can be ensiled for feeding during the dry season. Average dry matter yield of late-maturing forage sorghum variety E6518 was 14 t ha⁻¹. Forage sorghum may provide an important conserved feed for small-scale dairy enterprises in the semi-arid areas of the country.

Introduction

Land constraints in the high-potential agricultural zones of Kenya have caused migration of people into marginal areas of agricultural production. This trend resulted in subdividing land which was formerly used for beef ranching.

Maize forms an important staple cereal for Kenyans, while Napier grass is an important livestock fodder in high-potential areas. However, under marginal rainfall conditions, these crops are poorly adapted. Attempts to grow them result in frequent crop failures, leading to inadequate human food and livestock feed.

Sorghum and millets are well adapted to semi-arid conditions of the tropics by virtue of their heat and drought tolerance. In Kenya, sorghum and millet occupy only 4% of the suited agroecological zones and 18% of the most highly suited production zones (Anonymous 1986). Therefore, a vast potential for expansion exists, given a comprehensive pricing, marketing, and utilization policy.

Adapted forage sorghums have been identified for the semi-arid highlands of Kenya (Arkel 1978). These may be grown within agroecological zone UM5-6, which is transitional within an altitude range of 1500–2100 m above sea level. The merits of forage sorghum as an alternative feed for feedlot finishing of steers was evaluated by the UNDP/FAO Kenya Government Beef Industry Development Project in 1976. Its advantage over maize lay in its drought resistance, waterlogging tolerance, high dry matter yield per unit area, feeding value which ranged between 90 and 105% that of maize, and low competition as a human food. It is also able to use rainfall effectively during a 7–9 month growing period (Arkel 1976).

Under conditions at the KARI-Beef Research Centre, Nakuru (Lanet), variety E6518, a purely forage sorghum, and E1291, a dual-purpose sorghum type outyield maize in years of low rainfall. Average yields of 22 t dry matter (DM) ha^{-1} for E6518 and 17 t DM ha^{-1} for E1291 have been obtained against 5.5–9 t DM ha^{-1} for maize. However, adoption rates among small- and large-scale farmers has been negligible. This may be attributed to lack of awareness of the potential of sorghum as a forage crop.

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In order to diagnose the causes of nonadoption of forage and dual-purpose sorghum within the semi-arid highlands of Kenya, a study was undertaken based on the farming systems approach. This approach was chosen as it has been shown to yield higher technology adoption rates (Anon 1986).

Objectives

1. To identify constraints to adoption of highland sorghum cultivation and prioritize research to alleviate these constraints.
2. To obtain farmers' reaction to crop husbandry practices developed for forage and dual-purpose sorghum.
3. To identify target farmers for the highland sorghum.
4. To measure dry matter yield obtained from farmers' fields.

Materials and Methods

The study was conducted on 12 farms in Nakuru District in Rift Valley Province. Farmer selection was done by extension officers in the Ministry of Livestock Development and Farming Systems (K) Ltd., a nongovernmental organization. Selection was based on agroecological location of farms, which was ecozone 4 or transitional zone 3. Another criterion was that the farmers should be willing to actively participate by providing at least 0.1 ha of land and labor to grow sorghum and undertake management of the crop as advised. They should also be willing to have their farms used as demonstration sites during the crop growth period.

Land preparation

Land was prepared by individual farmers according to their normal practices. Seeds of forage and dual-purpose sorghum varieties, E6518 and E1291, were each alloted 0.05 ha for cultivation.

Diammonium phosphate (18:46:0 NPK) fertilizer was supplied to the farmer, and applied to the planting furrows at a rate of 100 kg ha^{-1}. The recommended row spacing was 60 cm. After thinning, the between-plant spacing was 20 cm for both varieties. The seeds were treated with periminphos powder at a rate of 50 gm per 90 kg of seed. Thinning was done 2 weeks after emergence. No pesticides were recommended.

Monitoring and evaluation

Evaluation of farmers' socioeconomic circumstances, crop and livestock production practices, and their expectations and limitations was done by using a questionnaire. Interviews were carried out by the researchers during visits to the farms.

Monitoring tours to the farms were conducted every 2 weeks for the first 2 months, and thereafter once every month. During these tours, advice was given to the farmers on relevant crop management procedures, as determined by stage of crop growth. Interviews of farmers on their perception of the crops, activities, problems, and suggestions on solving perceived problems were conducted.

Farmers' field days were organized in consultation with the farmers and other collaborators. Demonstrations were based on crop utilization methods. These were organized when the crops were between milk and hard dough stages. Dry matter yield was estimated by calculating the volume of trench silo filled with well-compacted silage material. One cubic meter of silo carries an average of 500 kg of well-compacted silage. This is multiplied by 25% to obtain dry matter yield ha^{-1} (Irungu 1983). Grain yield was measured by the farmers and reported as number of 90-kg bags harvested.

Results and Discussion

Farmer constraints

Factors limiting both dual-purpose and forage sorghum cultivation within the study area were cited as:

1. Lack of awareness of the potential for the utilization of sorghum as a livestock feed. As a food crop, farmers' awareness was restricted to the use of sorghum grain in making traditional beer, *ugali*, and *uji*. This has been considered to be a factor contributing to the low demand for sorghum in formal markets.
2. Lack of high-yielding, cold-tolerant varieties. Where farmers attempted to grow grain sorghum, available seeds were either Serena or Seredo from retail outlets. These are not cold tolerant, hence do not set seed under cold environments.
3. High bird damage was prevalent where farmers preferred white sorghum. Consequently, low grain yields were obtained.
4. Low market prices and limited market outlets for grain sorghum.
5. High labor cost for sowing in rows, thinning, and bird scaring.
6. Prohibitive cost of polythene sheet recommended for ensiling.

Farmers' reactions to crop husbandry recommendations

Most of the farmers in the study observed that thinning to maintain the recommended plant population was a laborious and costly management aspect. Only one farmer used the thinnings as a mulch for tomatoes, and hence did not consider it a disadvantage.

Suggestions were made for the manufacture of simple and affordable precision planters for better control of seed rate. The provision of such tools and equipment may be an important factor in increasing sorghum cultivation.

Other areas of concern for the farmers were (a) suitability of the crop for use in intercropping systems, and (b) the possibility of using herbicides to reduce labor costs.

Target farmer

The study identified the target farmer as one with not less than 1 ha of land, and having one to three dairy cattle, which were fed on a semi-zero grazing system. Milk production was viewed as an important source of income. Positive response on the use of forage and dual-purpose sorghum for silage was obtained from the test farmers and others who attended the field days. It was perceived as a crop which could alleviate the dry-season feed shortage when conserved as silage. Most of the response was biased towards the use of both varieties as livestock feeds.

Crop yields

Grain yield of variety E1291 obtained on farmers' fields ranged from 0. 5 t ha^{-1} to 2 t ha^{-1}. E1291 yields on average 3–4 t ha^{-1} of grain (Arkel 1978). Under good rainfall and management, grain yields of up to 6 t ha^{-1} have been obtained (Ouma, personal communication). Low yields of some farmers in this study could be explained as effects of delayed thinning causing higher population densities, delayed weeding due to labor constraint, and low rainfall.

Dry matter yield of variety E6518 ranged from 8 to 20 t ha^{-1}, with an average of 14 t ha^{-1}. This could be explained by factors similar to those which affected grain yield. Mean dry matter yields of 22 t ha^{-1} have been achieved at the KARI-Beef Research Centre, Nakuru (Lanet).

A dairy cow with an average mass of 400 kg consumes silage dry matter at a rate of 2.5% of its body mass (Onyango 1986) or 10 kg DM per day. On 0.1 ha of forage sorghum, a farmer would produce approximately 1.3 t of silage, giving a 3% allowance for ensiling losses. This would be sufficient feed for one animal for 130 days. The normal duration of the dry period in this zone is 90 days. Forage sorghum is therefore able to provide sufficient dry season feed to ensure cattle survival and to prevent losses in production.

Conclusion

Preliminary results indicate that the priority of farmers within this agroecological zone is to obtain sufficient feed to maintain their dairy cattle throughout the year. Forage sorghum is appropriate for this situation because of its high dry matter production and drought resistance. However, agronomic constraints requiring attention include the development of simple and affordable hand tools for precision sowing. This will reduce costs incurred for thinning to maintain correct plant densities for optimum dry matter yields. Studies on intercropping will also enhance adoption rates. Underutilization aspects, including the cost-benefit ratio of small-scale silage making requires evaluation, as this will be an important determinant of adoption or lack of adoption of forage sorghum.

In subsequent studies, it is proposed to increase the number of farmers, use formal survey methods to obtain a better diagnosis of farmers problems and priorities, and thereby form a strong basis for farmer-oriented research in the semi-arid highlands.

