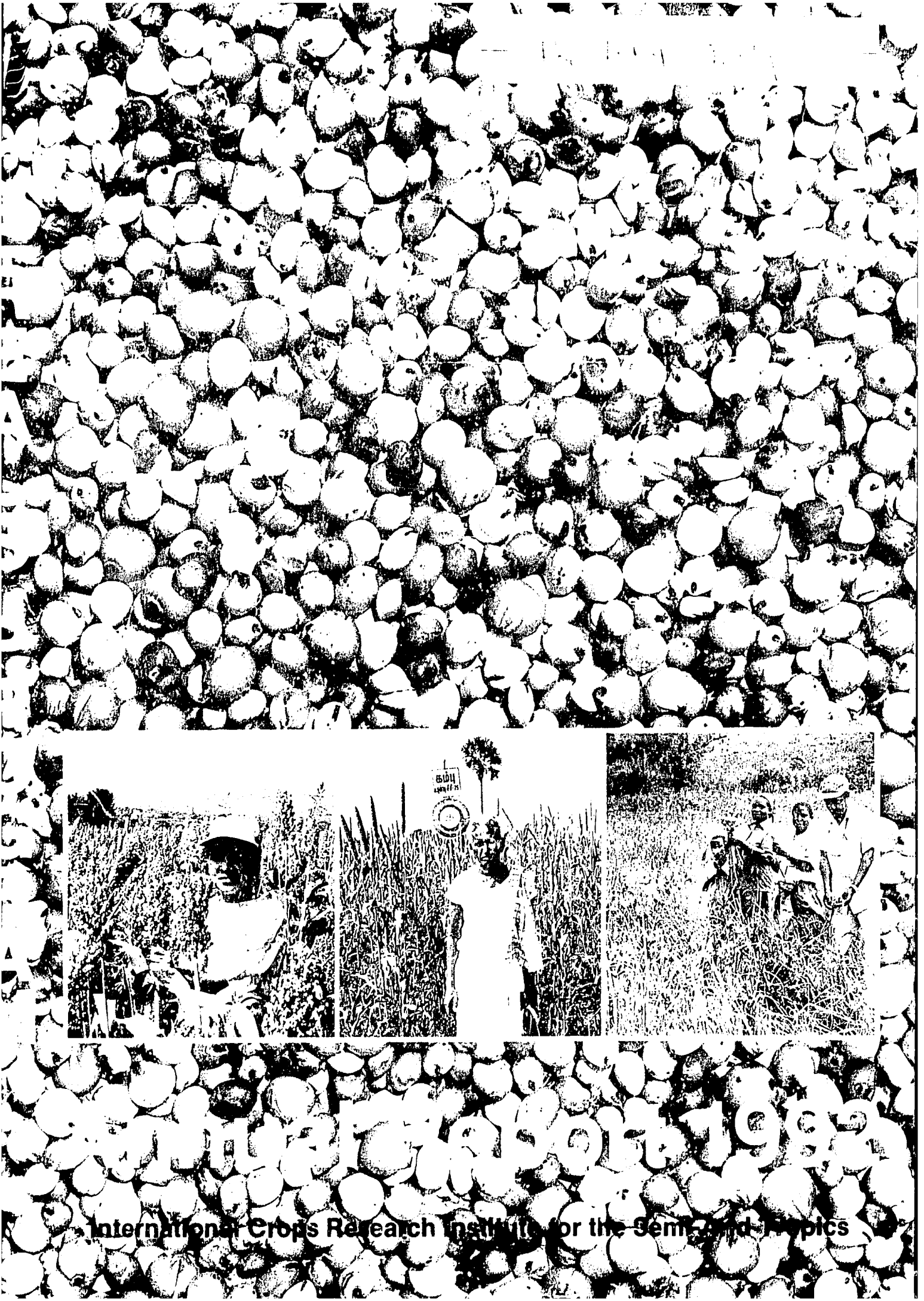

International Crops Research Institute for the Semi-Arid Tropics

PN-ABP-821

Annual Report 1992

Cereals Program

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

1993

Citation: Cereals Program, ICRISAT. 1993. Annual Report 1992. Patancheru, A.P. 502 324, India: Cereals Program, International Crops Research Institute for the Semi-Arid Tropics. (Semi-formal publication).

An ICRISAT semi-formal publication issued for limited distribution without formal review.

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 18 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 World Bank, and the United Nations Development Programme (UNDP).

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of ICRISAT concerning the legal status of any country, territory, city, or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries. Where trade names are used this does not constitute endorsement of or discrimination against any product by the Institute.

Contents

Program Overview 1

Research Highlights 6

Sorghum Research 9

Abiotic Stress 11
Diseases 16
Insect Pests 23
Varietal Improvement 43
Molecular Biology 53

Pearl Millet Research 55

Abiotic Stress 57
Diseases 62
Varietal Improvement 66
Molecular Biology 83

Technology Exchange 87

Human Resource Development 89
Network Activities 91
Workshops, Field Days, and Meetings 94
Seed Distribution 96

Eastern Africa Regional Cereals and Legumes Program 101

Sorghum Research 103
Millet Research 105
Collaborative Research with National Sorghum Programs 107
Network Activities 110
Research Travel and Consultancies 114
Workshops and Conferences Attended 116

Latin American Sorghum Improvement Program 117

Sorghum Research 119
Collaborative Research with National Programs 120
Technology Exchange 121
Seed distribution 122

Publications 123

Research Projects 129

Staff List 135

Appendices 141

Cumulative List of ICRISAT-bred Sorghum and Pearl Millet Cultivars 143
Research Travel and Consultancies 145
Workshops and Conferences Attended 150

Program Overview

Program Overview

D.E. Byth
Director, Cereals Program

The cereal crops of primary interest to the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are sorghum, pearl millet, and finger millet. Research on these crops is primarily aimed at the development of improved cultivars that combine high yields with resistance or tolerance to the main biotic and abiotic constraints to production of these crops in the semi-arid tropics (SAT) of Asia, Africa, and Latin America.

In order to meet the challenges of a widely diversified SAT, ICRISAT's research responsibilities for cereals crop improvement are devolved regionally: ICRISAT Center (IC) in India, which has significant strategic research capability and also carries regional responsibility for Asia; the ICRISAT Sahelian Center (ISC) in Niger, and the West African Sorghum Improvement Programs (WASIP) in Mali and in Nigeria for West Africa; the Southern Africa Sorghum and Millet Improvement Program (SADC/ICRISAT) in Zimbabwe for southern Africa; the Eastern Africa Regional Cereals and Legumes Program (EARCAL) in Kenya for eastern Africa; and the Latin American Sorghum Improvement Program (LASIP) in Mexico for that region. Each research program operates in close cooperation with the national agricultural research systems (NARSs) through collaborative research projects and regional networks to ensure that specific needs and priorities are addressed.

This annual report covers the research, network, and training activities of the programs at IC, EARCAL, and LASIP. Similar reports are produced by ISC, WASIP-Mali and WASIP-Nigeria combined for the West Africa region, and by SADC for southern Africa.

The integration of research across the regional programs allows for the mutual exchange of methodologies and products while ensuring that duplication of efforts is avoided. Research projects are the mechanism of operation at ICRISAT and must be frequently reviewed to ensure that objectives and goals are sharply focused on the primary needs and opportunities of the national systems, and that they are responsive to the dynamics of change arising from progress in basic research internationally.

The Medium Term Plan (MTP)

A major commitment in 1992 was the conduct of a medium term planning process. This was designed to establish the nature and thrust of cereals research in the Institute for 1994/98.

In brief, it was a fundamental and rigorous review of the priority needs and opportunities for cereals R&D involving ICRISAT scientists and NARS cooperators, and it culminated in the identification of a set of research themes around which future research projects will be structured. Prioritization of the themes was determined on efficiency (benefit/cost), equity, internationality, and sustainability, for particular research domains. The comparative advantage of ICRISAT for that research was a major consideration.

Cereals research themes are directed at three primary objectives: namely, improvement of potential for productivity and stability; study of abiotic constraints and identification of adaptive mechanisms; and research into biotic constraints to achieve robust crop protection in SAT farmers' fields.

The 1994-98 research portfolio will continue the shift towards strategic research, targeted to achieve identification of mechanisms underlying primary constraints and the development of technology through which these mechanisms may be exploited by the NARS. Sustainability will be a major focus. Biotechnology will increasingly complement the conventional crop improvement methods.

The balance of strategic vs applied vs adaptive research will vary with the problem, and change with time depending on need. Networking and advanced technical training will have an increasingly important role in assisting the NARS to develop and conduct the research necessary to exploit the results of strategic research elsewhere.

Systematic multi-disciplinary research is necessary to achieve the development and transfer of sustainable and improved technology to the NARS. The cereals research themes are designed to integrate disciplines across the Institute, in a continuum of strategic, applied, and adaptive research and technology development

and exchange. The MTP thematic structure provides a basis for project design within and across themes, and for objective project review and revision.

The shift to a research portfolio based on projects within a thematic structure focused on impact on priority outcomes will present new challenges and opportunities in research management. Linkages in research to advanced institutions based on comparative advantage, and networking with NARS for exchange of intermediate product technologies, will be an increasingly important dimension.

The Cereals Program In-house Review (IHR)

The IHR was held at IC on 30 Nov-4 Dec 1992. It was deliberately programmed to follow finalization of the draft MTP in order to grasp the opportunity to focus on the future.

There was significant participation in the IHR by cereals researchers from each of the subcenters of ICRISAT - from ISC, WASIP-Nigeria and WASIP-Mali, SADC/ICRISAT, EARCAL, and LASIP. The cereals research program of ICRISAT is strongly decentralized regionally, and this IHR represented an opportunity to take an integrated strategic view of the research needs and opportunities.

Four primary objectives were addressed:

- an open assessment of regional needs and opportunities;
- a rigorous review of progress in current research projects at IC, and authoritative summaries of related research at other centers;
- an analysis of the adequacy and opportunities of the current research portfolio in the context of the research themes embedded in the MTP; and
- preliminary identification of strategic research initiatives that focus on priority outcomes, integrate across the Institute, and link to NARS and the international research scene.

Aspects of the IHR review process are mentioned later in this report (see section on Workshop, Field Days, and Meetings).

The primary outcome of the IHR was a reassessment of the priority needs and opportunities for cereals research regionally, and a recognition of the need for a balanced program of strategic, applied, and adaptive research across the Institute that reflects the comparative advantage of ICRISAT and which is designed to achieve impact. A planning process to develop a targeted research project portfolio within and across MTP themes will occur in 1993.

ICRISAT Governing Board Visits Rajasthan

The Program Committee of the ICRISAT Governing Board and members of the ICRISAT Management Committee visited our collaborative research with the Rajasthan Agricultural Research Centers at Jaipur, Jodhpur, and villages in the district of Ajmer, Rajasthan, India. This collaborative research is targeted on the harshest pearl millet production environment of South Asia, and is a model in farmer participation in the identification of important traits for selection during variety development. Some detail of this work is presented under Pearl Millet Varietal Improvement.

Staff

D.E. Byth joined as Program Director on 25 May. L.K. Mughogho, Cereals Pathologist, was appointed as Executive Director of SADC. C.M. Pattanayak, Coordinator of the Cereals Coordinated Research Network (CCRN), resigned to take an assignment with the World Bank. K.V. Ramaiah, Principal Cereals Geneticist, left the Institute on conclusion of his assignment in March.

S.B. King, Cereals Pathologist, was transferred as Team Leader and Pathologist to EARCAL in Kenya, and S.Z. Mukuru was appointed as Coordinator for the Eastern Africa Regional Sorghum and Millets (EARSAM) Network. Suresh Pande, Pathologist, was transferred to the Legumes Program. R. Bandyopadhyay, also a pathologist, returned after spending one year of sabbatical leave at Cornell University. C.S. Busso, International Associate Scientist, Molecular Biology concluded his assignment in September. Santosh Gurtu, Senior Research Associate, Crop Quality Unit, was transferred to the Molecular Biology Unit in June, and N. Seetharama, Senior Scientist, returned from his study leave at Texas A&M University in November to join the Molecular Biology Unit. F.R. Bidinger, Cereals Physiologist, also returned to post after

spending his sabbatical leave in Namibia. V. Mahalakshmi, Physiologist, left in August to join ICARDA on secondment. Another physiologist, P. Soman, took voluntary retirement from the Institute to join a private commercial firm.

R.K. Maiti, Visiting Scientist from the University of Nuevo Leon, Mexico, completed his sabbatical leave in July and returned to Mexico. D.P. Giga, Senior Lecturer of the University of Zimbabwe, spent 3 weeks of his contact leave at ICRISAT.

Three postdoctoral fellows completed their assignments in 1992: A. Thomas of the UK in Cereal Physiology (January), F.W. Wehmann of Germany in Sorghum Breeding (February), and J.A. Sifuentes of Mexico in Cereal Pathology (June). S.J. Duffield of the UK joined Cereals Entomology as a postdoctoral fellow in May.

Several research fellows, research scholars, and in-service trainees from NARSs spent various periods in research units of the program. Details are provided in the section on Human Resource Development under Technology Exchange.

Networks, Technology Exchange, and Adoption

Activities of CCRN and the Asian Grain Legumes Network (AGLN) were merged in April into the Cereals and Legumes Asia Network (CLAN). The program of replicated International Trials and Nurseries in sorghum, and research into the characterization of production environments were established as activities of the Sorghum Breeding Unit. A workshop of Asian sorghum scientists is planned for the second half of 1993 to discuss the integration of a proposed Sorghum Research Network in Asia under CLAN.

The overall objective of CLAN is to enhance technology exchange of ICRISAT mandate crops and related resource management strategies in Asia. Existing linkages of ICRISAT cereals crop improvement to Asian NARS will be maintained, and collaborative research between Asian NARS and ICRISAT will be enhanced by the existing infrastructure of strong regional and bilateral linkages developed by AGLN. Collaboration at the bilateral and multi-lateral levels will be fostered through review and work plan meetings, workshops, monitoring tours, visiting scientist programs, training courses, and working groups.

Breeding materials represent an effective mechanism for packaging of improved technology, and ICRISAT's international trials and nurseries provide unique opportunities for the exchange and testing of materials between NARS, and between ICRISAT and NARS. A good example comes from the hybrid SPH 468. It was developed by the All India Coordinated Sorghum Improvement Project (AICSIP), and was among the top five entries in the International Sorghum Variety and Hybrid Adaptation Trial 1991 (ISVHAT 91) in Indonesia, Pakistan, Cameroon, Mali, Egypt, and drought-affected areas of Zimbabwe.