Acknowledgement

The funding of the project by USAID through KARI is acknowledged. All the technical staff of Beef Research Centre, Extension Officers of the Ministry of Livestock Production, Nakuru District and Farming Systems (K) Ltd., and the invaluable contributions of the participating farmers is highly appreciated.

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Changing Sorghum Production Practices in the Gezira Scheme in the Sudan

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Abstract

Research on sorghum improvement has been continuing for four decades in the Sudan, in order to develop high-yielding varieties and to determine optimal levels of inputs and practices. Several improved varieties and optimal practices have been recommended for sorghum farmers. The recommended package has been verified and demonstrated in farmers' fields in the Gezira scheme for several seasons and proved to be superior to traditional practices. However, adoption of these recommendations appears to be quite slow. This study examined adoption of sorghum recommendations by farmers in the Gezira scheme. A sample was randomly drawn from two groups of farmers, former participants in demonstration plots and nonparticipants. This distinction was made in order to test the effectiveness of the demonstration program. The role of different socioeconomic and institutional factors on farmers' adoption of the recommendations was examined.

Results showed that the recommendations were not well adopted by farmers, especially the mechanical components of the package. Some factors for this could be the nonavailability of inputs, due to the absence of private markets, especially for fertilizers and seeds, or the inability of the government to secure adequate amounts of these inputs. Moreover, most farmers could not afford to use fertilizers because sorghum production is not financed by the administration.

The study showed that there was statistically significant difference in response to the recommendations between participants and nonparticipants, and that adoption rates of participants were higher than those of nonparticipants. This is an indication that the extension message was not equally received by all farmers and might suggest the need to improve this program so that several farmers are exposed to the recommendations. Also, it was found that socioeconomic factors, and farmers' age and education could affect farmers' adoption behavior. The study revealed that younger and more educated farmers adopted the recommendations better than older and less educated farmers. The extension program should be improved to minimize the effects of these factors.

Introduction

Sorghum is the main cereal crop produced and consumed in the Sudan, especially in rural areas. Sorghum is sometimes exported, thus generating foreign exchange. A potential demand for sorghum is as feed for livestock. The livestock production system is still primitive and needs to be improved to meet the increasing demand for animal products, and sorghum appears to be the viable source for feed. Another potential demand for sorghum is for use with wheat in composite flour, a project which has been proved to be technically feasible.

Sorghum is produced all over the country under all farming systems. However, the mechanized rainfed sector produces the highest share of the country's total production. In recent years, because of drought conditions and unstable rainfed production, the government has been trying to increase irrigated sorghum production to ensure food security. The irrigated sector contributes 10–40% of total sorghum production, depending on the level of rainfed production. Within the irrigated sector, the Gezira scheme is the biggest sorghum producer, and it contributes up to 65% of irrigated sorghum.

Despite its importance as the main food crop, sorghum receives the least attention from the Gezira administration and from farmers. Other than irrigation water, sorghum receives no inputs or services from the administration. Further, tenant farmers invest little on sorghum because they are financially incapable and/or the crop is treated as a

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subsistence crop. As a result, production methods remain primitive and yields are low. The main factors that contribute to low yield are: the use of traditional low-yielding varieties, inadequate land preparation, use of little or no fertilizers, and no proper weed control (Elobeid and Farah 1990).

New Technologies

The government programs aim to increase sorghum production by expanding the cultivated area and by improving yield. Research on new technologies and improved practices has been conducted by the Agricultural Research Corporation (ARC) jointly with the help of concerned international research centers, foreign governments, and organizations. These research programs have developed and demonstrated packages of new technologies and improved practices that could increase yield of the crop.

Research has been conducted for the last four decades in order to develop improved varieties and to determine optimal levels of other inputs and practices. The components that have been recommended for irrigated sorghum include:

1. Several improved cultivars, which outyield the traditional varieties two-to-three fold, such as Gadam El Hamam, Dabar, and White Dwarf Milo.
2. The first sorghum hybrid, Hageen Durra-1 (HD-1), released for commercial production in 1983, outyields improved varieties by 37–90%.
3. A seed rate of 7.14 kg ha^{-1}.
4. Addition of 190 kg ha^{-1} of urea to be broadcast before planting.
5. Addition of 95 kg triple super phosphate (TSP) ha^{-1}, if necessary.
6. Adequate land preparation, including plowing, harrowing, leveling, and ridging. (Elobeid and Farah 1990).

Verification and demonstration of these packages have been conducted on farmers' fields for several years and found to be superior to traditional practices (Farah and Faki 1990). Although agronomic data and economic evaluation suggest that the improved package is a profitable alternative, adoption of these practices by farmers appears to be quite low. It is hypothesized that factors limiting farmers' adoption of the improved package are: (i) farmers cannot meet the higher-input requirements of the new technologies, particularly, fertilizers and credit, and (ii) the current marketing and credit policies are not conducive to farmers' adoption of the recommended package.

The objective of this study is to examine how well these new technologies have been accepted and adopted by farmers and what the factors that determine farmers' adoption behavior are.

Data and Methodology

The data used in this study were obtained from a field survey of sorghum farmers for the 1990/91 rainy season. The survey was conducted in two parts of the Gezira scheme, south and central. A sample of 100 tenant farmers was randomly drawn from two groups, former participants in demonstration plots and nonparticipants. The stratification was done in order to test the effectiveness of the extension program. To test the effect of socioeconomic factors and farmers' characteristics such as age, education, and farm size, smaller categories were defined. The sample was categorized into three educational groups: illiterate, elementary education, and higher than elementary. The sample was divided into two age groups, 40 years or less, and more than 40 years. The farm size groups were the existing tenancy sizes, the big tenancy and small tenancy. The results of the survey are summarized and discussed in the following sections.

Adoption of Recommendations

The survey results, in terms of the adoption rates of the individual components of the recommended package, are presented in Table 1. Except for hand weeding and ridging, which are traditionally practised by farmers, other recommendations were poorly adopted.

The biological components of the recommended package were adopted by 27% for HD-1 and by 42% for the other improved varieties. Irrespective of the cultivar used, farmers tended to use higher than the optimal seed rate, with 64% of the farmers using higher seed rates and only 9% using the recommended seed rate. Except for ridging, which was adopted by 87% of the sample, other mechanical recommendations such as deep plowing, harrowing, and leveling, were not adopted or were adopted by only one or two farmers. The recommended chemical fertilizer, urea, was adopted by 53% and TSP by 27%. For urea, 20% adopted the optimal dose, while 72% used less and 8% gave more than the recommendation. All farmers in the sample adopted hand weeding; 96% weeded their crop once and 4% weeded twice.

Table 1. Adoption of recommendations for improved sorghum production practices by Gezira farmers.

Factor	Adoption rate (%)
Biological components:	
HD-1	27
Improved varieties	42
Recommended seed rate	9
Mechanical components:	
Deep plowing	0
Disc harrowing	2
Leveling	1
Ridging	87
Chemical components:	
Nitrogen fertilizer	53
Recommended N dose	20
Phosphorous	27
Hand weeding:	100
One weeding	96
Two weedings	4

Explaining Adoption

For farmers to adopt any new technology, three necessary conditions must exist. These are:

1. The new technology must be more profitable than the old alternative.
2. The new technology and its profitability must be known to farmers.
3. The new technology should be available to farmers.

Profitability of any new technology or an improved practice is one of the main prerequisites for its recommendation.

Farmers' knowledge about new technologies is the responsibility of the extension department in charge of the scheme. Jointly with ARC and Global-2000, the Sudan Grain Board (SGB) has been conducting a demonstration program on farmers' fields. The effectiveness of the program can be measured by the degree of farmers' receptiveness and adoption of the recommendations.

Table 2 shows adoption rates of sorghum recommendations by former participants and nonparticipants. HD-1 was adopted by 51% of the participants and 12% of the nonparticipants. The adoption rate for urea was 71% and that for TSP was 61% for the participants, and 42% (urea) and 16% (TSP) for the nonparticipants. It is evident that more former participants adopted the recommendations than did the nonparticipants. This difference was tested statistically, using chi-square and proved to be significant for all components (Table 2). It is expected that participants would adopt more and/or not adopt earlier than nonparticipants, yet the difference should not be substantial if the message is getting through to all farmers. The demonstration program is conducted with the intention of extending the recommendations to all farmers, using the participants as the means. However, 68% of the nonparticipants indicated that they have no knowledge about these demonstrations or the factors demonstrated in them. Therefore, there may be need to improve the demonstration program so that a cross section of farmers are exposed to the recommendations.