A field day for seed producers of India on 11 and 12 Mar at IC attracted 55 representatives from 26 private and 4 public seed production agencies and the All India Project Coordinators for sorghum and pearl millet improvement. The potential of emerging new technologies - e.g., the use of RFLP-based linkage maps, and research products including breeding lines, segregating progenies, open-pollinated cultivars, and hybrid parents - generated considerable interest. Seed requests following the field day were overwhelming, and this is reflected in the appendices of this report.

In Africa, EARSAM held its Eighth Regional Workshop from 30 Oct to 5 Nov at Wad Medani, Sudan. Forty-three participants from nine countries were present. Among other things, the workshop recommended the organization of scientific working groups for drought, ergot, anthracnose, and grain mold of sorghum, and for blast of finger millet. Elsewhere, at the Kenya Agricultural Research Institute's (KARI) Kiboko Research Station, a field day was organized in collaboration with KARI, which was attended by 98 participants including scientists, extension officers, farmers, and representatives of donor agencies. Impressed by the range of food products on display, participants suggested that short training courses should be organized, especially for women, on nutrition and the preparation of new food products from sorghum, millet, and pigeonpea.

In Latin America, the First Annual Meeting of the Comision Latinoamericana de Investigadores en Sorgo (CLAIS), South America Subprogram was held on 6-10 Oct in Campinas, Brazil. During this first meeting of NARS sorghum scientists from South American countries, important decisions on intercountry collaboration were made.

Research Highlights

Sorghum Research

Techniques developed by our pathologists have paved the way for rapid progress in improving disease resistance. Using a new in vitro screening technique, we identified resistance to grain mold fungi in five photoperiod-sensitive, white-grain sorghum genotypes (IS 7326, IS 7173, IS 23773, IS 4011, and PM 210). The technique, which involves inoculating seeds with a spore suspension of mold fungi and incubating in a moist petri plate chamber at 30°C with 12 h light cycle for 5 days, relies on the level of colonization for the determination of resistance. Resistance identified by this technique was confirmed in normal field screening.

In another area, a modified leaf-clearing and staining technique was developed to study the histopathology of anthracnose and leaf blight pathogens. The technique involves the use of Cellufluor or Fungifluor stains instead of the usual Uvitex and easily differentiates the level of conidial germination and appressorial formation between resistant and susceptible genotypes.

In entomology, we investigated several factors associated with shoot fly resistance in germplasm from a wide range of geographic origins and taxonomic races and found that sorghum genotypes of African and Indian origin were better than other origins for breeding to improve shoot fly resistance.

In a study on factors associated with resistance to shoot fly, results of an experiment strongly suggested that the moisture on the central whorl leaf of seedlings originated from the plant and was not associated with stomatal density or cuticular thickness.

ICRISAT sorghum midge resistant variety, ICSV 745, which was developed in collaboration with the University of Agricultural Sciences, Dharwad, Karnataka, India, was recommended for cultivation in midge-endemic areas. This variety is also now in multilocational on-farm trials in the neighboring state of Tamil Nadu.

In on-farm trials in the Telangana area of north-central Andhra Pradesh, ICSV 745 yielded up to 3.0 t ha^{-1} compared to a maximum of 1.8 t ha^{-1} by local Maldandi, ICSV 422, and ICSV 112. An Indo-Swiss Livestock Project in the area has undertaken an extensive testing of this cultivar among farmers.

Field studies by entomologists and breeders showed that midge-resistant females and restorers contribute significantly towards resistance to midge. Resistance is needed in both the parents to produce midge-resistant hybrids. Hybrids based on midge-resistant females (PM 7061A and PM 7068A) were in general less susceptible than those based on midge-susceptible females (296A and ICSA 42).

A 406 cM-long RFLP map of sorghum, based on maize probes, was finalized in collaboration with Italian collaborators. Comparison with the maize map suggested a possible inversion of the long arm of maize chromosome 3, in sorghum.

Pearl Millet Research

Earlier research on the genotypic differences in terminal drought stress conditions identified threshing percentage (ratio of grain mass to total panicle mass) as an effective, integrated measure of tolerance/ susceptibility to terminal stress. We have now completed the first cycle of selection in an experiment to test threshing percentage as a potential selection criterion. Results indicate that selection for threshing percentage under stress is effective in improving grain yields in terminal stress environments (in comparison to the control practice of selection for grain yield in non-stressed conditions), but that this is probably at the cost of potential yield improvement in non-stressed environments.

In the first phase of our collaborative research with the Institute of Grassland and Environmental Research (IGER) and the Rajasthan NARS, we were able to demonstrate that the variation in seedling heat tolerance obtained under field conditions is heritable. In phase II, which is a 5-year ODA-funded collaborative project with IGER on comparative field, laboratory, and biochemical selection techniques, we developed a special population from a cross between a highly tolerant landrace from Rajasthan and a newly released pearl millet variety, ICMV 155. Differences among individual full-sib lines from the population ranged from 20-80% survival in the first field evaluation, and indicate the potential for effective screening and selection using simulated field environments and plant biochemical responses to stress.

The identification of RFLP markers for genes that contribute to seedling heat tolerance is being actively pursued using crosses based on an elite inbred line from the Haryana Agricultural University, Hisar, India. Our ability to maintain

and improve seedling heat tolerance in breeding materials in the harsh environments of western Asia and West Africa should be significantly enhanced by this approach.

In another collaborative research initiative with institutions in the UK, we have identified RFLP markers for quantitative trait loci that contribute to the resistance of P7 and ICMP 85410 against Indian and West African isolates of pearl millet downy mildew. The results suggest that these lines carry several factors which confer isolate-specific resistance that is effective against isolates from either Indian or West African locations but not effective across these regions. The immediate implication of this finding is that we now have the potential to pyramid effective resistance genes, and thus can improve the durability of resistance for Indian and West African target environments.

Finger Millet Research

A disease survey in Kenya and Uganda confirmed that blast is the most important disease of finger millet, with finger blast and neck blast phases being more severe than the leaf phase.

A simple field screening technique to screen for resistance to blast disease was developed at Kiboko, Kenya. The technique involves the use of infected plant debris from a previous crop, and will be especially useful at NARS locations.

Several related and nonrelated grass species were tested with various isolates of the finger millet blast pathogen and typical blast symptoms were formed in leaves and panicles of nine species. This result indicates the potential of these grass species to serve as sources of inoculum for finger millet and as the vehicles for carry-over of the organism for blast disease during the dry season.

Sorghum Research

Previous Page Blank

Abiotic Stress

Seedling Emergence in Low Moisture Seedbeds

P. Soman and F.R. Bidinger

Seedbed conditions and seedling emergence. Sorghum requires a minimum of 3 days after sowing for germination and emergence, under favorable moisture and temperature conditions. This period will be increased if seedbed temperature or moisture is above or below optimum. Emergence may not occur at all if temperatures are above a critical level, or if the moisture in the seed zone evaporates before the primary root is established in lower soil layers where moisture is still available. Decreasing moisture and increasing temperatures in the seed zone commonly occur together in light textured soils in the semi-arid tropics. High radiation levels cause rapid rates of evaporation of surface soil moisture, resulting in rapid drying of the seed zone with a concomitant increase in seed zone temperature with the loss of evaporative cooling of the soil surface. Farmers generally know, from experience, the lower limits of seedbed moisture for sowing, and complete stand failures are less of a problem than partial failures due to local conditions in areas in the field or deteriorating conditions at the end of the day.

Previous research has established the existence of genotype differences in emergence and establishment under marginal soil moisture and temperature conditions (ICRISAT Annual Report 1987, pp. 78-79). However, screening techniques for genotypic differences depend on the careful control/management of seedbed moisture and temperature, because such differences are operative over only relatively narrow ranges of seedbed environmental conditions. Outside this range genotypes either all emerge or all fail to emerge.

There is thus a question of how important are genetic differences in emergence ability, relative to environmental variation and to a probable large amount of genotype x environment interaction. We have reanalyzed data from an experiment done in 1988 and 1989 to test the repeatability of genotype differences in emergence, in order to directly compare the magnitude of the above three sources of variation. The experiment consisted of two different seed lots, each of 25 genotypes, which were tested for emergence under a seedbed moisture gradient created by a line source sprinkler system. The experiment was repeated for 2 years in an Alfisol wth 54% coarse sand in the surface layer, under high radiation (22-26 MJ $m^{-2}d^{-1}$), and high evaporation (10-11 mm d^{-1}) conditions in which soil surface drying is extremely rapid. The amounts of water applied by the line source were selected to create soil moisture conditions in which partial emergence, rather than complete failure of emergence, would be expected.

Genotypic vs environmental effects. The extreme moisture environments created by the line source irrigation were distinctly different in both years (Fig. 1a). Soil moisture contents declined from 8% on the first day after sowing to less than 6% on the third day in the wet treatment, compared to a decline from 5.5% to 3.5% in the dry treatment. Midday soil surface temperatures remained below 40°C in the wet treatment (with the exception of day 2 in 1989, which appears to be anomalous), compared to 41-44°C in the dry treatment (Fig. 1b). Both the temperature and moisture conditions in the dry treatment were marginal for stand establishment for sorghum.

Not surprisingly, the amount of moisture applied with the line source was the major determinant of seedling emergence, accounting for 35% of the total variation in emergence (Table 1). The year effect, surprisingly, was virtually nonexistent, but there was a significant year x moisture level effect. This result occurred because the rate of decrease in emergence across the three moisture levels was greater (77 to 30%) in the second year than in the first (66 to 41%), but the overall mean emergence percentage in the 2 years was similar (57 and 59%). The fraction of the total variation in emergence due to the interaction of year and moisture level was not large, however.

The sources of genetic variation in the experiment - genotype itself, seed lot, and their interaction - were all significant, and together accounted for about 10% of the total variation for seedling emergence (Table 1). The range in mean emergence among genotypes was large (44-74%); in comparison to the difference in mean

Previous Page Blank

Table 1. Pooled analysis of variance of environmental and genetic factors affecting sorghum seedling emergence from varying seedbed moisture conditions.

	df	% SS[1]	F ratio
Environmental Effects	5	38.1	
Year	1	0.2	0.15
Moisture level	2	35.1	160.00***
Year x moisture	2	2.8	12.7**
Genetic Effects	49	9.9	
Seed lot	1	1.1	13.0**
Genotype	24	5.3	4.1***
Seed lot x genotype	24	3.5	2.7***
Genetic x Environmental Factors	125	6.1	
Seed lot x year	1	0.0	0.1
Seed lot x moisture	2	0.5	2.7
Seed lot x year x moisture	2	0.8	4.6*
Genotype x year	24	1.3	1.0
Genotype x moisture	48	1.6	0.6
Genotype x grain x moisture	48	1.9	0.7

1. % SS = Percentage of the sums of squares for seedling emergence from the combined analysis of variance.

emergence between the two seed lots (61 vs 55%). The difference in seed lots may have been an aging effect as the first seed lot had been produced 2 years earlier than the first. The significance of the interaction between genotype and seed lot is hard to explain as the difference in emergence between the first and second seed lots varied from -15% to +31% among the 25 genotypes.

The contribution of genotype x environment interaction in the experiment was smaller than expected. The interactions of the genetic and environmental factors (Table 1) together accounted for only 6% of the variance for emergence and only the seed lot x year x moisture interaction was significant. The most encouraging result was the lack of significance of any of the interactions of genotype with the

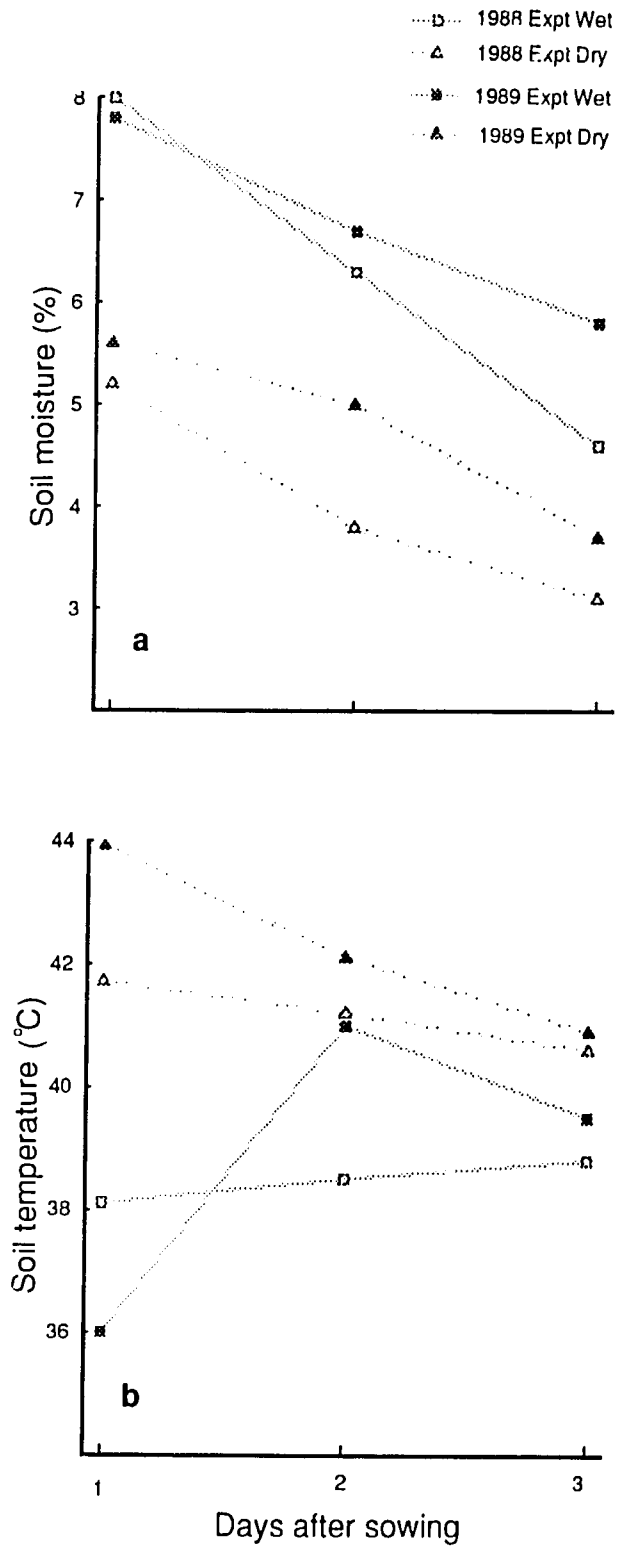

Figure 1. Changes in gravimetric water content in the top 5 cm of the soil (a) and midday soil temperature at 2 cm depth (b) for the wet and dry extremes of the moisture environments created by the line source irrigation in 1988 and 1989.

components of 'environment,' suggesting that genotype differences in emergence under moisture/temperature stress will be effective over different environments within the range of those that will cause partial stand establishment.

These results should not be extrapolated beyond the environmental conditions (Fig. 1a, b) under which the research was done. They did, however, represent a range of from 30 to 77% emergence, which is very significant in agronomic terms. While genotype differences represented a much smaller fraction than did environmental effects, they were significant and, most importantly, virtually unaffected by GxE variation. Genetic differences in emergence ability, therefore, do represent an effective, if not complete, solution to poor stands under the environmental conditions of these experiments.

Determination of Genetic Coefficients Necessary to Simulate Phenology in Selected Sorghum Cultivars

G. Alagarswamy

The most important requirement in breeding cultivars adapted to marginal, water-limited environments is an appropriate phenology to match the development of the crop to the expected pattern of available water. This is particularly important for most tropical sorghums which, unlike pearl millet, do not possess the developmental plasticity of tillering, which allows within-season adjustment to moisture stress. Large advances have been made in the last several years in the ability to model crop phenology from an understanding of the effects of photoperiod and temperature on crop development, so that phenology simulation models may soon become applied breeding tools.

Most cereal crop simulation models operate on a similar basic set of assumptions about the pattern of crop development. The vegetative stage of cereal species is divided into (1) an initial period in which the species is not sensitive to photoperiod - the so-called preinductive stage - and (2) an inductive stage in which plants are capable of changing from vegetative to reproductive growth if they experience an inductive photoperiod. The total length of the vegetative period is the sum of the preinductive and postinductive periods, both of which are assumed to be under genetic control. Successful modelling of the occurrence of panicle initiation in a given cultivar requires the ability to determine the length of these two periods for any specific set of photoperiod and temperature conditions.

Most cereal crop simulation models also assume that the photoperiod-sensitive phase ends at panicle initiation. However, recent work at the University of Reading, UK, has indicated that in maize and rice plants photoperiod influences persist for sometime even after panicle initiation. The past-initiation responses of sorghum are not known.

As a part of our research on the characterization of sorghum test location environments (ICRISAT Cereals Program Annual Report 1991, p. 11), we are determining genetic constants and coefficients necessary to model the phenology of the set of cultivars used in the multilocation, multiyear field experiments. The results for some selected cultivars from this study are discussed here.

Duration of the inductive period. The duration of the photoperiod insensitive and sensitive stages in photoperiod-sensitive cultivar IS 2284 was determined from a reciprocal transfer experiment, in which plants (grown outdoors in pots) are transferred from short day (SD = 9h) to long day (LD = 17h) treatments, and vice versa, at different times after seedling emergence. The control treatments involved continuous SD and LD conditions. The date of panicle initiation was recorded from a dissection of plant apices for each transfer. The duration of photoperiod insensitive and sensitive stages was graphically determined by plotting time to panicle initiation (PI) against time of transfer from one treatment to the other.

The time to PI for control plants kept in continuous SD conditions was 14.6 $\pm$0.19 days, and 30.0 $\pm$0.19 days for control plants kept in continuous LD conditions days (Fig. 2). These times agreed with the minimum times to PI for plants transferred from LD to SD conditions and with the maximum times to PI for plants transferred from LD to SD conditions. The plants in both exchange treatments did not respond to a change in photoperiod for the first 6 days after emergence, indicating that the duration of the photoperiod insensitive, preinductive stage in IS 2284 is 6 days.

Plants transferred from SD to LD between 7 and 10 days after emergence reached PI progressively earlier as the time of transfer was delayed, reaching the SD control value at 10 days (Fig. 2). There was no further effect of time of transfer on time to PI after this time. Thus, plants received an inductive stimulus from the original SD conditions between day 7 and day 10, and a transfer to noninductive, LD conditions after this stage no longer had a delaying effect on PI. The duration of inductive stage therefore was 4 days under inductive SD conditions.

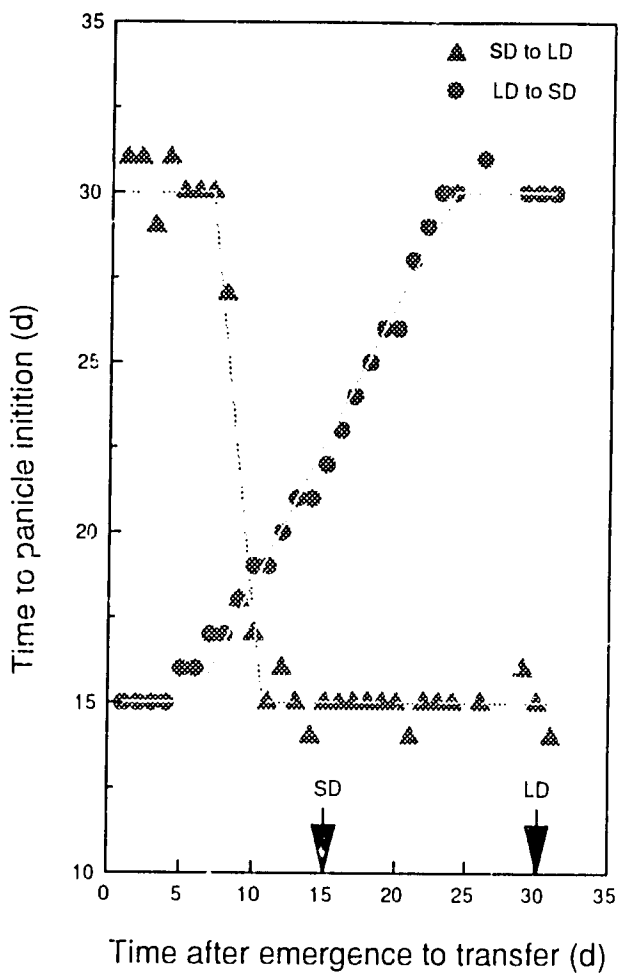

Figure 2. Time to PI for plants moved from SD to LD or from LD to SD at various times after emergence. (Arrows indicate time to PI for plants that were kept continuously either at SD or LD.)

Plants transferred from LD to SD showed an opposite response, reaching PI progressively later as they were transferred to LD from day 7 to day 24 (Fig. 2). The plants transferred from LD to SD conditions did not respond to a transfer to SD following 24 days after emergence, indicating that they had been induced to begin reproductive development even in the LD conditions by 24 days. The duration of inductive stage under the LD treatment therefore was 17 days, an increase of 13 days compared to the SD treatment.

In both the transfer treatments the photoperiod inductive stage ended approximately 5 days before PI was actually observed in the dissection of the apices (Fig. 2). This interval probably represents the time required for the inductive stimulus to promote sufficient cell division and growth for the change to become visible in the shoot apex.

This duration of the inductive stage for IS 2284, during which plants are sensitive to photoperiod, ranged between a minimum of 4 days (determined in the SD to LD transfer) to 17 days (from the SD to LD transfer). This is considerably shorter than comparative values reported for rice and maize.

Effect of photoperiod after panicle initiation. There was no evidence that the time to flowering in IS 2284 was affected by a change in photoperiod after PI (Fig. 2). This supports the assumption in several sorghum simulation models that the photoperiod-sensitive phase ends at PI in this species.

To specifically test this conclusion we conducted a daylength transfer experiment after PI, with two highly photoperiod-sensitive cultivars, IS 2284 and Naga White, plus an insensitive one, IRAT 204. Plants were grown in containers in a SD regime of 9h and dissected periodically to determine the time of panicle initiation. As soon as this occurred, plants were transferred from SD to a broad range of different photoperiods of 9 to 18 h. Days to flowering and total leaf number were recorded for individual plants as they flowered. The duration of the panicle development phase was calculated from days to panicle initiation and days to flowering.

Photoperiod treatment after panicle initiation had only very small effects on duration of the panicle development phase in any of the cultivars.

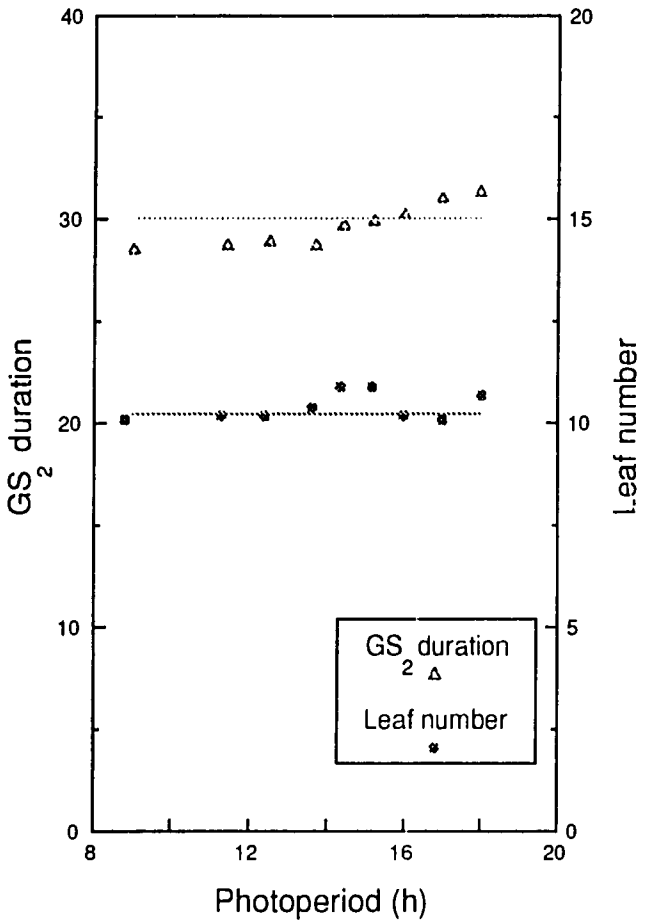

Figure 3. Effects of photoperiod after panicle initiation (PI) on duration of the panicle development (GS 2) phase and on total leaf number in IS 2284.

In IS 2284, for example, the duration increased only from 28.7 ±0.31 to 31.5 ±0.87 days as photoperiod increased from 9 to 18 h, and total leaf number was not influenced by changes in photoperiod (Fig. 3), indicating that no additional leaves were formed on the apex under the long photoperiods after PI (Fig. 3).

These results indicate that the phenology of the diverse cultivars used in this study was not sensitive to changes in photoperiod after panicle initiation. This supports the assumption in sorghum crop models that photoperiod sensitivity influences development only until panicle initiation.

Diseases

Sorghum Leaf Blight (*Exserohilum turcicum*) and Rust (*Puccinia purpurea*)

Breeding for Resistance to Rust and Leaf Blight

Belum V.S. Reddy and S.D. Singh

In continuation of our work to breed improved, leaf blight and rust-resistant seed parents (ICRISAT Cereals Program Annual Report 1991, p. 24), we made a total of 346 selections (116, 171, and 59 from crosses involving durra, rust-resistant, and anthracnose-resistant source lines respectively) that were resistant to one or both diseases. We made testcrosses of the selections to milo cytoplasmic-nuclear male-sterile (cms) lines at Bhavanisagar in the 1992 summer, and evaluated the testcrosses in the 1992 rainy season. We found 15 testcrosses that were sterile, and backcrossed these to their male parent line at IC.

Following a previous demonstration of resistance in established A/B and R-lines (ICRISAT Cereals Program Annual Report 1991, p. 24), we confirmed three R-lines resistant to leaf blight, three R-lines and one B-line resistant to rust, and six R-lines resistant to both. In initial screening of more B- and R-lines, 21 R-lines were resistant to rust, and 3 B-lines and 21 R-lines were resistant to leaf blight. These lines and the 346 selections mentioned above are undergoing further screening during the 1992 postrainy season.

Rust-resistant source lines ICSV 91022 and ICSV 91023 were found to be sterility maintainers with A_3 and A_4 (Maldandi) cms systems, and have been converted (BC_6) to male sterility on both these cytoplasms.

Inheritance of Resistance to Sorghum Leaf Blight

J.A. Sifuentes, L.K. Mughogho, and R.P. Thakur

Leaf blight is an important disease in major sorghum-growing areas of the world, particularly in areas characterized by moderate temperatures and heavy dews. The disease can be best controlled through host plant resistance. Although several sources of resistance to leaf blight are known and some of these are being utilized in resistance breeding, information on the genetics of resistance was lacking. We studied the inheritance of resistance with the objective of achieving more effective utilization of resistance to leaf blight.

Two leaf blight resistant (A 2267-2 and ICSB 26) and four susceptible (ICSB 13, H 112, 296B, and ICSV 359) sorghum genotypes were used to generate seven single and reciprocal crosses.

In a field experiment during the 1990-91 postrainy season, plants of the parental lines, F_1, F_2, and BC generations were grown and inoculated by placing sorghum grains colonized by *E. turcicum* into the leaf whorl at 40 days after emergence. Inoculation was repeated by placing infected sorghum leaf pieces into the whorl 10 days later. Single row plots were used, and the susceptible cultivar H 112 was grown after every 10 rows as a disease spreader. The parental lines were grown in 2-4 rows, F_1 and BC populations in 6-10 rows, and F_2s in 30-40 rows each. High relative humidity was created by providing sprinkler irrigations between 1530 and 1630 h on alternate days until flowering and disease development.

Plants were scored for blight development 15 days after flowering, as percentage of leaf area covered with blight symptoms on the top three leaves. Scores were divided into resistant (<30% leaf area blighted) and susceptible (>30% leaf area blighted) classes, and the segregation among the classes was tested by Chi-square.

F_1 plants from resistant (R) x susceptible (S) or SxR crosses showed resistant reaction, indicating that resistance was dominant with no influence of cytoplasm. Disease reaction of BC populations indicated the presence of a single dominant gene governing resistance in A 2267-2 and ICSB 26. The F_2 plants of all RxS crosses segregated on a 3R:1S ratio, confirming a single dominant gene for resistance. However, in an F_2 population of an RxR cross, some plants showed susceptible reaction, indicating involvement of different genes for resistance in A 2267-2 and ICSB 26.