Socioeconomic factors and farmers' characteristics such as education and age can, in a way, affect the degree of farmers' receptiveness to the extension program, and their adoption behavior. The response of the different educational and age groups in terms of adoption of recommendations was measured and found to be statistically significant for some recommendations. For example, the adoption rates of HD-1 by illiterate farmers was 14%, it was 28% by the elementary-education farmers, and 39% by the higher-than-elementary-educated farmers. Adoption rates of HD-1 by different age groups were 44% by the young farmers and 20% by the old farmers. A chi-square test showed that educational and age differences were statistically significant. The justification might be that adoption of HD-1 (a new variety) requires a change in taste and consumption habit in which case educated and younger people are more likely to respond quicker than less educated, older people. The same result was observed in the adoption of urea, that is, there was statistically significant difference in the response of the age groups. The implication is that treating these different groups equally would result in the observed behavior of differential responses and adoption rates. Therefore, the extension program should be designed to minimize the effect of these differences.

Availability of all recommended components and timeliness of optimal improved practices are necessary to attain the maximum possible benefits of the package. Nonavailability of technologies is well reflected in the adoption rates of most of the recommendations, especially mechanical operations.

The mechanical components were not adopted because of the nonavailability of machinery and finance. In addition, it appears that farmers had not comprehended the recommendations, as half of them indicated that ridging alone was

Table 2. Adoption of sorghum recommendations by two farmers' groups—former participants in demonstration plots and nonparticipants.

Factor	Partici-pants (%)	Non-partici-pants (%)	Signifi-cance (*P* value)
Cultivar:			
HD-1	51	12	
Improved	40	46	0.00003
Traditional	9	42	
Fertilizer:			
N fertilizer	71	42	0.0062
Optimal N dose	36	4	
<Optimal N dose	48	96	0.0009
>Optimal N dose	16	0	
P fertilizer	61	16	0.0000

sufficient, and that there was no need for other operations. Therefore, more work needs to be done to demonstrate to farmers the agronomic superiority and profitability of these technologies. HD-1 was adopted by 27% of the sample. HD-1 seed production is a highly technical task and undertaken by the SGB. However, the amount of seeds produced was insufficient to reach all farmers. All non-adoptors of urea (47%) attributed this to the non-availability of the fertilizer. The adopters attributed the use of suboptimal doses to financial difficulties (26%), and to the nonavailability of the fertilizer itself (75%). The only other formal fertilizers market is the Agricultural Bank of Sudan but the prices are more than twice those of the SGB. In addition, farmers have to pay in cash and travel long distances, as there is only one branch in the whole scheme. With sorghum receiving no credit from the Board, most farmers could not afford using fertilizers. Therefore, securing inputs is a matter of physical availability and purchasing power. For sorghum, farmers' purchasing power is a reflection of their own financial sources. The tenancy size was used as a proxy for their own financial sources assuming that farmers with big tenancies are financially better off than those with small tenancies. Adoption rates of urea by farm size group were 47% by small tenants and 73% by big tenants. Likewise, adoption rates of TSP were 21% by small farmers and 42% by big tenants. This difference was tested and found to be statistically significant. The implication is that development of private input markets should be encouraged so that farmers can get adequate inputs at the right time. However, securing finance is equally important, especially for needy farmers.

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Sorghum Production in Rainfed Agriculture: Current Production Practices and Improvement Possibilities

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Abstract

Sorghum is the main cereal crop produced and consumed in the Sudan. It is the staple food and is produced under all farming systems. The mechanized rainfed subsector is the main sorghum producer, and contributes up to 75% of the country's total production. Since its's establishment in the mid-1940s, this system has witnessed substantial area expansion. However, yields are variable and low, relative to the potential. Although variability in amount and distribution of rains is the main factor causing yield variability, farmers' practices also contribute to low and variable yields, when they do not adopt steps to combat and minimize natural and environmental risks.

The objective of this study was to examine farmers' current production practices and determine the most important factors that contribute to yield variability. A field survey was conducted in the Gedarif area, a major production site. Regression analysis was then used to examine the relative contribution of different factors to yield variability.

Compared with the recommendations, the survey results indicated that there is a tendency towards sorghum monocropping, use of traditional early-maturing varieties, late planting, low seed rate, and no pest control. The regression results indicated that the most significant factors that contribute to yield variability are sowing date, pest incidence, seed rate, and site. The implication is that farmers' failure to follow the recommendations in sowing time, seed rate, and pest control, caused a substantial reduction in yield. The effect of site can be controlled by defining smaller recommendation domains and designing practices that minimize the site effect.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the main field crop produced and consumed in the Sudan. It is the staple food and produced all over the country under all farming systems. The rainfed subsector is the main producer of sorghum, and in some years, it contributes as much as 89% of the country's total production. Within the rainfed subsector, two systems exist. These are the mechanized production system and the traditional production system. The traditional system consists of small subsistence family farms with little or no use for modern inputs. The mechanized subsector consists of large commercial farms of 1000–1500 feddans each (420–630 ha). This system is characterized by the use of machinery in land preparation and threshing and little or no use of other modern inputs. The mechanized subsector is the major sorghum producer, and it contributes as much as 75% of the country's total production. Other crops produced are sesame, pearl millet, and cotton, but sorghum is the major crop and it occupies up to 87% of the cultivated area. The mechanized sector is located in four states, the Eastern State (Gedarif area), the Central State (Damazin area), the Upper Nile State (Rank area), and Kordofan State (Habiela area). Although the four areas differ in the amount and distribution of rain, farmers' practices are more or less the same.

Since its establishment in the mid-1940s, the mechanized rainfed sector witnessed substantial area expansions. However, yields are variable and generally low, relative to the potential. Although variability in amount and distribution of rainfall is the main factor causing instability of yield, poor cultural practices by farmers also contribute to low and variable yields.

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The objectives of this study were:

1. to examine current sorghum production practices in the mechanized rainfed sector; and
2. to determine the most important factors that contribute to yield variability.

The study used the Gedarif area, the most important mechanized area, to represent the whole subsector.

Data and Methodology

The data used in this study were obtained from a field survey of sorghum farmers in the Gedarif area for the 1991/92 rainy seasons. A sample of 50 farmers was randomly drawn from northern and southern Gedarif areas. Half the sample was from northern Gedarif and the other half was from the southern part of the area. The stratification was done in order to examine the effect of environmental differences, particularly rainfall. The southern part is known to have relatively higher rainfall. Farmers were interviewed and asked about their production practices. Farmers were also asked their opinion on some production issues and the problems they face. The data were then used to calculate frequencies and other descriptive measures. Finally, a regression analysis was used to relate yield to different factors and practices.

Farmers' Practices

Cropping pattern (Rotation)

Sixty-one percent of the farmers indicated that they do not follow specific rotation or crop sequence. The rest (39%), although they thought they followed a rotation, actually follow similar practices. Farmers do grow crops other than sorghum, such as sesame and pearl millet, but these are at a very low level. Forty-two percent of the farmers grew sorghum in the same area for three consecutive years. Therefore, there is a tendency of sorghum monocropping. With no fertilization, this practice will most likely result in soil fertility loss and ultimately a decline in yield over time.

Varieties

Sixty percent of the farmers sampled grew traditional and early-maturing varieties (Feterietas). Very few farmers grew improved cultivars.

Seed rate

The seed rate given by the sample ranged from 2 to 24 kg ha^{-1} with an average of 7 kg ha^{-1}.

Land preparation

All farmers in the sample used disc harrowing for seedbed preparation. However, 80% of the sample did it once and sowed in the same operation. Nine percent gave two disc harrowings and 11 % gave three harrowings.

Sowing date

Only one farmer (2%) sowed his sorghum in the second half of June, 71% sowed in July and 27% in August. Fifty-five percent of the sample needed to resow. Because sowing was late, resowing extended up to September.

Hand weeding

All farmers practised hand weeding; 37% did it once, 56% did it twice, and 7% hand weeded three times.

Pest incidence

Sixty-seven percent of the sampled farmers reported pest incidence in their sorghum crop. Specifically, 56% reported the presence of the American bollworm, 52% reported locust, and 7% reported birds. No controls were practised.

Harvest operation

All farmers practised the same harvest operations, i.e. hand cutting of heads and feeding stationary threshers.

Prospects of Yield Improvement

Research has been conducted to develop suitable technologies that would improve average yields. The main areas are crop establishment, soil moisture conservation, fertilization, crop sequence, and weed control.