Sorghum Anthracnose
(*Colletotrichum graminicola*)

Breeding for Resistance

Belum V.S. Reddy and S.D. Singh

Based on their resistance under artificial inoculation, we selected 21 single plants from F_5 and F_4 families derived from the resistant source TRL 74/C-57. We also created three new F_2 populations involving another resistant source line, A 2267-2, and six four-way cross F_2s using the source TRL 74/C-57.

Further breeding and backcrossing during the 1991/92 postrainy season (ICRISAT Cereals Program Annual Report 1991, p. 25) provided 20 single cross F_7, 34 three-way cross F_6 and 12 four-way cross F_4 progenies, and 8 single cross F_6, 16 three-way cross F_5 and 10 four-way cross B-lines. These were evaluated for resistance in the 1992 rainy season after artificial inoculation using whorl application of infected grains under sprinkler irrigation. The susceptible control received a score of 7 on a scale of 1 to 9, where 1 = highly resistant and 9 = highly susceptible to the disease. The range for the disease score was 2 to 5 among the progenies, and 2 to 7 among B-lines. The mean disease severity in the selections (3.2 to 4.7) was considerably less than susceptible control, IS 18442 (7.0). There was considerable range among the selections in plant height (1.0 -2.0 m), and in time to 50% flowering (65-95 days).

We selected plants for high grain yield and agronomic desirability from the families that scored ≤ 3 for resistance. We obtained 27 F_8 (from single crosses), 44 F_6 (from three-way crosses), and 15 F_4 (from four-way crosses) progenies derived from TRL 74/C-57; and 28 F_4 progenies from single crosses of A 2267-2. Also, we made 87 new testcrosses from which we identified 16 sterility maintainers. First backcrosses were completed for these lines and fourth backcrosses for eight other maintainer lines identified earlier.

We completed six backcrosses to convert TRL 74/C-57 to male sterility on four cms systems - A_1, A_2, A_3, and A_4 (Maldandi) - and A 2767-2 on A_3 and A_4 (Maldandi) cms systems.

Inheritance of resistance. All six crosses were made among two anthracnose-resistant lines, IS 2058 and IS 7775 (identified from greenhouse and multilocational screening experiments in India and Africa between 1984 and 1990), and two highly susceptible lines, IS 914 and IS 18441, together with the reciprocal crosses and backcrosses to both of the parents. The parents, F_1, F_2, backcrosses, and their reciprocals were evaluated by artificial inoculation with the local isolate of anthracnose in the 1991 rainy season at IC under field conditions. Individual plant observations on the extent of leaf area affected by the disease were taken using a 1 to 5 rating scale (1 = leaves free from disease and 5 = >40% leaf area damaged). The analysis showed that a single dominant gene controls resistance to anthracnose in both the resistant parents, and that the effect of cytoplasm on resistance is not significant.

Screening for resistance. We screened 7 B-lines, 56 R-lines (including 12 selected for resistance in 1991), and 28 potential new R-lines during the 1992 rainy season screening nursery at Pantnagar. Also, we screened 59 midge and 17 stem borer resistant potential new restorer lines. One B-line, ICSB 91001, was resistant to anthracnose for the second year. Of the 12 R-lines selected for resistance earlier, 7 (ICSR 26, ICSR 89030, ICSR 89034, ICSR 90001, ICSR 90023, ICSR 91001, and ICSR 91006) were resistant for the second year. Thirty-two R-lines were selected from the remaining 44 R-lines for resistance to anthracnose. We also selected 10 potential new R-lines, and 46 pest-resistant potential new restorer lines for further screening.

Sorghum Downy Mildew
(*Peronosclerospora sorghi*)

Identification of Resistance

S.D. Singh

We continued to screen sorghum accessions with the objective of diversifying our sources of resistance to downy mildew. Earlier tests evaluated most of the available accessions that flower in less than 80 days at IC. During 1991-92, we screened 800 accessions that flower in more than 80 days at IC, using a seedling inoculation technique described previously (ICRISAT Cereals Program Annual Report 1991, p. 29).

Each accession was sown in three pots with at least 20 seedlings per pot. Sorghum cultivar DMS 652 served as a susceptible control. About 100 accessions were screened at a time.

There was a high level of disease development in all the tests, with DMS 652 developing >95% downy mildew. Plants of 10 accessions (IS 18512, IS 18552, IS 18713, IS 18714, IS 19018, IS 19096, IS 19105, IS 19239, IS 20049, and IS 20205) did not develop disease symptoms, and 4 accessions (IS 18716, IS 19019, IS 19506, and IS 19971) developed <5% downy mildew. We will retest the reactions of these entries.

Breeding Resistant Seed Parents

Belum V.S. Reddy and S.D. Singh

Maintainer lines of 296BxIS 18757 (QL3). Eighteen downy mildew resistant maintainer lines selected from a cross of elite maintainer line 296B and downy mildew resistant line IS 18757 (QL 3) have now undergone 7 backcrosses to develop male-sterile lines with milo cytoplasm (ICRISAT Cereals Program Annual Report 1991, p. 26). After the sixth backcross, both A-lines and B-lines were evaluated for downy mildew resistance, using a seedling inoculation technique in a greenhouse during the 1991 postrainy season. The results showed that all the lines were free from disease, confirming their resistance to downy mildew. Both male-sterile lines and their maintainer lines were equally resistant, indicating that the milo cytoplasm did not differ from the fertile cytoplasm in its effect on resistance.

During the 1991 postrainy season, the selected resistant A/B-lines (SP 85013, SP 85019, SP 85023, SP 85035, and SP 85047) produced higher grain yields at least equal to the control check, 296B, and also flowered 10 days earlier than 296B, indicating that they were less sensitive to low temperatures (Table 2). Grain mass and height of the selected lines were similar to that of 296B.

Table 2. Performance of downy mildew resistant B-lines, evaluated[1] during postrainy season 1991, ICRISAT Center[2].

Entry	Grain yield (t ha^{-1})	Time to 50% flower (d)	Plant height (m)	100-grain mass (g)
SP 85013	2.6	90	0.9	2.0
SP 85019	2.0	92	1.0	2.3
SP 85023	3.0	92	0.8	2.0
SP 85035	2.6	88	0.9	2.3
SP 85047	2.0	93	1.0	2.3
296B (Sus.)	1.6	102	0.9	2.0
QL 3 (Rest.)	2.7	87	1.1	2.0
SE	± 0.5	± 2.3	± 0.05	± 0.4
CV%	24	3	6	20

1. Randomized complete block design, three replications.
2. Location BM8 = Vertisol, high fertility (N86:P40:KO), and sprayed.

296B backcross materials. We earlier reported selection of 85 F_4 single plants from backcrosses to 296B of downy mildew-resistant derivatives from the cross 296B x IS 18757 (Cereals Program Annual Report 1991, p. 26). We selected 269 F_5 plants from the families derived from these plants during the 1991 postrainy season, based on seed mass, plant height, and grain yield. We screened these progenies for downy mildew resistance and found that 78 of the families were highly resistant (<5% susceptible plants), 70 were moderately resistant (5-20% susceptible plants), and 121 families were highly susceptible (>20% susceptible plants). We selected 282 individual F_6 plants based on grain mass and yield (226 from resistant and 56 from the moderately resistant families) and backcrossed them to milo male-sterile lines to identify sterility maintainers for conversion to male sterility.

Materials with diversified resistant source and maintainer lines. We crossed resistant source line IS 18757 (QL3), SP 36257, and other lines with confirmed resistance to elite ICRISAT-bred milo cytoplasm B-lines to diversify our sources of downy mildew resistance, and selected several resistant progenies (ICRISAT Cereals Program Annual Report 1991, p. 26). We evaluated the progenies for resistance and good agronomic type in the 1991 postrainy season, and selected 59 single cross F_7, 75 three-way crosses F_6, and 12 four-way cross F_5 progenies. All these families were again evaluated for resistance in the greenhouse and for agronomic desirability in the field during the 1992 rainy season. We identified 57 lines with sterility maintenance reaction and 60 other progenies with resistance and high yield. The maintainer lines are at various stages of conversion (BC_1 to BC_4) to male sterility.

Effect of selection. Selection was carried out for resistance on a family basis, and for agronomic desirability among individuals within the selected family. All the progenies mentioned above are in F_5 and subsequent generations. Considering them all as pure lines, we assessed the effectiveness of different numbers of cycles of selection for downy mildew resistance carried out using the seedling inoculation technique in different types of crosses. The final number of selections in F_5, F_6, and F_7 progenies is the reflection of the selection for resistance and agronomic desirability. The results (Table 3) showed that the proportion of resistant progenies was higher in the advanced selection cycles irrespective of type of cross, indicating that the selection for resistance and agronomic desirability was effective. The proportion of the number of selections in the advanced generations to those in the initial generations was 0.47 in single cross (three selection cycles), 0.53 in three-way cross (two cycles), and 0.21 in four-way cross (one cycle) progenies. This indicates that the three-way cross system is advantageous.

Inheritance of resistance. Based on screening for resistance of F_4 and F_5 families from the cross 296B x IS 18757 (QL3) using the seedling inoculation technique, we deduced that resistance to downy mildew is controlled by dominant alleles at two loci interacting in an epistatic and complementary manner. To verify these findings, we made crosses involving the resistant lines IS 18757 and SP 36257 and the susceptible 296B. We generated F_1, F_2, and backcross generations and their reciprocals, and screened them for resistance using the greenhouse seedling inoculation technique during the 1991 postrainy season. None of the various single and two-gene models with various forms of interaction gave consistent fit across all generations.

There were some differences in the percentages of susceptible plants in the crosses alone depending on the female parent. However, these were not significant and there was no evidence of cytoplasmic effects.

In the screening exercise, we noted that some seedlings of the resistant control IS 18757 showed susceptible symptoms during their early stages but later recovered and that all plants of the susceptible control 296B did not express symptoms. We therefore feel that some seedlings of the test material may have been misclasified in the screening exercise, leading to the observed discrepency and our inability to discern a clear pattern of inheritance of resistance.

Table 3. Progenies with different levels of downy mildew resistance in various crossing systems, ICRISAT Center 1990-92.

Crosses/ progenies		No. of progenies	% Progenies with infestation levels <5%	5-20%	>20%	Cycles
Biparental	F_3	126	27	21	52	
	F_7	59	73	3	24	3
Three-way	F_3	139	24	18	58	
	F_6	75	56	17	27	2
Four-way	F_3	57	7	9	84	
	F_5	12	17	8	75	1
296B (296B x QL3)	F_5	269	29	26	45	

Sorghum Ergot (*Sphacelia sorghi*)

Identification of Resistance in Hybrid Parents

Belum V.S. Reddy and R. Bandyopadhyay

We previously selected 8 B-lines and 11 R-lines for resistance to ergot, based on high efficiency of self pollination at low temperatures and low reduction in percentage of healthy florets on inoculated heads (ICRISAT Cereals Program Annual Report 1991, p. 27). The selected B- and R-lines, and an additional set of 12 B-lines, 72 R-lines, and 113 potential new restorer lines were screened in the 1991 postrainy season under field conditions with artificial inoculation. Only 2 R-lines (ICSR 89041 and ICSR 64) were selected from the earlier identified set of 11, and none of the 8 B-lines was found to be resistant, based on a criterion of $\geq$85% healthy florets under inoculation. From the initial screening set, one B-line (ICSB 90002) and four R-lines (ICSR 90015, ICSR 90020, ICSR 91019, and ICSR 91010) were found to have <19% damaged florets under

inoculation, and were selected for further evaluation. None of the potential new restorers was resistant to ergot.

Sorghum Grain Molds

Identification of Resistance

S.D. Singh and K.E. Prasada Rao

We tested photoperiod-sensitive, white-grain sorghum accessions from GRU for the identification of resistance to grain mold fungi. Initially, 66 guinea sorghum accessions were tested against three major grain mold fungi: *Fusarium moniliforme*, *F. pallidoroseum*, and *Curvularia lunata*, using a newly developed in-vitro screening technique. The technique involves inoculation of seeds with the spores of grain mold fungi, transferring inoculated seeds into presterilized petri-plate humidity chambers, and incubation at 28^{0}C for 5-6 days. Fourteen of the accessions showed a moderate to high degree of grain mold resistance against all three pathogens in three successive tests.

Seedlings of the 14 resistant genotypes from the in vitro tests were transplanted into pots in June 1992. Twenty-one days after transplanting, the plants were exposed to 8-hr-day light treatment (by covering the pots with a thick black cloth from 1600 to 0800 h the following day) for 30 days to induce flowering. At heading, the pots were shifted to the grain mold nursery where high humidity was maintained by operating overhead sprinklers.

Panicles of all the entries were inoculated with a spore mixture (1 x 10^{6} spore mL^{-1}) of the three fungi. Observations taken 55 days after inoculation showed that four entries (IS 7173, IS 23773, IS 23783, and PM 210) did not develop grain mold. Six entries (IS 7326, IS 4963, IS 5726, IS 4011, IS 5292, and IS 27761) developed low to moderate grain mold (ratings of 2 to 3 on a 1 to 5 rating scale). The remaining four entries could not be screened successfully. We plan to retest the reactions of all these entries next year.

This result indicates that photoperiod-sensitive guinea-based germplasm has promise for grain mold resistance. Further screening of accessions from this group will be desirable to identify more sources of grain mold resistance. It would be useful if this material was converted to a day-length insensitive background for its utilization.

Breeding Resistant Seed Parents and Hybrids

Belum V.S. Reddy and S.D. Singh

Milo cytoplasmic male-sterile lines. Agronomic evaluation of selected grain mold resistant progenies (ICRISAT Cereals Program Annual Report 1991, p. 28) was carried out during the 1991 postrainy season and gave us 225 white-grained, 220 red-grained, and 55 brown-grained selections.

These were evaluated under sprinklers at IC in the 1992 rainy season for grain mold resistance and for agronomic desirability. We continued to select for short plant height (<1.75 m), bold grain with reduced glume coverage, and low grain mold incidence on the unthreshed panicles. After threshing, we also selected for low threshed grain mold rating (TGMR) on a 1 to 9 scale (1 = no molds on grain surface, 9 = >50% grain surface area with molds). A total of 94 white-grained, 88 red-grained, and 25 brown-grained selections were made by selecting those that rated 6 or below in white-grained types, 5 or below in red-grained types, and 4 or below in brown-grained types.

These selections were evaluated in a nursery for grain hardness, grain mass and density. The results (Table 4) showed that white and red-grained selections were (numerically) harder and yet less mold resistant than brown-grained selections, and had higher grain mass than brown-grained selections.

Table 4. Characteristics of grain mold-resistant selections, ICRISAT Center, rainy season 1992.

Grain color	TGMR[1] ±SE	Hardness[2] ±SE	100-grain mass (g) ±SE
White	4.6±(0.02)[3]	4.4±0.06	2.7±0.05
Red	3.0±(0.02)	4.6±0.09	2.7±0.04
Brown	2.4±(0.06)	4.0±0.24	2.4±0.09

1. TGMR = Threshed grain mold rating on a 1 to 9 scale, where 1 = no mold; 9 = over 50% of the surface of the threshed grain molded.
2. Pressure (kg cm^{-2}) required for breaking the grain.
3. Figures within parenthesis are based on square root transformation values.

We have been testcrossing resistant selections to milo cytoplasm male-sterile lines to identify sterility maintainers that have been backcrossed to convert them to male sterility. We now have, at the end of the 1992 rainy season, 64 lines in BC_1, 10 in BC_2, and 85 in BC_3.

We also evaluated 10 white, 10 red, and 10 brown-grained mold-resistant maintainer lines (obtained after two cycles of selection for mold resistance) for grain yield, mold resistance, and agronomic desirability. The results showed that the white-grained genotypes were least resistant (mean mold rating on unthreshed heads = 7.0 on a 1 to 9 scale, where 1 = no mold on head, and 9 = >90% head molded) while red-grained selections were intermediate (mean mold rating = 4.9) and brown-grained selections highly resistant (mean mold rating = 3.4). Two brown-grained selections produced grain yields significantly higher than 296B, while others were on par with 296B. All were found to be agronomically desirable for conversion to male-sterility (Table 5).

Table 5. Characteristics of B-lines selected for grain mold resistance, ICRISAT Center, rainy season 1992.

Entry no.	Grain color	Time to 50% flowering(d)	Plant height (m)	Mold[1] score	Grain yield (t ha^{-1})
8	White	68	2.0	7.0	2.6
11	Red	67	1.8	4.0	2.7
12	Red	74	1.3	3.7	2.7
20	Red	75	1.3	4.0	2.6
21	Brown	73	1.2	4.3	3.0
22	Brown	67	1.7	3.0	2.6
23	Brown	63	1.3	3.3	2.6
28	Brown	66	1.9	2.3	3.0
296B	White	76	1.3	9.0	1.9
SE		±0.8	±0.05	±(0.21)[2]	±0.3
CV%		2	6	19	31

1. Grain mold score on panicle on a scale of 1 to 9; 1 = free from mold; and 9 = >50% of the grain surface molded.
2. Figure within parenthesis is based on square root transformed values.

We also analyzed selections obtained in different crossing systems for their panicle grain mold resistance levels. The results presented in Table 6 showed that the biparental cross system was superior to the backcross or

Table 6. Panicle grain mold resistance scores in the progenies derived from different crossing systems, ICRISAT Center, 1992 rainy season.

Cross	Range: Mean ±SE	Min.	Max.	No. of progenies
White grain				
Biparental cross	7.8[3] ± (0.00)[4]	3	9	259
Backcross[1]	8.2 ± (0.02)	7	9	15
Three-way cross[2]	7.9 ± (0.02)	6	9	24
Red grain				
Biparental cross	6.5 ± (0.02)	3	9	210
Backcross	6.9 ± (0.06)	3	8	13
Three-way cross	6.7 ± (0.05)	5	8	11
Brown grain				
Biparental cross	3.3 ± (0.03)	3	6	30
Backcross	3.5 ± (0.04)	3	4	2
Three-way cross	6.3 ± (0.04)	5	8	6

1. Backcross to resistant parent.
2. Two susceptible parents and one resistant parent.
3. Score on 1 to 9 scale (1 = no molds and 9 = >50% grain mold).
4. Figures within parentheses are based on square root transformed values.

three-way cross system when considered on the basis of number of selections. However, when based on resistance levels (means and ranges), all types of crossing systems were equally good except in one of the brown grained selections in which the three-way cross system was inferior to the single cross and back cross systems.

Hybrids. The selected grain mold resistant hybrids (ICSH 91200, ICSH 91201, and ICSH 91202) obtained from crossing mold susceptible, red-grained female lines and white-grained male lines (ICRISAT Cereals Program Annual Report 1991, p. 29) continued to maintain grain mold resistance in the third consecutive screening. They were also evaluated for grain yield over three locations in the rainy season. They produced 5.0 to 5.6 t ha^{-1} grain yields, while the mold-susceptible control hybrid ICSH 153 yielded 6.4 t ha^{-1} (SE $\pm$0.17).

Preliminary hybrids were derived by crosses between white, red, and brown-grained pollinators (bred in the above program), and the Texas A&M red-grained but mold-susceptible female lines. Comparison of females, restorers, and their fertile hybrids for grain mold resistance is given in Table 7. The results showed that grain mold resistance was dominant in brown-grained hybrids of brown-grained males x red-grained females and in red-grained hybrids of red-grained males x red-grained females; and over dominant in red-grained hybrids of white-grained males x red-grained females. Red-grained but grain mold susceptible females and red and brown-grained but resistant males that were known to contain flavan-4-ols in quantities sufficient to maintain resistance were involved. The flavan-4-ols might have been inherited on a dominant trait resulting in resistant hybrids. In the latter group of white-grained hybrids, hardness in white-grained males might have contributed to the increased resistance level expressed.

Conversion of source lines to male sterility. We began conversion of source lines IS 9470 and IS 15119 to male sterility in the 1989 post-rainy season. Thus, by the end of the 1992 rainy season we have male sterile versions for IS 9470 with A_1 (milo), A_2, A_3 and A_4 (Maldandi), and IS 15119 with A_3 and A_4 (Maldandi) cytoplasms.

Table 7. Grain mold scores on panicles in hybrids and their parents, ICRISAT Center, 1992 rainy season.

Males		Red grain females	Hybrids	
Grain color	Mold score[1]	Mold score	Grain color	Mold score
White	7.3 (4)[2]	7.0 (4)	Red	6.0 (4)
Red	5.1 (48)	6.9 (13)	Red	4.8 (48)
Brown	3.5 (5)	7.2 (5)	Brown	4.2 (5)

1. Score on 1 to 9 scale, where 1 = free from molds and 9 = >50% grain surface area molded.
2. Numbers in parentheses indicate the number of lines/hybrids on which the means are based.

Insect Pests

Shoot Fly (*Atherigona soccata*)

Seasonal Variation in Sorghum Resistance to Shoot Fly

M.A. Farah[1] *and K.F. Nwanze*

1. Research Scholar, Department of Entomology, Andhra Pradesh Agricultural University, Hyderabad, India.

In Somalia the sorghum shoot fly (*Atherigona soccata*) is the most damaging sorghum insect pest after the stem borer (*Chilo partellus*). Sorghum is cultivated during both the long (Apr-Jun) and short (Oct-Dec) rainy seasons. The two seasons differ in temperature, daylength, humidity, etc., which affect both crop growth and insect population and activity.

In order to examine the effect of seasonal differences on sorghum shoot fly infestation, we made four experimental sowings (late postrainy season, 17 Feb 1990; early rainy season, 17 Jun 1991; late rainy season, 17 Jul 1991; and early postrainy season, 5 Oct 1991) under natural field conditions at IC. The test material consisted of 265 sorghum germplasm accessions of Somali origin with shoot fly susceptible (CSH 1) and resistant cultivars (ICSV 705 and IS 18551), and a local cultivar, IS 1054 (Maldandi), as controls. Data were recorded on egg laying, seedling damage (deadheart), recovery (tillering), grain yield, and environmental factors (temperature, humidity, and rainfall).

The early rainy season crop sown on 3 Jun 1991 was relatively free of shoot fly damage but grain yield was very low due to delayed flowering of the photoperiod-sensitive Somali germplasm. Results from this sowing were not used in our analysis. The crop sown in the late rainy season suffered the highest mean shoot fly damage (99% deadhearts) and recorded the lowest mean grain yield (494 kg ha^{-1}). Average maximum and minimum temperatures were 30°C and 20°C, respectively. The late postrainy season crop gave the highest mean grain yield (1845 kg ha^{-1}) in spite of a high mean shoot fly damage of 89% deadhearts. This was due to good crop recovery and a high rate of tiller productivity, and was associated with the highest maximum (38°C) and minimum temperatures (20°C) of the four cropping seasons. Although the early postrainy season crop suffered comparatively low shoot fly damage (55% deadhearts), mean yield was lower (1249 kg ha^{-1}) than in the late postrainy season crop due to poor growth and low crop recovery associated with very low minimum temperatures (14°C).

Very few germplasm entries were consistent in their response to shoot fly infestation across seasons. The lowest rates of oviposition were recorded on IS 32530 (10% plants with eggs), IS 32512 (14%), and IS 32525 (15%) in the postrainy season sown crops. Similarly IS 32530 and IS 32512 suffered the lowest shoot fly damage (25% and 35% respectively).

These results indicate that some genotypes are not too adversely affected by seasonal differences in insect population and environmental conditions.

Shoot Fly Resistance Factors

S.L. Taneja and R.K. Maiti[1]

1. Visiting Scientist (Sep 1991-Jul 1992), University of Nuevo Leon, Mexico.

In order to assess the contribution of various factors associated with resistance to sorghum shoot fly, selected morphophysiological traits (glossiness, seedling vigor, and trichomes) and shoot fly reaction (oviposition and damage) were compared in 520 sorghum genotypes in field and pot experiments conducted in 1991 and 1992. The intensity of glossiness and relative seedling vigor were scored separately on a 1-5 scale (1 = most glossy/vigorous and 5 = nonglossy/least vigorous), 14 days after crop emergence (DAE). The fourth leaf in each genotype was sampled at 14 DAE, cleared with alcohol, acetic and lactic acid, and examined under the microscope for the presence of trichomes on the upper and lower surfaces. Shoot fly infestation was recorded as oviposition (%) at 14 DAE and deadhearts (%) at 28 DAE.

Shoot fly infestation was negatively related to the intensity of glossiness and seedling vigor. Shoot fly infestation was also lower in genotypes with trichomes on both leaf surfaces. Genotypes with the maximum intensity of glossiness

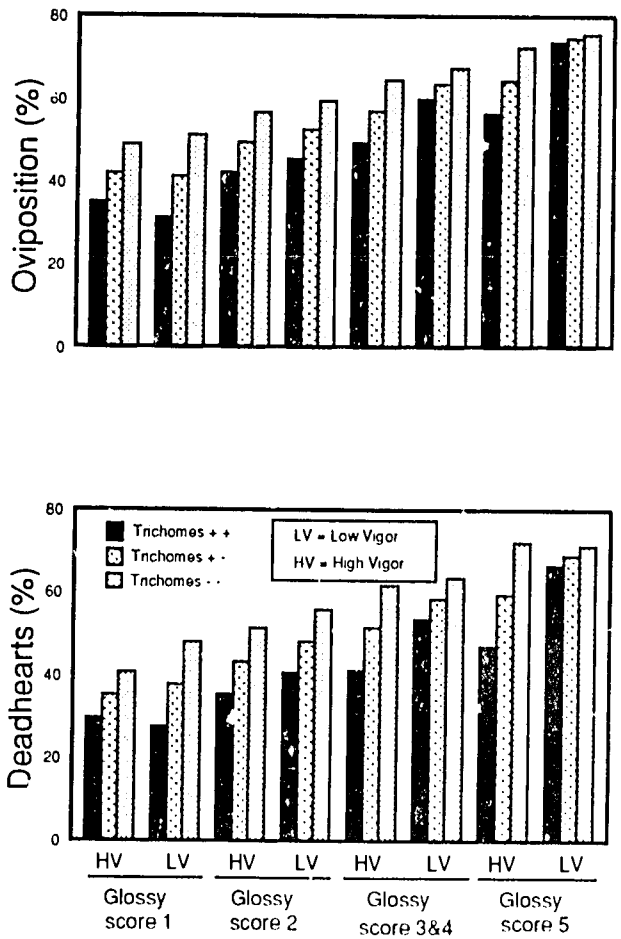

Figure 4. Effect of glossiness, seedling vigor and trichome on shoot fly oviposition and damage, postrainy season ICRISAT Center.

and the presence of trichomes on both leaf surfaces had the lowest shoot fly oviposition and damage (Fig. 4).

These genotypes were further classified on the basis of geographic origin and taxonomic race. Minimum shoot fly infestation was recorded in genotypes from the USA and bicolor race in glossy score 1. However in glossy score 2, durra sorghums of Indian origin had the lowest shoot fly infestation. Genotypes with higher level of resistance belonged to durra and bicolor races, and most of them originated or were assembled in India and the USA. Maximum infestation was observed in guinea sorghums of African origin. Among the geographical groups, heritability (%) for shoot fly resistance was positively related to the level of glossiness in both sorghums of Indian and African origin. This suggests that genotypes of African and Indian origin with a high glossy score were better than other origins for breeding to improve shoot fly resistance.

Morphological Factors Associated with Leaf Surface Wetness

P. Swarna Sree, D.R. Butler, and K.F. Nwanze

Leaf surface wetness (LSW) of the central whorl leaves of sorghum seedlings is closely associated with susceptibility to shoot fly damage (ICRISAT Annual Report 1988, p. 7). An earlier study using low temperature scanning electron microscopy showed distinct differences between resistant and susceptible genotypes in epicuticular wax morphology and leaf wettability, but gave no indication if LSW originates from atmospheric condensation or from the plant. We designed an experiment to determine the source of LSW and also examined several morphological structures of the central whorl leaf for their role in LSW.

The first part of this study was an experiment to determine whether moisture on the central whorl leaf condenses from the atmosphere. Condensation should be detected by an increase in seedling weight during the night. Using intact and excised 10-day old seedlings of two sorghum cultivars, shoot fly susceptible CSH 1 and resistant IS 18551, we recorded a rapid decrease in weight of excised seedlings from 2100 to 0300 h (Fig. 5a) when LSW on intact seedlings was increasing (Fig. 5b). Differences between CSH 1 and IS 18551 in the weight change of excised seedlings were not significant but there were large differences in LSW between these genotypes on intact plants. The weight loss from the excised seedling showed that water was evaporating at the time when LSW was increasing. This implies that LSW originates from the plant and that the rate of supply exceeds the rate of evaporation. The increase in weight of excised seedlings between 0300 h and 0500 h occurred when atmospheric conditions were conducive to dew formation and condensed water was observed on expanded leaves.