Rotation and cropping pattern

Sorghum monocropping is believed to be one of the main factors contributing to the observed trend of low yield over time. The recommended crop sequence is sorghum, sesame, and fallow, but apparently this rotation is not followed. The Canadian Project is conducting crop sequence experiments where several legumes are tested. Cowpea, guar, and green mung bean seem to be well adapted to the local conditions. They also show a beneficial residual effect, reflected in improving the yield (70–155%) of the succeeding sorghum crop (Sim Sim Project, 1990, 1991). There is no doubt that legumes are very beneficial when included in the rotation; however, unless there are markets for them, farmers are not likely to adopt them.

Crop establishment

Continuous sorghum cropping using the same tillage operation (harrowing) is believed to have led to the deterioration of the physical properties of soils and may have created a hard pan at the plow depth. This, in turn, is most likely to limit water infilteration, reduce root growth, and cause runoff (Salih and El Amin 1986). Tillage experiments have been carried out in order to improve soil physical properties and improve moisture-holding capacity. In these experiments, different tillage implements and different depths were used. Salih and El Amin (1986) found that subsoiling (45 cm) and deep harrowing (25 cm) increased sorghum yield significantly over traditionally used tillage operations. Farah (1985a) found that tied ridges improved HD-1 yield by 86% over traditional practices in the Gadambaliya area, a relatively low-rainfall area. The Canadians are also conducting postharvest tillage experiments and the results so far indicated that it can improve sorghum yield.

Fertilization

The response of sorghum to fertilizers, particularly nitrogen, has been examined and found to be positive. Farah (1985b) found that different sorghum cultivars showed positive responses to nitrogen. The Canadian Project has shown for two seasons (1990 and 1991), that nitrogen can significantly increase sorghum yield (136%). The highest marginal rate of return (758%) was obtained with 21 kg N ha^{-1}. Because of risk factors, farmers are less likely to use nitrogen, especially in relatively low-rainfall areas.

Conclusions

Results of this survey showed that there is a tendency towards sorghum monocropping, use of traditional low-yielding varieties, late sowing, and no pest control. The most significant factors contributing to yield variability are sowing date, pest incidence, seed rate, and site. Research on tillage, crop sequence, and fertilization has shown that there is a potential for yield improvement. However, farmers' practices and their failure to follow the recommendations are major factors contributing to low and variable yields. Extension is a critical input needed to demonstrate to farmers, the superiority of improved practices.

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The Role of Village Studies in Crop Improvement Research: Experiences from ICRISAT's West African Sorghum Improvement Program

S K Debrah and D Sanogo[1]

Abstract

The importance of village-level studies (VLS) in agricultural research has been illustrated using the experience of ICRISAT's West African Sorghum Improvement Program (WASIP). Village-level studies closely monitor production systems in study areas over time and identify constraints and opportunities for increased production. They permit continuous interaction with the farmers for early feedback on introduced technology. Since 1989, the WASIP program has conducted diagnostic, biological, and special-purpose studies in four villages selected from different agroclimatic zones in Mali. One of the findings emerging from the VLS in the WASIP program is that the local sorghum varieties which farmers use have been grown by millions of farmers over centuries, and have been selected to suit the ecosystem in which they operate as well as their food habits. The farmers in the study sample expressed concern about the postharvest characteristics of introduced sorghum varieties, even though their yields are higher than the yields of local sorghum varieties. Other findings from the VLS guided the program to pay more attention to postharvest and food quality issues in our varietal research by emphasizing more collaboration among social and technical scientists (breeders, pathologists, entomologists, and agronomists) as well as farmers to ensure that the developed varieties would be adopted.

Introduction

The goal of most International Agricultural Research Centres (IARCs) is to increase the productivity of key crops and to develop sustainable production systems in their mandate areas. A combination of on-station and on-farm experimentation has been employed by the IARCs in crop improvement research. Their efforts have resulted in moderate progress in raising the productivity of maize, rice, and some root crops in many parts of the world. However, the productivity of sorghum and millet has not risen to any appreciable level, particularly in the West African semi-arid tropics (WASATs). Matlon (1985) estimated that only about 5% of the total sorghum and millet area in the region has been planted to cultivars developed through modern plant breeding, despite several years of crop improvement research.

The low impact of the improved sorghum cultivars in the region can be attributed to several factors. Until recently, crop improvement programs paid little attention to postharvest characteristics and consumer preferences in their selection criteria. Also, research was conducted more along disciplinary lines without much interaction among disciplines. Consequently, research results were generalized without adequate consideration of the wide diversity of the physical, socioeconomic, and institutional environments of the WASAT.

This article describes how longitudinal village-level studies (VLS) can be used to provide a better understanding of the production environment, and therefore provides a more reliable database for crop improvement research. It is based on a multidisciplinary research approach of the West African Sorghum Improvement Program (WASIP) of ICRISAT, where VLS play an important role in the technology development and verification process.

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ICRISAT Conference Paper no. CP 1034.

Importance of Village Level Studies for Crop Improvement Research

The village has been used as a focal point for agricultural and social science research since the first world war, when Mann (1917) formally surveyed households in an Indian village. Ever since, VLS have been carried out as single-point interviews, as farm management studies or as ethnographic studies where anthropologists reside in study villages and make personal observations on factors of interest to them. The most systematic VLS, combining features of ethnographic inquiry, farm management studies, special purpose surveys, and on-farm research were initiated by ICRISAT's economic program in India in 1975 (Walker and Ryan 1990). The primary objectives of the VLS, in an interdisciplinary setting which is characteristic of ICRISAT's research, are to understand the production systems, to characterize constraints to increased production, and to provide a real-world milieu for the verification of the performance and acceptability of introduced varieties and new technology.

The VLS are longitudinal and permit continuous interaction with the farmers for early feedback on introduced technology. They also provide base-line data over time, permitting a better understanding of the technical, socioeconomic, and institutional factors underlying the farming system, and are useful for setting crop improvement research priorities.

Village-Level Studies in WASIP

The research program of WASIP, started in 1988, is based at Samanko about 25 km from Bamako, Mali. Scientists of the WASIP-Mali program consist of researchers from the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and from ICRISAT, working as a consolidated team. WASIP-Mali's aim is to provide scientists in the national program in West Africa with stable, high-yielding sorghum cultivars adapted to the northern guinean and sudanian climatic zones, with resistance to *Striga*, diseases, insects, and pests. Sorghum-based cropping systems research, with emphasis on improvement of existing systems through more efficient management of available moisture and other resources, is also part of the team's activities. The team also works with the commodity networks and other regional organizations to ensure a free exchange of breeding materials among scientists in the region.

WASIP-Mali's VLS program, which started in the 1989 cropping season, is based on the premise that farmers' production capabilities are determined by technical factors (e.g., biological and technological factors), as well as the socioeconomic and institutional environment (e.g., markets, land tenure, and credit institutions) in which farmers operate. The objectives of the VLS are: (i) to study the sorghum-based cropping systems of different agroclimatic zones, to identify recommendation domains for alternative sorghum technologies; (ii) to characterize farmers' resource endowments and utilization patterns; (iii) to diagnose on-farm constraints to increased production in sorghum-based systems, and (iv) to determine the productivity and acceptability of new sorghum technologies under farmer conditions. Village-level studies provide continuous interaction with the farmers in the study panel, and allow the collection of uniform data across the panel over several years.

VLS Sites and Research Methodology

WASIP-Mali's VLS sites are located in the Operation Haute Vallee (OHV) in central Mali and the Compagnie Malienne de Développement des Textiles (CMDT) zones in southern Mali (Figure 1). The OHV zone covers a total land area of about 7500 km^2, where the climate is characterized by a rainy season from May to October, and a rainy season the rest of the year. The northern portion of the zone falls into the sudano-sahelian agroecological zone and receives between 400 mm and 900 mm of annual rainfall. Pearl millet is the principal crop, grown either as a sole crop or intercropped with sorghum or groundnuts. The southern portion is situated in the sudano-guinean zone and receives between 1000 mm and 1200 mm of annual rainfall. The clay-line soils found in the zone are medium rich and favor sorghum and maize production. Sorghum is rotated with maize, pearl millet, or groundnuts, and grown either as a sole crop or intercropped with cowpea.