In the second part of this study, microscopic examinations were made of the leaf cuticle, trichomes, and stomata of five cultivars (three shoot fly resistant cultivars, IS 18551, IS 1057, and IS 1054, and two susceptible cultivars, IS 1046 and CSH 1). Trichomes were present only in the resistant cultivars and were more numerous on the upper than on the lower leaf surface. Differences in stomatal density among genotypes were not significant. Although there were differences between cultivars in the thickness of the cuticular membrane, these

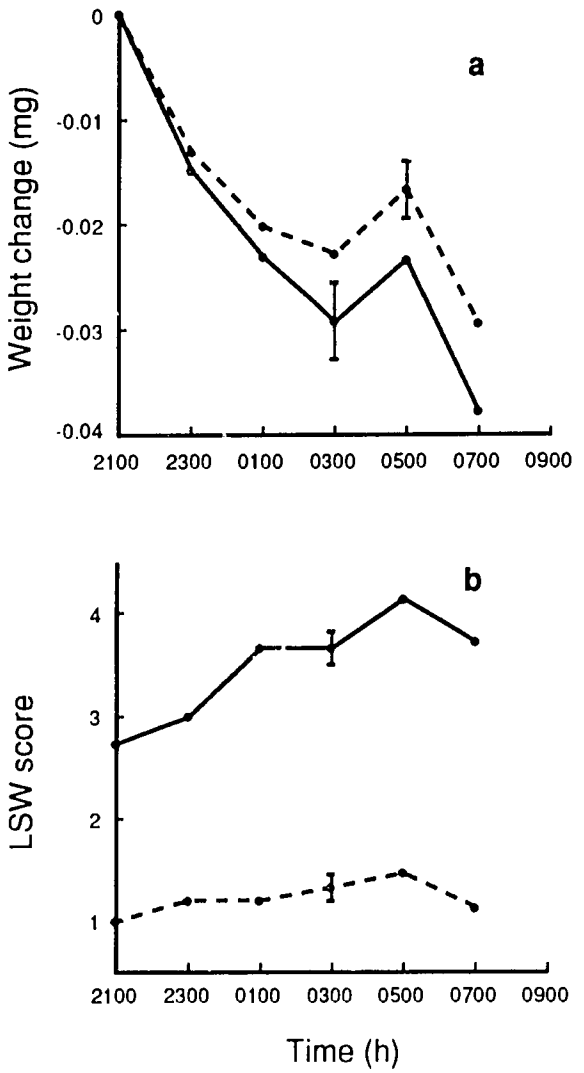

Figure 5. Changes with times of (a) weight of seedlings and (b) LSW on the central whorl leaf of intact 10-day seedlings (CSH 1 ——•——, IS 18551 ------•------).

differences were not related to resistance or susceptibility.

We conclude that, although LSW originates from the plant, it is not associated with any of the leaf characters studied, except possibly the presence of trichomes.

Chemical Control

S.L. Taneja and S.K. Pal

In the 1991 postrainy season, we evaluated the efficacy of different insecticide as soil, whorl, and foliar applications for shoot fly control (ICRISAT Cereals Program Annual Report 1991, p. 41). The most effective control was obtained with whorl application of carbofuran (which resulted in grain yield four times as great as the untreated control), followed by foliar application of cypermethrin. Soil application of carbofuran was the least effective treatment. We also established that two applications of carbofuran (whorl) and cypermethrin (foliar) at 6 and 12 days after crop emergence (DAE) gave optimum control.

To determine the effectiveness of these chemicals in the rainy season, we compared the above treatments with other formulations used as soil, seed, and foliar applications in a 1992 rainy season crop of using shootfly susceptible genotype CSH 5. Shoot fly infestation was 100% in the untreated control. Carbofuran soil application, carbosulfan seed treatment and quinalphos foliar application (three sprays) gave very poor protection (98-100% infestation). The most effective treatment was imidacloprid (a nitromethylene analogue systemic insecticide) seed treatment (10% infestation). Whorl application of carbofuran was the second best treatment (45% infestation). Although cypermethrin foliar application was significantly superior to the other foliar sprays, it was not as effective as in the postrainy season, primarily because of continuous rains and early shoot fly infestation that occurred much before the first application (6 DAE) of the insecticide. Thus, effective control of shoot fly in the rainy season requires, either seed treatment with imidacloprid or whorl application of carbofuran. Foliar application of cypermethrin, if used, should be started even before 6 DAE and with a total of three applications at 6-day intervals.

Crop Management in Pest Control

K.F. Nwanze and M.M. Anders

Sorghum shoot fly (*Atherigona soccata*) is the major pest of postrainy season sorghum in India where a negligible proportion of farmers apply insecticides on their sorghum crop. In order to determine the potential for optimizing shoot fly control within the framework of existing farming practices, we designed a factorial experiment during the 1991/92 postrainy season to evaluate the effect of cultivar [shoot fly resistant ICSV 705, moderately resistant IS 1054 (Maldandi), and susceptible CSH 5 and CSH 9], sowing date (24 Oct and 14 Nov), fertilizer (ammonium phosphate, 75 kg ha^{-1}), and soil moisture

(rainfed and irrigated) on shoot fly populations and damage. The irrigated plots were intended to simulate conditions of late rains that extend the sowing date and ensure establishment of the postrainy season crop. Observations were recorded on deadhearts, soil moisture, and grain and fodder yield.

In the postrainy season, a depression in shoot fly population usually occurs in the first half of October and crops sown during this period suffer less damage. However, in this study, late September rains resulted in the October crop being sown 10 days late, and susceptible cultivars (CSH 5 and CSH 9) suffered higher shoot fly damage (50-80% deadhearts) in the October sowing than the November sowing (3-60%) (Fig. 6a and b). Damage was considerably lower in resistant ICSV 705 and IS 1054 for both sowings (Oct: 5-15%; Nov: <5%).

Irrigation effects were negligible in the October sowing (due to late September rains), but the November irrigated, fertilized crop suffered twice as much damage (mean of 55% in susceptible genotypes) than the rainfed, fertilized crop. Fertilizer application increased shoot fly damage in all treatments, but the effects were more pronounced on susceptible genotypes in the November-sown crop.

The local cultivar, IS 1054 (Maldandi), gave better yields than all other genotypes under all management conditions. Dry grain yields were highest for IS 1054 in both plantings (Fig. 7). CSH 9 produced the highest dry fodder yields in the October sowing (Fig. 8a) while IS 1054 was highest in the November sowing (Fig. 8b). Of the commercial genotypes, CSH 9 grain yields were lowest but its fodder yields were higher than CSH 5. Grain and fodder yields for ICSV 705 were low because of poor stand establishment. IS 1054 is a locally adapted postrainy season while CSH 5 and ICSV 705 are rainy season cultivars. CSH 9 is recommended for both seasons.

The results for grain and fodder yield in this trial reflect of both differential shoot fly infestation and differential adaptation to postrainy seasonal conditions and therefore should be interpreted with caution. Shoot fly is a primary constraint to postrainy season sorghum production and differences in infestation are conditioned by both genotype and management. However, there also is a need to develop cultivars with improved postrainy season performance under existing management conditions.

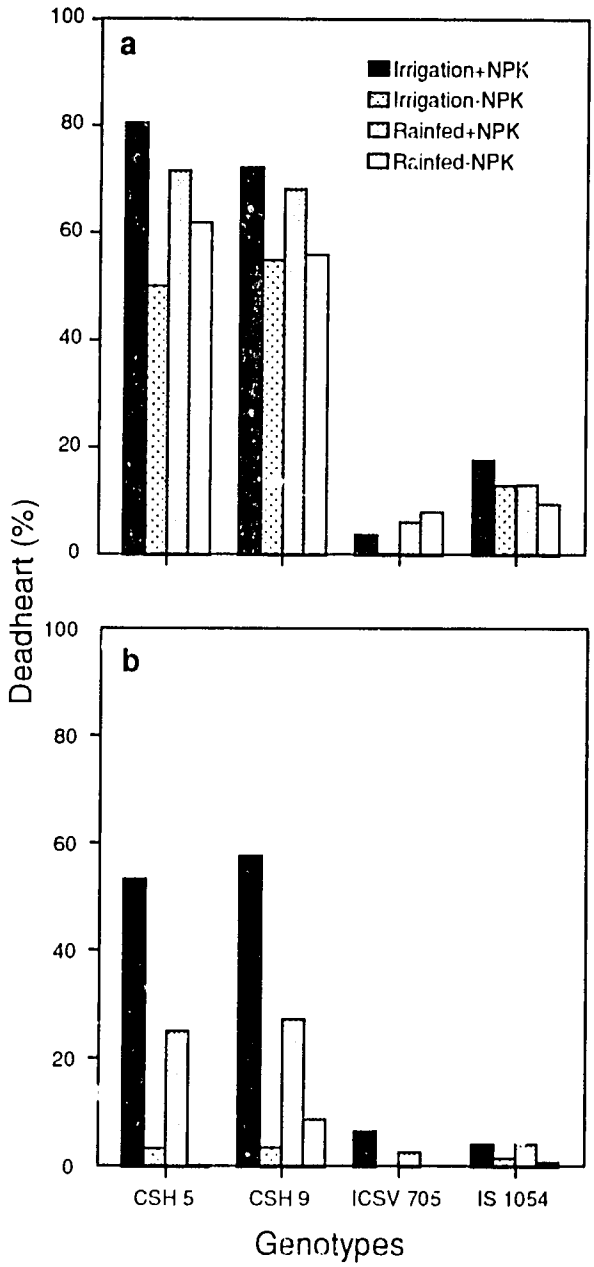

Figure 6. Shoot fly damage (deadhearts) in four sorghum genotypes sown under various crop management practices, (a) October and (b) November sowing.

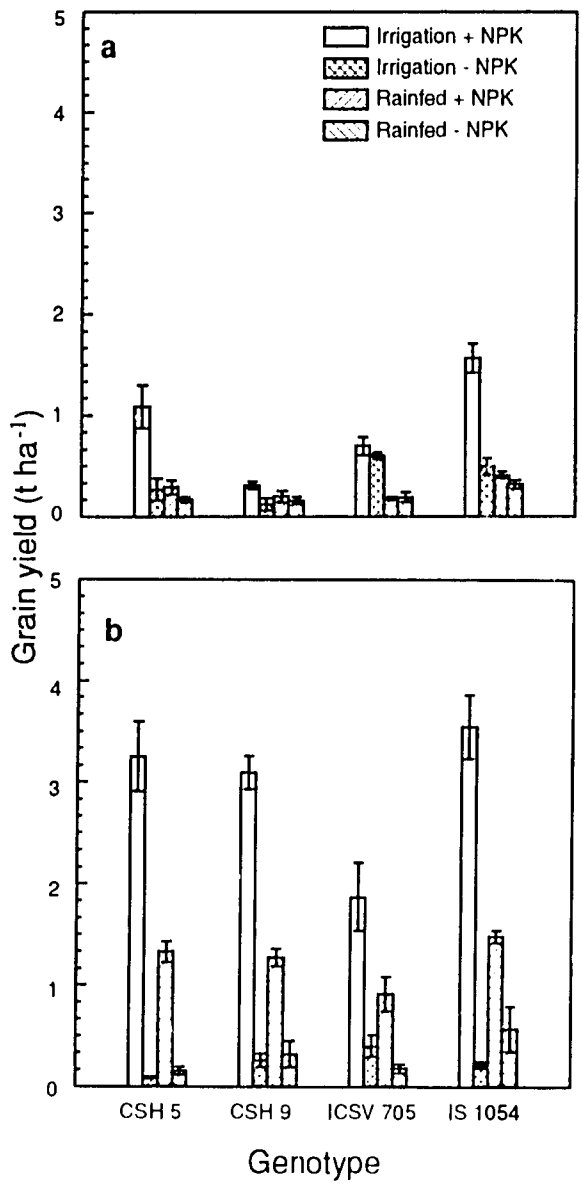

Figure 7. Grain yield (t ha^{-1}) of four sorghum cultivars sown under various crop management practices, (a) October and (b) November sowing.

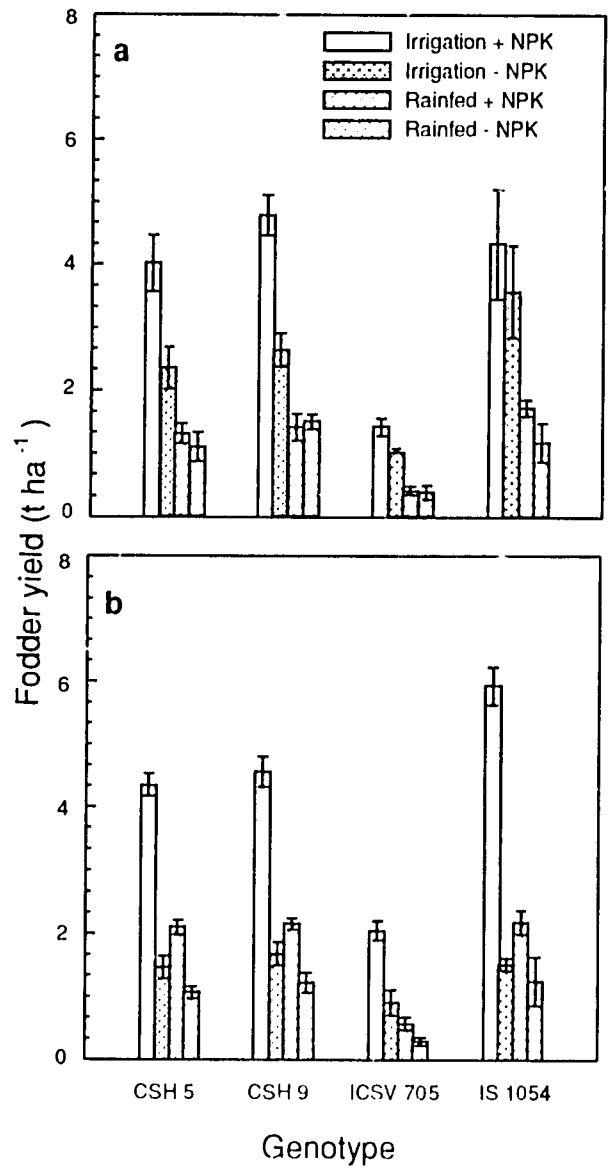

Figure 8. Dry fodder yield (t ha^{-1}) of four sorghum cultivars sown under various crop management practices, (a) October and (b) November sowing.

Breeding Shoot Fly Resistant Seed Parents

Belum V.S. Reddy, S.L. Taneja, and K. Vijayalakshmi[1]

1. Research Scholar, Department of Entomology, Andhra Pradesh Agricultural University, Hyderabad, India.

Breeding and conversion. Development of milo cytoplasm male steriles was initiated in 1990. Single cross F_6, three-way cross F_5, and four-way cross F_4 selections from 1989 (ICRISAT Cereals Program Annual Report 1991, pp. 43-45) were screened in the 1991 postrainy season using the infester row-fish meal technique, with selection for resistance among families and for grain yield within the selected resistant families. A total of 452 single cross F_7, 167 three-way cross F_6, and 21 four-way cross F_5 selections was subsequently screened in 1992 rainy season. We obtained 386 selections of which 277 lines were yet to be testcrossed, and another set of 109 lines which were in various stages of backcrossing to convert them to male sterility (76 testcrosses, 16 BC_1, 13 BC_2, and 4 BC_3).

Selection response across generations. Shoot fly damage (deadhearts) in the resistant and the susceptible controls differed greatly in test materials planted in different blocks (Table 8). Also the overall mean infestation as shown by deadheart percentage in the resistant control was much lower (24%) in the postrainy season than in the rainy season (64%).

To overcome this difficulty, we used a resistance index [RI(%), ICRISAT Cereals Program Annual Report 1991, p. 43]. Mean and distribution of the progenies in various RI values were used to compare the selection response across generations. The results (Table 9) suggested that, unlike the early segregating generations, there was no response to selection for shoot fly resistance in the advanced generations. Two possible explanations are: (1) there was limited residual variability for resistance; and (2) differential genotype x season or genotype x pest pressure interactions might have existed. Future studies will involve independent selection in different seasons.

Table 8. Shoot fly deadhearts (%) in resistant and susceptible controls in two seasons, ICRISAT Center, 1991-92.

Year and season[1]	Test materials generation[2]	Deadhearts (%) Mean and SE	Range Minimum	Range Maximum
IS 18551 (RSC)				
1991PR	SC F_6	25±1.3	11	36
1992R	SC F_7	64±0.9	42	87
1991PR	TC F_5	24±2.7	4	42
1992R	TC F_6	65±0.8	40	74
1991PR	FC F_4	31±4.8	14	46
1992R	FC F_5	36[3]	32	40
CSH 1 (SSC)				
1991PR	SC F_6	85±1.5	67	98
1992R	SC F_7	96±0.2	92	100
1991PR	TC F_5	92±1.0	84	99
1992R	TC F_6	93±0.3	87	98
1991PR	FC F_4	95±1.4	90	99
1992R	FC F_5	90[3]	82	98

1. R = rainy season; PR = postrainy season;
2. SC = singlecross; TC = three-way cross; FC = four-way cross; RSC = resistance control; SSC = susceptible control.
3. Mean of two plots.

Grain yield potential and resistance. A total of 10 tall and 10 dwarf breeding lines from the above program were evaluated for various morphological traits (early plant height, trichome density and glossiness intensity) and shoot fly resistance parameters [percentage plants with eggs (PE%) and percentage deadhearts (DH%)]. Four lines (SPSF 1103, SPSF 1029, SPSF 1169, and SPSF 1105) in the tall group, and four lines (SPSF 1170, SPSF 1052, SPSF 1014, and SPSF 1101) in the dwarf group were superior to the susceptible control, 296B, for grain yield potential, shoot fly resistance, and other morphological traits. Dwarf selections had more erect leaves but were equal in height to the tall selections in the early growth stages. While the parental B-lines contained nonglossy leaves, the lines resulting from empirical selection were glossy and had trichomes (Table 10). The grain mass [g (100 grains)$^{-1}$] of these lines was comparable to 296B, and there was a range among lines for plant height and time to 50% flowering. These results indicate the effectiveness of empirical selection in combining traits that have a bearing on shoot fly resistance.

Trait associations. Correlations of key traits with % deadhearts are presented in Table 11. It was observed that:

1. The correlations with PE% were greater in talls than in dwarfs across seasons. This indicated that shoot fly resistance in talls was due almost entirely to ovipositional nonpreference, and suggested that there was a prospect of using other mechanisms as well .rm 6.50"
   as ovipositional nonpreference in dwarfs.
2. Glossiness intensity was significantly and negatively correlated in both the plant types and seasons.
3. Early plant height and leaf length showed negative and significant correlations with DH% in the dwarfs but not in the tall types.

Table 9. Percentage distribution of the progenies bred for resistance to shoot fly among the classes of RI(%)[1] in various generations, ICRISAT Center, 1991-92.

Year and season[2]	Generation[3]	RI(%) mean & SE	% of families in each class of RI(%)				
			<-50	-50 to -26	-25 to -1	>0	Total
1991PR	SC F_6	-30±1.3	23	34	32	11	441
1992R	SC F_7	-56±1.2	62	26	8	3	452
1991PR	TC F_5	-36±1.8	27	34	32	6	226
1992R	TC F_6	-53±2.4	59	25	10	7	147
1991PR	FC F_4	-63±3.4	75	16	9	0	55
1992R	FC F_5	-65±6.0	80	5	10	5	21

1. Resistance index.
2. R = rainy season; PR = postrainy season.
3. SC = single cross, TC = three-way cross, and FC = Four-way cross.

4. The correlations between drooping depths and DH% were in general positive in the talls, but negative in the dwarfs.
5. Trichome density was negatively correlated with DH% in all situations; the correlations between adaxial trichome density on the 5th and 7th leaves with DH% were in general stronger than abaxial trichomes with DH% in both plant types in both seasons.

Path analyses studies. An earlier study at IC indicated that three traits (glossiness, trichomes, and number of eggs/plant) contributed to percentage deadhearts. In a more detailed study, the effects of five traits were estimated by path analysis on shoot fly parameters, namely, (1) trichome density (5th leaf adaxial surface in DH% and abaxial surface in PE%), (2) glossiness intensity, (3) early plant height (17 DAE), (4) 5th leaf length, and (5) 5th leaf droopiness. The important combinations are presented in Table 12. The effects of trichome density at different developmental stages along with glossy intensity on shoot fly parameters were also estimated.

Based on the residual effects, the combination having intensity, trichome density (5th leaf - adaxial), leaf length, and leaf droopiness explained the most variability in both talls and dwarfs. However, substitution of leaf droopiness by early plant height in dwarfs further improved the fitness, indicating that early plant height had a greater effect on resistance in dwarfs than in talls. After exclusion of the two leaf characters and early growth, trichome density and glossiness intensity accounted for limited variability in DH% in both the groups. The effect of the 5th leaf trichome density was far greater than glossiness in dwarfs than in talls, while trichome density and glossiness intensity played an equal role in talls. However, addition of the 3rd and 7th leaf trichome density at the exclusion of leaf length and droopiness did not improve the efficiency in explaining the variability in DH% in dwarfs.

For PE%, early plant height did not play a role in egg laying while droopiness did so, and the effect was greater in dwarfs than in talls. The effect of the 5th leaf trichome density on egg laying and deadhearts was greater in dwarfs than in talls. By contrast, substitution of the 3rd and 7th leaf trichomes for leaf droopiness and length had an adverse effect in talls, and a positive effect in dwarfs.

These results suggest that breeding for resistance to shoot fly should emphasise reduction in drooping depth (perhaps without reducing leaf length), an increase in glossiness intensity and early plant height in talls, and an increase in trichome density, glossiness intensity, and leaf length (without increasing droopiness or reducing early plant height) in dwarfs.

Table 10. Grain yield potential, early plant height, time to 50% flowering, and shoot fly parameters in shoot fly-resistant selections, 1991 postrainy and 1992 rainy seasons, ICRISAT Center.

Genotype	Reaction[1]	Grain yield (t ha^{-1}) PR[4]	Grain yield (t ha^{-1}) R	No. of trichomes 5th leaf (mm)$^{-2}$ PR AD	PR AB	R AD	R AB	Plant height 22/17 DAE[2] PR (cm)	Plant height 22/17 DAE[2] R (cm)	5th leaf droopiness[3] (cm)	Dead-hearts(%) PR	Dead-hearts(%) R
Tall												
SPSF 1103	B/Rt	3.6	4.0	73	41	32	128	11.8	10.0	6.9	48	91
SPSF 1029	B	3.4	4.1	99	7	81	23	12.6	12.5	6.1	49	86
SPSF 1169	B	3.2	4.0	224	51	264	528	11.2	9.8	6.8	32	89
SPSF 1105	Rt	3.1	4.0	137	60	73	146	12.7	8.9	8.3	40	88
Dwarf												
SPSF 1170	B	3.6	4.1	281	36	521	172	0.7	9.2	7.1	33	90
SPSF 1052	B	4.0	4.1	142	17	312	183	11.5	9.6	5.8	35	85
SPSF 1014	Rt	3.4	3.4	82	17	199	128	10.5	9.5	4.4	22	89
SPSF 1101	B/Rt	3.5	3.7	43	18	138	159	9.6	8.7	2.7	14	90
Controls												
IS 18551[4]		2.7	2.2	454	32	813	318	12.3	10.6	3.6	17	62
296B[5]		1.0	2.8	0	0	0	0	8.7	6.7	2.7	82	97
Trial mean		2.8	3.05	157	29	272	143	9	11	4.5	37	87.7
SE		±.52	±.50	±74	±21	±47	±54	±.02	±.01	±1.8	±(2.0)	±(1.6)
CV%		18	18	47	75	17	38	11	14	11	16	4

1. Sterility/fertility reaction - Rt = restorer, B = maintainer.
2. 23 and 17 = days after emergence (DAE) in postrainy and rainy seasons respectively.
3. Rainy season only.
4. PR = postrainy season; R = rainy season; AD = adaxial; AB = abaxial.
5. Resistant check.
6. Susceptible check.
7. Figures in parentheses are based on angular transformation values.

Table 11. Correlation coefficients between percentage shoot fly deadhearts and various plant characters in sorghum, ICRISAT Center, rainy and postrainy seasons, 1992.

Plant character correlated with % deadhearts	Plant type/season: Postrainy season Tall	Postrainy season Dwarf	Rainy season Tall	Rainy season Dwarf
Glossiness	-0.59**[3]	-0.64**	-0.64**	-0.74**
Plant height				
23/17 DAE[1]	-0.35	-0.32	-0.18	-0.73**
Leaf length				
3rd leaf	-	-	-0.16	-0.57**
4th leaf	-	-	0.00	-0.66**
5th leaf	-	-	-0.01	-0.65**
Drooping depth				
3rd leaf	-	-	0.39	-0.42*
4th leaf	-	-	0.51*	-0.67*
5th leaf	-	-	0.60**	-0.51*
Trichomes				
AD[2] 3rd leaf	-0.46*	-0.66**	-0.85**	-0.51*
AB	-0.03	-0.51	0.09	-0.52*
AD 5th leaf	-0.79**	-0.60**	-0.82**	-0.42*
AB	-0.26	-0.17	-0.73**	-0.72**
AD 7th leaf	-0.76**	-0.42*	-0.67**	-0.06
AB	-0.32	-0.07	-0.62**	-0.22
%Pl.Eggs(PE)	0.95**	0.85**	0.95**	0.79**

1. 23 DAE = 23 days after emergency in postrainy season; 17 DAE = 17 days after emergency in rainy season.
2. AD = Adaxial surface of the leaf; AB = Abaxial surface of the leaf.
3. *Significant at 5% probability; ** Significant at 1% probability.

Nonmilo cytoplasm male-sterile lines. The newly developed shoot fly-resistant lines ICSV 705 and ICSV 708 were maintainers on A_3 and A_4 (Maldandi) cytoplasms. We have completed six backcrosses to convert them to male sterility with both cytoplasms.

Stem Borer (*Chilo partellus*)

Screening Technique

S.L. Taneja

Screening for stem borer resistance is done by artificial infestation at IC. Early deadheart formation (the primary criterion for stem borer resistance) may also be caused by shoot fly when screening is done in the postrainy season when shoot fly infestation occurs simultaneously. Removal of shoot fly-affected plants reduces plant stands and results in high error variances. This can be avoided by insecticidal control of shoot fly before artificial infestation by the first instar borer larvae.

We evaluated the effect of insecticide spray (cypermethrin) for shoot fly control on first instar borer larvae released 4, 6, 8, and 10 days after foliar application. Crop damage by the borer larvae (leaf feeding and deadhearts) and insect biological parameters (larval survival, weight, and duration) were unaffected in all the treatments. This information indicates that sorghum seedlings can be protected from shoot fly infestation by foliar application of cypermethrin, without affecting the artificially introducted stem borer larvae.

Resistance Screening

S.L. Taneja and J.W. Stenhouse

In continuation of our efforts to incorporate stem borer resistance into a good agronomic background, we screened 25 lines in the International Sorghum Shoot Pest Nursery (ISSPN), 85 lines in the Advanced Screening Nursery, 64 lines in the Preliminary Screening Nursery, and 145 lines in the Yield Trials for stem borer resistance under artificial infestation at IC. We selected 10 lines from preliminary screening showing <50% deadhearts as compared to >90% in susceptible control ICSV 1. Highly resistant lines (<40% deadhearts) were PB 14839-1-3, PB 14844-1, PB 15157-4-2-1, PB 15522-2-2-1, PB 15522-2-2-2, PB 15976-2-1, PB 15837-1-1, PB 15856, and PB 15880-2.

We estimated means and genetic variances of sorghum genotypes in three sets of materials: International Sorghum Shoot Pest Nursery (ISSPN, 25 genotypes), Advanced Screening Nursery (100 genotypes), and Preliminary

Table 12. Residual effects from path analyses with different combinations of independent traits on shoot fly parameters, ICRISAT Center, rainy season, 1992.