The CMDT zone covers about 9200 km^2, and encompasses the sudano-sahelian, the sudanian, and the sudano-guinean agroclimatic zones. It receives between 600 mm and 1200 mm of annual rainfall between May and October, and the rest of the year is dry. The production system is agropastoral, and cotton is the most important cash crop which usually generates capital for investment in technical innovations and rural development in the zone. Cotton is rotated

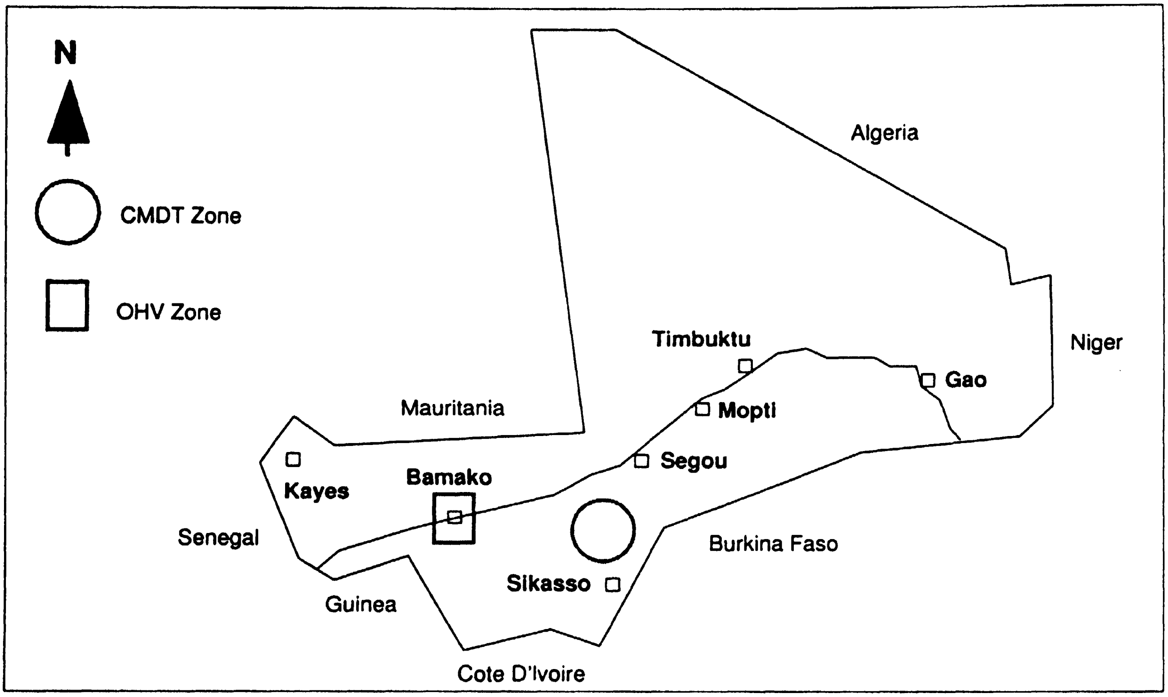

Figure 1. The Operation Haute Valtee (OHV) and Compagnie Malienne de Développement des Textiles (CMDT) zones in southern Mali.

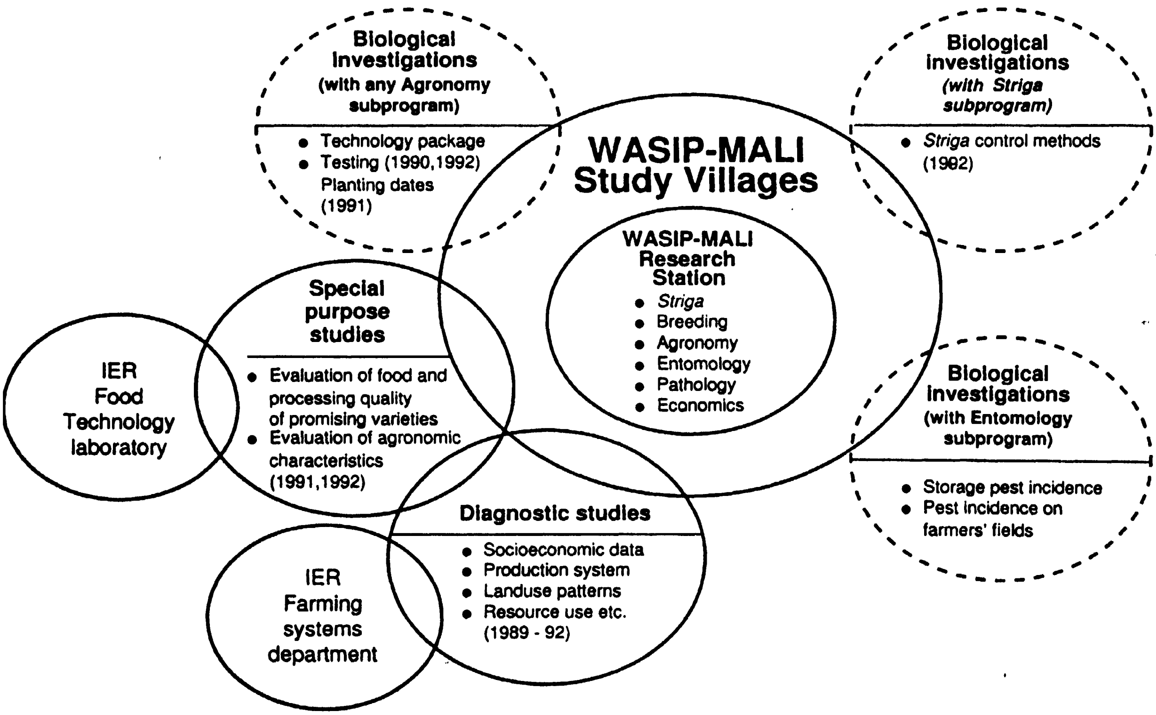

Figure 2. Village-level studies at WASIP-Mali, and their relationship with other programs, 1989–1992.

with cereals such as sorghum (grown either as a sole crop or intercropped with cowpeas), maize, and pearl millet. Although no concerted effort is made to fertilize sorghum fields, sorghum benefits from the fertilizer applied previously, to cotton. The CMDT zone thus provides a sharp contrast to the OHV zone in the level of animal traction use and the presence of a cash crop in the cropping system.

From the start of the VLS in 1989, we followed a panel of about 100 households selected from four villages in the two zones (Sanogo et al. 1992). A household in the study was defined as an extended family living in the same compound, where most decisions concerning the management of the household's resources and production, particularly on the collective farms is vested in the household head. The selected households were stratified into four groups according to the level of animal traction equipment possession, using the Kleene criteria (Kleene et al. 1988). Households belonging to category A are well equipped with animal traction equipment (oxen, plows, seeders, and carts), while those belonging to category D are manual households. In between, households have incomplete animal traction equipment or use them rarely or on a irregular basis.

A field technician was assigned a study village where he collected data during the entire cropping season (usually from Apr to Dec). Structured questionnaires, field observations, and measurements were used for data collection on a daily, weekly, or other pre-determined intervals, according to the type of data required. For example, data on the amounts of human and oxen labor spent on various farm operations in a household's collective farm were collected on a weekly basis, while socioeconomic data, data on resource utilization, crop production, and utilization patterns, sales, purchases, and other household transactions were collected less frequently.

Results and Discussion

The studies conducted in the WASIP-Mali's study villages can be classified into three broad categories as (i) Diagnostic or baseline studies, (ii) Biological investigations, and (iii) Special-purpose studies. Figure 2 summarizes these studies and their relationships with the various disciplines within and outside the WASIP-Mali program. Breeding, agronomy, and plant protection research is done at the WASIP-Mali research station, and promising varieties and technologies in advanced stages are tested by the agronomy subprogram, in collaboration with the economics subprogram and national scientists on the farmers' fields. The economics subprogram also conducts diagnostic and special-purpose studies and provides relevant information to the crop improvement scientists.

Diagnostic studies

The diagnostic or base-line studies were initiated in the study villages in 1989 and have provided a good understanding of the technical, socioeconomic, and institutional factors underlying the farming system in the study area. Tables 1, 2, and 3 summarize some important characteristics and principal constraints of the farming systems studied. Land holdings range from 1.5 to 12.3 ha per household and are usually segmented into a number of fields which are owned either individually or communally by the household. Family size averages 12 members per household and animal traction households possess on average, 14 Tropical Ruminant Livestock Units (TRLUs) of livestock per household, compared with three for manual households. Sorghum, pearl millet, maize, cotton, rice, groundnuts, and cowpeas are the main crops which are grown either as sole or as intercrops. The system is based on local varieties which not only fit into the ecosystem but also meet the food requirements of the farmers.

The principal constraints faced by farmers in the study include poor soil fertility and labor bottlenecks during peak periods of the season. An analysis of labor availability and usage profiles during the year confirmed the labor constraint. For example, a typical family supplied only between 9 and 18% of the total human labor requirement during the cropping season, necessitating the supply of extra labor from the market. The lack of improved varieties was viewed as a constraint by only 8% of the farm households surveyed. This contrasts the view among certain researchers that the absence of improved varieties is a major constraint to increased crop production in West Africa.

Biological investigations

Biological investigations are normally conducted in conjunction with the crop improvement scientists. In 1990, we conducted on-farm trials with the agronomy subprogram in the four study villages, where a total of 32 households (eight per village) were involved. We tested the performance of sorghum cultivars (ICSV 1063, ICSV 1079, CSM 388) and a local variety under two levels of management, traditional, and improved.

Farmers' practices represented traditional practices and the improved practice was a defined spatial arrangement, with a recommended fertilizer dosage of 100 kg ha^{-1} NPK (17-17-17) at sowing and 30 kg ha^{-1} of urea, 30 days after sowing. Each sorghum variety was intercropped with groundnuts with one row of sorghum and four rows of groundnut.

The trials were observed and scored for disease and pest incidence by the pathology and entomology subprograms on a regular basis. Sorghum yields using improved practices varied between 24% and 205%, while groundnut yields varied between 72% and 122% over traditional practices. An economic analysis (partial budgeting) showed that it would be profitable for farmers to switch from their traditional to improved practices on condition that the value of groundnut straw is considered in the analysis.

Table 1. Resource ownership (mean) in the production systems in four study villages, Mali, 1989–91.

Resource ownership (mean)	
Land holding (ha per household)	8
Family size (sex and age combined)	12
Family size (adult-man equivalents)[1]	8
Livestock holding	
Animal traction households (TRLU)[2]	14
Manual tillage households (TRLU)	3

1. The adult-man equivalent conversion indices used were: men = 1, women = 0.75, and children (5–15) = 0.5.
2. Tropical ruminant livestock unit (TRLU) is defined as a tropical ruminant of 250 kg live weight. The ruminant conversion indices used were: camel = 1, cattle = 0.7, sheep and goats = 0.1.

Special-purpose surveys

The special-purpose surveys were specifically designed to seek farmers' opinion about the overall performance of the varieties either already tested or about to be tested on farmers' fields. In 1991, for example, farmers in the four villages who had participated in the on-farm trials in the 1990 season, were asked to rank the test varieties in terms of agronomic performance. CSM 388 was unanimously ranked first in overall performance, followed by ICSV 1079 and ICSV 1063. In an organoleptic test that followed, farmers again ranked CSM 388 ahead of ICSV 1079 and ICSV 1063 in that order.

The surveys indicated that farmers were very much concerned about the processing and food qualities of introduced sorghum varieties. Their acceptance would therefore most likely be conditioned to a large extent by these qualities. In 1992, a survey was carried out in the villages for farmers to evaluate the processing and traditional food qualities of four promising sorghum varieties from the ICRISAT and the Malian research programs (Debrah et al. 1992). The evaluation was done to identify sorghum varieties that combine good processing and food qualities with desirable agronomic traits for further screening in the program.

Table 2. Level of fertilization and yields of principal crops (1990 cropping season) in the production systems in four study villages, Mali, 1989–91).

	Crop				
Level of fertilization (kg ha^{-1})	Sorghum	Maize	Cotton	Millet/ Cowpea	Sorghum/ Cowpea
Organic fertilizer[1]	1792	2690	1162	0	0
Chemical fertilizer[2]	8.6	96.6	64	35	0
Urea	37.2	88.8	26	35	8.8
NPK[3]	136.4	298.6	148	47	11.4
Crop yield	896	2008	1658	556	713

1. Organic fertilizers used were in the form of farmyard manure, compost, and cow dung.
2. Chemical fertilizers used were in the form of 'complex coton' NPK (14–22–12) and 'complexe céréale' NPK (15–15–15).
3. NPK represents quantity of nutrients in both organic and chemical fertilizers. Organic fertilizer was converted by using the conversion 1 kg organic fertilizer = 0.018 kg N, 0.015 kg P_2O_5, and 0.030 kg K_2O).

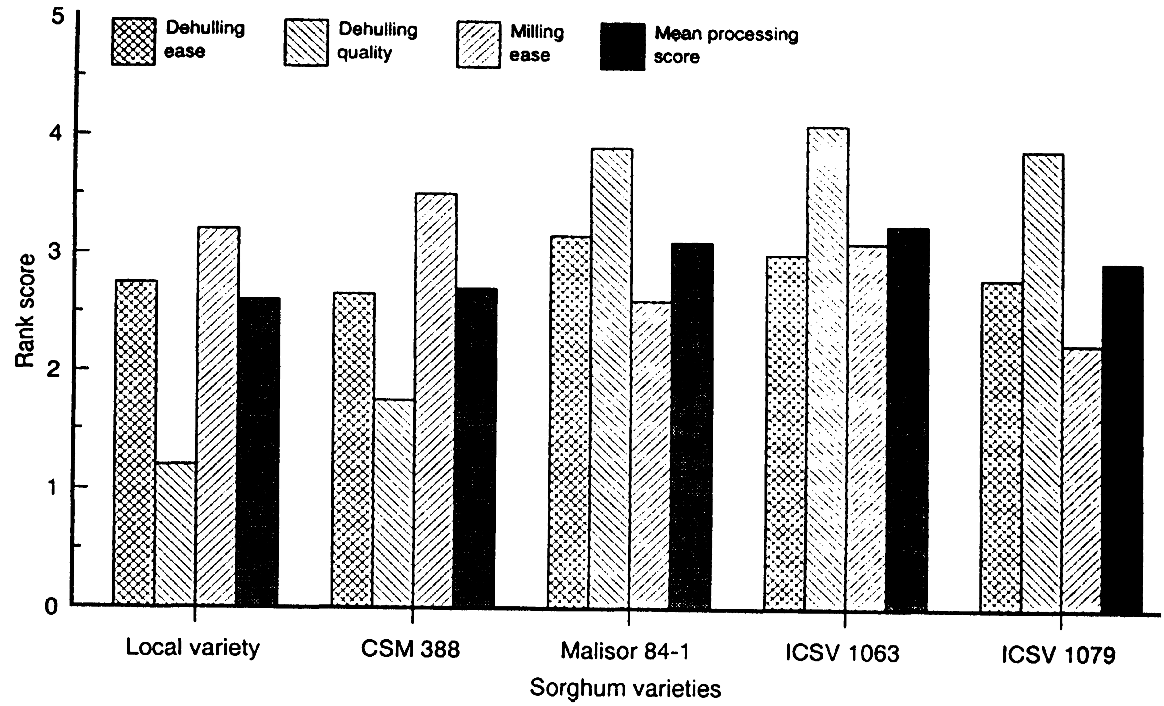

Figure 3a. Mean score rankings (rank scores: 1= best, 5 = worst) of five sorghum varieties, according to processing quality characteristics, Mali, 1992.

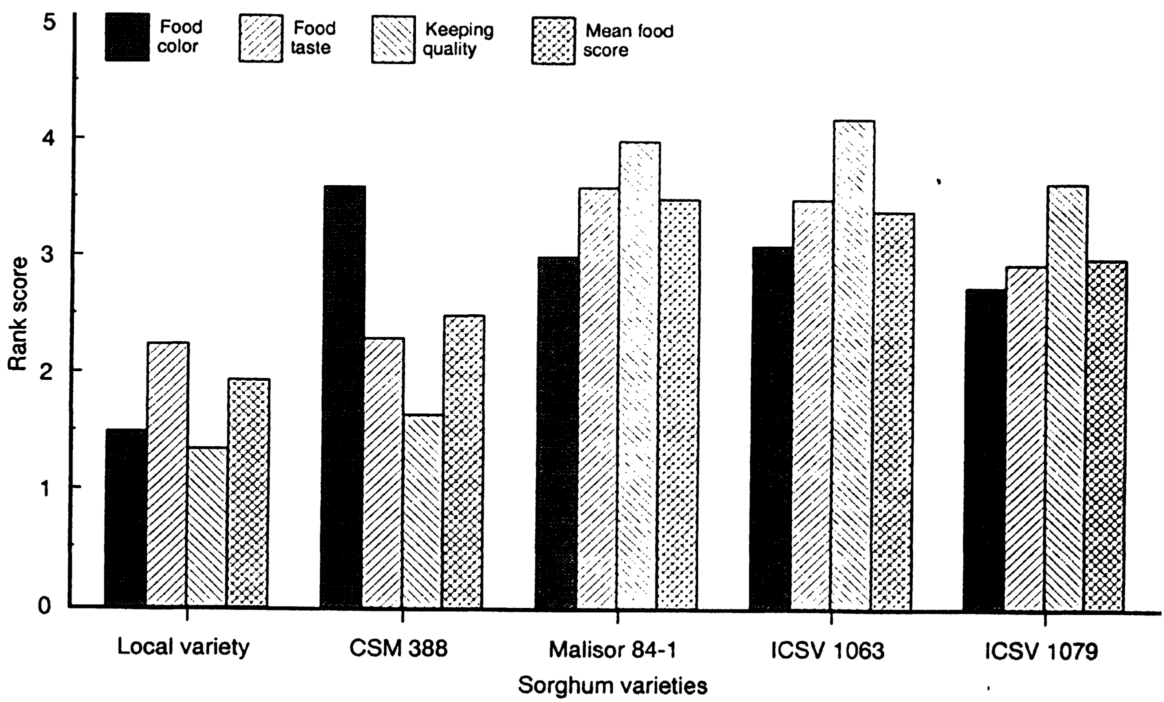

Figure 3b. Mean score rankings (rank scores: 1= best, 5 = worst) of five sorghum varieties, according to food quality characteristics, Mali, 1992.

The test varieties were quantitatively and qualitatively evaluated. Measurements were taken at every stage of the primary processing (dehulling and milling), and processing losses and yield recoveries were estimated for all the varieties (Table 4).

The smallest processing losses were recorded for the guinean-type sorghums (local variety and CSM 388) where losses due to processing were between 28% and 33%. The biggest processing losses were observed for compact-panicle caudatum sorghums (ICSV 1063, ICSV 1079, and Malisor 84-1), where losses averaged 50%.

The farmers qualitatively evaluated the varieties based on six components, commonly used in describing cereal processing and food characteristics in general. The first three components (dehulling ease, dehulling quality, and milling ease) represented processing qualities, while the other three (color, keeping quality, and taste of *tô*) represented food qualities. For each component, the five sorghum varieties were ranked on a scale of 1–5, where a variety having the best quality for the component received a ranking of 1, and that with the worst quality received a ranking of 5. The varietal rankings of processing and food quality characteristics of the various components are presented in Figures 3a and 3b. If we consider an average processing score of 3 as a threshold of acceptance so that varieties scoring 3 or less are 'acceptable', then the local varieties, CSM 388 and ICSV 1079 would be candidates for acceptance. For food quality characteristics, the threshold of acceptance could be 2.5 as farmers would generally not compromise on food quality characteristics. So defined, only the local variety and CSM 388 would meet the food quality criterion and would be candidates for acceptance.

Table 3. Principal constraints to production in the production systems in four study villages, Mali, 1989–91.

Constraints	Respondents citing (%)
Lack of access to implements	57
Lack of access to fertilizer	31
Poor soil fertility	31
Labor constraints	19
Difficult access to credit	18
Lack of improved varieties	8

1. The principal constraints were taken one at a time and the percentage of respondents citing as major constraint was noted.

Table 4. Total processing losses of five sorghum varieties decomposed into dehulling and milling losses in three villages in Mali, 1992.

Processing losses	Local variety	CSM 388	Malisor 84-1	ICSV 1063	ICSV 1079
Dehulling loss (%)	16.9	20.7	32.1	36.1	30.8
	(5.4)[1]	(7.4)	(8.8)	(10.4)	(9.8)
Milling loss (%)	10.6	12.2	15.1	15.0	17.1
	(9.5)	(8.2)	(12.4)	(15.6)	(11.8)
Total loss (%)	17.6[b2]	32.9[b]	47.5[a]	50.9[a]	47.8[a]
	(13.1)	(9.7)	(11.8)	(18.9)	(11.3)
Recovery (%)	72.3[b]	67.1[b]	52.4[a]	49.1[a]	52.2[a]
	(13.1)	(9.7)	(11.8)	(18.9)	(11.3)

1. Figures in parentheses are standard deviations.
2. Means with the same letter are not significantly different from each other at the 5% level according to the Waller-Duncan K-ratio.

Even though high yields are desirable, the grain quality suitable for the preparation of specific traditional foods is of equal importance to farmers (Subramanian and Jambunathan 1990). Malisor-84-1 yields 130%, ICSV 1063 yields 35%, and ICSV 1079 yields 17% over the local, but they lose approximately 50% during processing and dehulling (Debrah et al. 1992). Compared with the local varieties, they may not have a high chance of being adopted by the farmers because the yields are not high enough to compensate for the poor processing and food quality characteristics.

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Discussion Session 5: Utilization and Socioeconomics

Title of Paper: Nonwheat Bread Research and Development

Name of Speaker: P.L. Bureng

Question: *Senayit Yetneberk*

What is the advantage of pre-gelatinization of cassava starch for bread making? How do you compare the cost of additives such as starch, emulsifier, and guar gum to the cost of wheat? The question of shelf-life of bread for 7 days might not be practical due to the phenomenon of retograduation, where the bread becomes stale after storing it for 2–3 days.

Answer: *P L Bureng*

Pre-gelatinized starch adds plasticity and stickiness to envelop the air and gases during mixing, proving, and baking. The mixture of gelatinized and raw cassava starches complement each other, resulting in good quality bread. The additional cost for starch, emulsifiers, and guar gum were found least significant, since the cost of cassava starch is very low compared with that of wheat. This balances the emulsifier and guar gum prices. Seven days shelf-life was at below −42°C, in a deep freezer. Normal bread storage period gave similar results with nonwheat bread. The retrogradation phenomenon was expected to be immediate, but inclusion of emulsifiers and high levels of fat (margarine) tended to slow down retrogradation of starches. But the problem is still significant.

Question: *L B Olugbemi*

The major problems with nonwheat bread are short shelf life, loaf volume, and taste, which usually make such bread unacceptable. How does the new product satisfy the requirement of an acceptable bread?

Answer: *P L Bureng*

The new nonwheat bread formula developed in Nigeria under FAO project TCP/NIR/0052 gave good bread quality. The shelf life was 2–3 days, then it tended to become crumbly. The volume improved significantly from the usual 1.1–1.9 to a new level of 2.5–3.0 mL g^{-1} (specific volume). The taste was rated as acceptable. Consumers who usually consume sorghum and cassava rated it as very good and acceptable.

Title of Paper: Highland Forage Sorghum in Kenya: What Prospects?

Name of Speaker: J P Ouma

Question: *B N Mitaru*

1. Would you consider a region with 400–800 mm rainfall, as a region in the semi-arid tropics?
2. Do you have forage cultivars other than those from the 1970s?
3. What advice would you give to those farmers who wish to produce grain food and also forage?

Answer: *J P Ouma*

1. This would fall within the semi-arid and transitional zones (ecozone 4 and transitional zone 3). Studies in high-altitude sorghum showed that sorghum will outyield maize when rainfall is less than 750 mm annually.
2. No new forage or dual-purpose high altitude (cold tolerant) sorghums have been released by the highland sorghum and millet program in Kenya. The reason is basically lack of donor funds for beef research, since this is the main mandate of the center where the program is based.
3. Advise farmers to harvest grain from the main stalk of E1291 (dual purpose). This variety matures earlier than E6518 (forage). The tillers and stover from E1291 can be harvested together with the forage variety for ensiling.

Question: *Zenon Kabiro*

I observed from my experiment that sorghum stems are either sweet, bitter, or tasteless. Have you made such an observation on E6518? Were these animals eating sorghum forage because it tasted good or was it because they were hungry?

Answer: *J P Ouma*

1. The juice from the stem of E6518 has a bland taste.
2. The animals prefer to feed on either maize stover or other crop residues, if these are available. In the absence of these, the cows eat the sorghum stover.

Comment: *C Mburu*

Some of the slides showed food products made from sorghum. These were mainly cakes and biscuits, which are very unpopular dishes in Kenya, and which would be difficult to sell in the presence of similar products from wheat. My recommendation would be to improve on the already existing and more popular dishes like *ugali* and porridge from sorghum and millets.

Comment: *J P Ouma*

In addition to porridge and *ugali*, the cakes and biscuits displayed were made of composite flours. The high cost of wheat products may keep them out of reach of most families. If these alternative food products are acceptable, they will save the country foreign exchange to import wheat.

Title of Paper: Sorghum Grain Utilization in Western Africa

Name of Speaker: L B Olugbemi

Question: *H M Saadan*

In bread preparation using composite sorghum flour, have you tried to use waxy endosperm sorghum?

Answer: *L B Olugbemi*

Presently, we have limited ourselves to the use of some of the institute-recommended varieties of sorghum. In this respect, the white grain variety '*Farafara*' is the best.

Question: *J P Esele*

As you said, we must popularize the utilization of sorghum in Africa, in order to save this continent from hunger and the poor economic situation. Who should lead the campaign—crop researchers, socioeconomists, industrialists, or politicians?

Answer: *L B Olugbemi*

This is a collective responsibility of the government, the researchers, socioeconomists, etc. Government policy is very important. Whether a product is accepted or not depends on many factors, including cost in relation to other products which the government sometimes fixes, government encouragement, etc. For example, when the government of Nigeria banned wheat importation in 1987, the industrialists had to look inwards for their raw materials. This brought significant increases in the earnings of the farmers from their local grains, especially maize and sorghum.

Question: *Zenon Kabiro*

Research on sorghum has made an impact on the industry, especially on malt. Bread making is being adopted. Have you tried to ask for grants from users since funds from the government are not always enough?

Answer: *L B Olugbemi*

The work reported is in collaboration with two flour mills—the Northern Nigeria Flour Mills, Kano, and Ideal Flour Mills, Kaduna, in addition to the financial support received from the West and Central African Sorghum Research

Network. Additionally, the industries in the country are now expected to make a contribution of 1% of their profit after tax, towards research. Previously, the industries were usually very reluctant in funding research, even though they were great beneficiaries.

Question: *A Ekwamu*

I observe that many African people tend to think that their own products, including foods, are inferior to imported products, even when provided with concrete evidence to the contrary. What is your comment on this and what do you recommend as possible strategies to change our African attitudes, so that we appreciate and use our own products.

Answer: *L B Olugbemi*

Africans are generally very conservative and difficult to change. It seems that the attitudes of Africans to look down on their own products emanates from colonial days when it was widely felt that everything African was inferior to those of Europeans. I think we need to seriously educate our people on what we feel is good for them and what is not. Government policy is also very important. They must learn to lead by example.

Title of Paper: Studies on Methods to Improve *Injera*-making Qualities of Two Brown Sorghum Varieties

Name of Speaker: Senayit Yetneberk

Question: *A Ekwamu*

What is the rationale behind your treatment combinations for sorghum and teff for *injera*? You used low and high sorghum, but not intermediate quantities, why was this so? It would have been nice to see the performance of a 50:50 mixture.

Answer: *Senayit Yetneberk*

There were intermediate quantities of the mix. In fact, the 50:50 mixture (sorghum with teff) was the optimum mixture to make good *injera*.

Question: *B N Mitaru*

I take it that *injera* is a fermented food. Would you say it is only the tannins in the sorghum which affect the quality of *injera*?

Answer: *Senayit Yetneberk*

Yes, *injera* is a fermented food product. It is the tannins that affect the quality of *injera*, because the quality attributes of *injera* were improved after the seed coat, along with the tannin, was removed by dehulling. The tannin also affected the fermentation process, probably by inhibiting the fermenting micro-organisms.

Question: *A Ekwamu*

Is *injera* made both from sorghum and teff? If so, what is the rationale behind combining sorghum and teff? Why don't you use them separately?

Answer: *Senayit Yetneberk*

Yes, *injera* is made from both teff and sorghum. The reasons for combining sorghum and teff are:

1. From our survey, farmer households have the tradition of mixing sorghum with teff to improve the sorghum *injera* quality.
2. To promote the use of brown sorghum, which is bird resistant.

Question: *C O A Oduori*

Considering the people in your country prefer teff-made *injera*, and teff is produced in your country, don't you think that the emphasis should be on the improvement of teff production than try to replace it with sorghum in its main use (teff), i.e. produce more teff to cut on its cost?

Answer: *Senayit Yetneberk*

We are not trying to substitute sorghum for teff. The objective of this work is to solve the bird depreciation in some of the sorghum-growing areas by introducing a better method of brown sorghum *injera* preparation.

Recommendations

The workshop participants split into four discipline groups to develop sets of recommendations.

Group 1: Breeding

1. Additional papers should be solicited and presented during the next workshop on topics such as impact assessment of developed technologies on the farmer, report on host country program activities, and network coordinator's report on action taken so far on previous workshop recommendations, to avoid repetition of recommendations which pile up without any action being taken.
2. Breeders should define the yield potentials of environments in which they work, in view of the varieties (or hybrids) that they have already developed, to determine whether it is worthwhile putting more emphasis on breeding or on the development of better cultural practices. Strategies that give consideration to production under minimum input levels should be adopted in breeding.
3. The network should organize short training courses in seed multiplication, computer data analysis, and drought-screening techniques.
4. Scientific work groups should be encouraged to work on topics such as drought, ergot disease, anthracnose disease, grain mold, and finger millet blast disease.
5. In addition to the above recommendations, the group also adopted the following 1990 workshop recommendations that they felt are still important and relevant, but which have not yet been implemented.
   a. Interaction among NARS scientists working in similar environments should be encouraged.
   b. NARS should take steps to move the better varieties to farmers' fields.
   c. Integration of other disciplines (pathology, entomology, physiology, agronomy, utilization) with breeding for sorghum and millets improvement should be encouraged.
   d. Provide further support for a targeted and well-focused breeding project to identify and incorporate *Striga* resistance in sorghum.
   e. Recognize the need to develop experience in breeding seed parents and hybrids.

Group 2: Agronomy and Resource Management

1. In order to solve the production bottlenecks of sorghum and millet, a multidisciplinary research approach should be implemented at an early stage, so that it has its input in the design process.
2. Socioeconomic surveys should be conducted on farmers' fields to identify the farmers' needs and priorities as the basis for an effective, applicable research program.
3. The on-station research should be followed up by on-farm trials, taking into account traditional farmers' practices, as dictated by their constraints and priorities.
4. Task force teams comprising different disciplines are necessary in following up the recommended packages, by making frequent field visits during the season.
5. Specific areas of research priorities for agronomic and resource base management should include the following:
   a. *Striga*, pest and disease control should be handled using the appropriate cultural practices.
   b. Since water is the most limiting production factor under dryland farming, soil and water conservation, water-harvesting techniques, and suitable tillage practices should be investigated, which alleviate drought constraint and improve sorghum and millets productivity.
6. An agroclimatological data analysis which compares different production zones within the network, should be studied to enhance exchange and adoption of research methodology and production aspects.

7. Crop physiology studies should be encouraged so as to understand the mechanisms governing drought tolerance, escape, and yield response.
8. Field days should be held occasionally to bring together researchers, extensionists, administrators, and farmers to exchange ideas, knowledge, and experience, and act as feedback for further improvement of recommended packages.
9. Pests such as birds, locusts, etc., which are usually common among the network countries, should be considered as a regional problem and solved collectively.

Group 3: Crop Protection

1. The group noted that little is known about virus diseases of sorghum or finger millet, and recommended that the network seek the help of ICRISAT to identify virus diseases in the region and report on their distribution.
2. As fungal diseases are an important limiting factor in the production of sorghum in the region, the group recommended that screening for resistance be conducted as follows: anthracnose (Ethiopia, Kenya, the Sudan), leaf blight (Kenya, the Sudan, Uganda), grain mold (Ethiopia, Kenya, Tanzania, Uganda), long smut and charcoal rot (the Sudan), and ergot (Ethiopia). Studies on the biology of ergot should continue in Ethiopia.
3. Studies in the Americas, Africa, and Asia have shown that the populations of the anthracnose pathogen, *Colletotrichum graminicola*, differ in virulence. Therefore, the group recommended that the International Sorghum Anthracnose Virulence Nursery (ISAVN) be evaluated widely (Burundi, Ethiopia, Kenya, the Sudan, Tanzania, Uganda), to facilitate a better understanding of virulence within the region.
4. *Striga* is a major threat to sorghum production in the region and as such, research involving screening for resistance and control through cultural and chemical means should continue in Ethiopia, Kenya, the Sudan, and Tanzania.
5. Noting the damaging effects of insect pests on sorghum production in the region, it was recommended that screening for resistance be conducted for midge and aphids (Ethiopia, Kenya, the Sudan, Uganda), American bollworm (the Sudan), and central shoot fly and stem borers (Ethiopia, the Sudan, Uganda). Stem borer population dynamics and loss assessment will also be studied in Ethiopia.
6. The group recommended for pearl millet, that screening for resistance to ergot be conducted in Tanzania, for rust in Uganda, and for head caterpillar in the Sudan.
7. The group recognized blast disease as the single most important protection problem of finger millet. Research areas requiring attention include development of a uniform rating scale, improvement of screening techniques, clarification of disease etiology, and assessment of loss due to disease. It was agreed that Kenya and Uganda should investigate these topics.

Group 4: Utilization and Socioeconomics

1. Food technologists should evaluate varieties of sorghum and millets for specific quality parameters in food preparation as used in:
   a. Staple foods
   b. Snack foods
   c. Beverages (alcoholic and nonalcoholic)
   d. Industrial uses.
2. With respect to livestock feed, evaluate varieties of sorghum and millets that may be appropriate for small farmers.
3. Disciplines involved in national and regional food system production should closely collaborate with socioeconomists on demand assessment and marketing of products.
4. Short-term training and visits for technical staff and scientists within the region or in the institutions that support or collaborate with EARSAM should be encouraged and supported.

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About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 16 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank.

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