Combination of independent traits				Dependant traits (shoot fly parameters)			
	SF Deadheart (%)			No. of SF eggs/100 plants			
1	2	3	4	Tall	Dwarf	Tall	Dwarf
Pl. height 17 DAE[1]	Glossiness intensity	Tri.density AB[1]/AD[1]5Lf	Leaf length 5th	0.286	0.171	0.383	0.665
Pl. height 17DAE	Glossiness intensity	Tri.density AB/AD 5Lf	Drooping depth	0.269	0.199	0.300	0.371
Pl. height 17 DAE	Glossiness intensity	Leaf length 5th	Drooping depth	0.243	0.338	0.325	0.469
Pl. height 17DAE	Tri.density AB/AD 5Lf	Leaf length 5th	Drooping depth	0.236	0.238	0.275	0.367
Glossiness intensity	Tri.density AB/AD 5Lf	Leaf length 5th	Drooping depth	0.214	0.209	0.214	0.372
Glossiness intensity	3rd leaf tri.density AB/AD	5th leaf tri.density AB/AD	7th leaf tri.density AB/AD	0.181	0.232	0.533	0.284

1. DAE = Days after emergence; AB = abaxial surface for number of eggs; AD = adaxial surface for deadhearts.

Screening Nursery (90 genotypes) evaluated for stem borer resistance at IC (artificial infestation) and at Hisar (natural infestation). Genotypes were evaluated for leaf injury (1-9 scale, where 1 = highly resistant and 9 = highly susceptible) and stem borer deadhearts (%) at both locations. Mean leaf feeding score and deadheart percentage was 5.2 and 42.5, respectively in ISSPN as compared to 6.2 and 60.2 in the Advanced Screening Nursery and 5.7 and 53.9 in the Preliminary Screening Nursery, indicating the improvement in resistance level in this nursery. Significant genotypic differences were observed in all the three sets. Genotype x environment interactions were also significant in all the three sets of materials, indicating the requirement of more test locations for stem borer resistance screening. Although error variance was high in all three sets for both characters, heritabilities were between 46 and 56% for leaf injury and between 59 and 69% for deadhearts.

Breeding Stem Borer Resistant Seed Parents, Restorer Lines, and Hybrids

Belum V.S. Reddy and S.L. Taneja

Milo cytoplasm seed parents. Earlier we generated new variability by crossing resistant lines, ICSV 700 and ICSV 702, with elite milo cytoplasm maintainer lines, and carried materials through three generations of selection for stem borer resistance under artificially infested conditions (ICRISAT Cereals Program Annual Report 1991, p. 47). A total of 91 single cross F_6s, 112 three-way cross F_5s, and 30 four-way cross F_4s were screened during the 1991 postrainy season, and selections from these (174 single cross F_7s, 192 three-way cross F_6s, and 47 four-way cross F_5) were screened during the 1992 rainy season.

Selection response across generations. As for shoot fly screening, the pest infestation varied greatly among the seasons and among the blocks of different test materials within the season (Table 13). Therefore a resistance index [RI(%)] mean and distribution of the progenies in various RI values (ICRISAT Cereals Program Annual Report 1991, p. 43) were used to compare the selection responses across generations. The results were similar to those for shoot fly in that the early generation response to selection for resistance was not maintained in the advanced generations. Two possible explana-tions are: (1) there was limited residual variability for resistance, and (2) differential genotype x season or genotype x pest pressure interactions might have existed. Future studies will involve independent selection and be conducted in different seasons.

Table 13. Percentage stem borer deadhearts in resistant and susceptible controls in rainy and postrainy seasons, ICRISAT Center, 1991-92.

Year and season[1]	Test materials generation[2]	Deadhearts (%) Mean and SE	Range Minimum	Range Maximum
IS 2205 (R)[3]				
1991PR	SC F_6	31±1.2	24	36
1992R	SC F_7	64±0.9	42	87
1991PR	TC F_5	35±3.4	22	54
1992R	TC F_6	65±0.8	40	74
ICSV 1 (S)[4]				
1991PR	SC F_6	69±3.0	56	78
1992R	SC F_7	96±0.2	92	100
1991 PR	TC F_5	75±2.6	61	86
1992R	TC F_6	93±0.3	87	98

1. R = rainy season; PR = postrainy season.
2. SC = biparental cross; and TC = three-way cross.
3. (R) = resistance control.
4. (S) = susceptible control.

Grain yield potential and resistance. A sample of 42 selections ranging in height from 1.1 to 2.3 m in the rainy season revealed significant variability for a number of traits in the 1991 postrainy and 1992 rainy seasons. However, the lines differed significantly for percentage of deadhearts only in the postrainy season. Stem borer infestation was extremely high in the rainy season (mean deadhearts: 85%; range 51-100%) and relatively less in the postrainy season (mean: 44%; range 15-76%). We selected on the basis of percentage deadhearts in the postrainy season, and grain yield and 7th internode length (measured 45 days after emergence; see next section on correlations) in the rainy and postrainy seasons, together with agronomic desirability.

The selections thus obtained were superior to 296B for grain yield and stem borer resistance in the postrainy season, and comparable to it in the rainy season (Tables 14 and 15).

Trait associations. Earlier studies at IC had suggested that deadharts due to stem borer damage were related to plant growth. The results of the trials above were used to identify marker trait(s) to select for improved stem borer resistance by estimating the correlations of the traits with deadhearts. The results are presented in Table 16. Some of the key findings are as follows:

1. The 2nd internode length measured 45 days after emergence or at maturity, and the 7th internode length measured at maturity, were significantly and negatively correlated with percentage deadhearts in both the seasons. This was also borne out by the fact that the dwarf stem borer resistant control, IS 12308, had the longest 2nd (measured at 45 DAE or at maturity) and 7th (measured at maturity) internodes (Table 14). In fact, they were longer than internodes in the tall resistant control, IS 2205 (Table 15).
2. Stem circumference (2nd internode girth at maturity) was significantly and positively correlated with percentage deadhearts in both the seasons, indicating that thin-stemmed genotypes were not preferred by stem borer.
3. Time to 50% flowering was significantly and positively correlated with deadhearts in both the seasons.
4. Grain yield potential had very low correlation with deadhearts percentage in both the seasons, indicating a potential to combine high grain yield with reduced susceptibility.

Table 14. Performance of stem borer-resistant dwarf sorghum genotypes evaluated[1] during 1991 postrainy and 1992 rainy seasons, ICRISAT Center.

Genotype	2nd node (45DAE) Length (cm) PR[1]	R	Girth (cm) PR	R	7th node length (cm) PR	R	Time to 50% flowering (d) PR	R	Grain yield (t ha^{-1}) PR	R	Dead-hearts(%) PR	R
SPSB 971	1.7	3.9	3.3	4.9	7.1	7.5	90	73	2.9	4.8	52	93
SPSB 975	2.8	3.3	3.4	4.7	8.7	7.9	67	65	4.1	4.1	33	93
SPSB 978	2.5	3.1	4.0	5.0	7.4	13.7	83	70	4.5	3.5	40	96
SPSB 984	1.9	4.2	3.3	4.7	11.1	12.0	81	69	2.8	3.2	54	93
SPSB 997	2.5	3.7	3.5	5.0	12.5	11.0	87	72	2.5	4.1	39	92
SPSB 1114	1.9	3.3	3.2	5.1	10.7	9.5	82	72	3.7	2.9	47	86
SPSB 1118	1.4	2.8	3.5	5.5	9.2	10.1	90	72	3.4	3.4	60	85
SPSB 1356	1.7	2.8	3.3	4.7	6.9	9.8	80	66	3.3	4.2	39	95
SPSB 1397	2.8	3.7	3.3	4.6	11.8	10.3	80	63	2.7	2.8	42	90
SPSB 1493	1.9	2.6	3.1	4.9	9.6	8.3	81	72	2.5	2.8	32	85
296B[3]	2.3	1.9	3.5	5.4	7.0	7.5	84	68	3.4	4.8	76	84
IS 12308[4]	9.4	9.0	1.9	3.1	13.4	27.0	50	51	1.9	2.5	34	51
SE	±0.4	±0.7	±0.2	±0.2	±1.3	±1.2	±1.0	±0.9	±0.3	±0.3	±(3.6)[5]	±(5.2)
CV%	31	37	12	9	19	18	2	3	19	15	26	13

1. Randomized complete block design with three replications, Vertisol, high fertility (N 86:P 40:K 0).
2. PR = postrainy season; R = rainy season.
3. Susceptible control.
4. Resistant control.
5. Figures in parentheses are based on angular transformation values.

Path analyses studies. We determined the direct and indirect effects of the 2nd and 7th internode length and 2nd internode circumference, and time to 50% flowering on percentage deadhearts. The combination explained nearly 40% of the total variability in deadhearts in both the seasons. The major direct effects were by 2nd internode length and its circumference, 7th internode length, and time to 50% flowering. The association of the 2nd internode length with other dependant traits had the dominant indirect effect (Table 17).

Nonmilo cytoplasm male-sterile lines. We completed earlier four backcrosses in converting the resistant source lines ICSV 700 and ICSV 702 to male sterility on A_3 and A_4 cytoplasms (ICRISAT Cereals Program Annual Report 1991, p. 47). We have now completed six backcrosses for both lines to both cytoplasms.

Restorer lines. A total of 12 S_7 lines selected for resistance (ICRISAT Cereals Program Annual Report 1991, p. 48) were screened in the 1991 postrainy season. Three lines (GDSB 3003, GDSB 3053, and GDSB 3104) showed RI values ranging from -0.92 to 3.8 when compared with the resistant control IS 2205. Of these, GDSB 3053 was selected again in the third screening in the 1992 rainy season.

Hybrids. We previously evaluated hybrids for resistance (ICRISAT Cereals Program Annual Report 1991, p. 48). These were evaluated again for resistance in the 1991 postrainy season and for grain yield in the 1992 rainy season. ICSH 91162 and ICSH 91169 produced high grain yield and had moderate resistance to stem borer. Another hybrid, ICSH 91120, showed high levels of stem borer resistance, but produced low grain yield.

Table 15. Performance of stem borer-resistant tall sorghum genotypes evaluated[1] during 1991 postrainy and 1992 rainy seasons, ICRISAT Center.

Genotype	2nd node (45DAE) Length (cm) PR[1]	R	Girth (cm) PR	R	7th node length (cm) PR	R	Time to 50% flowering (d) PR	R	Grain yield (t ha^{-1}) PR	R	Dead-hearts(%) PR	R
SPSB 1142	4.5	5.5	3.6	4.8	19.8	16.5	78	64	3.6	3.4	30	89
SPSB 1166	2.7	5.8	3.6	4.9	15.7	16.2	85	70	3.7	3.0	43	80
SPSB 1221	5.8	4.8	3.7	4.4	17.6	20.0	80	66	3.4	3.2	30	88
SPSB 1237	2.0	3.1	3.6	4.7	14.1	18.1	18	65	2.8	4.0	35	84
SPSB 1263	2.2	5.4	3.5	5.2	19.3	20.3	89	78	4.0	2.7	62	91
SPSB 1403	5.3	4.8	3.8	4.4	18.4	22.0	81	70	3.7	3.8	32	70
SPSB 1456	3.4	3.5	3.5	4.9	12.4	12.8	85	73	3.5	2.1	31	81
SPSB 1475	4.7	5.0	3.6	4.4	19.7	20.4	70	64	3.8	3.6	15	95
SPSB 1476	6.0	4.8	3.4	4.3	21.3	18.6	77	64	3.7	3.5	17	88
SPSB 1495	3.1	3.6	3.7	4.6	16.1	17.1	78	70	3.7	2.8	30	84
296B[3]	2.3	1.9	3.5	5.4	7.0	7.5	84	68	3.3	4.8	76	84
IS 2205[4]	3.9	6.1	3.5	5.0	19.2	16.8	83	71	3.3	2.4	22	90
SE	±0.4	±0.7	±0.2	±0.2	±1.3	±1.2	±1.0	±1.0	±0.9	±0.3	±(3.6)[5]	±(5.2)
CV%	31	37	12	9	19	18	2	3	19	15	26	13

1. Randomized complete block design with three replications, Vertisol, high fertility (N 86:P 40:K 0).
2. PR = postrainy season; R = rainy season.
3. Susceptible control.
4. Resistant control.
5. Figures in parentheses are based on angular transformation values.

Table 16. Estimates of correlation coefficients between various important traits and agronomic traits and percentage of stem borer deadhearts in sorghum, during 1991 postrainy and 1992 rainy seasons, ICRISAT Center.

Characters	Plant height at maturity PR[1]	R	Time to 50% flowering (d) PR	R	Deadhearts(%) PR	R
2-int. node length (45 DAE[2])	0.51**	0.68**	-0.50**	0.06	-0.59**	-0.38**
2-int. node girth (45 DAE)	0.23	-0.30*	0.47**	0.66**	-0.08	0.54
2-int. node length (maturity)	0.78**	0.74**	-0.42**	-0.17	-0.62**	-0.20
2-int. node girth (maturity)	-0.04	-0.19	0.78**	0.66**	0.45**	0.50**
7-int. node length (maturity)	0.80**	0.85**	-0.39**	-0.26	-0.47**	-0.54**
Plant height (45 DAE)	0.39**	0.77**	-0.49**	-0.42**	-0.49**	-0.49**
Plant height (maturity)	1.00	1.00	-0.23	0.06	-0.55**	-0.32*
Time to 50% flowering	-0.08*	0.06	1.00	1.00	0.38**	0.31*
Grain yield (t ha^{-1})	0.23	-0.13	0.36*	-0.17	0.09	0.01

1. PR = postrainy season; R = rainy season.
2. *, ** significant at P = 0.05 and 0.01 respectively; DAE = days after emergence.

Sorghum Head Pests

Effect of Host Plant Resistance on Economic Injury Levels (EILs)

H.C. Sharma

Sorghum midge (*Contarinia sorghicola*). We assessed the economic injury levels for sorghum midge on two midge-resistant cultivars (ICSV 197 and ICSV 745) and three midge-susceptible cultivars (ICSV 1, ICSV 112, and CSH 1), using the headcage technique. Panicles were tagged at flowering and infested with 5, 10, 20, or 40 midge females for 1, 2, 3, or 4 consecutive days. Twenty panicles were infested at each level of infestation. Midge damage (% chaffy spikelets, which approximates % loss in grain yield) was recorded at maturity from a sample of 1000 spikelets drawn at random from each level of infestation. Data were subjected to regression analysis to determine the relationship between insect density or number of infestations with percentage loss in grain yield.

There was closer association between insect density and plant damage when susceptible cultivars were infested 3 to 4 times with a range of insect densities (r^2 = 70-90%; P = 0.05) than with single infestations (r^2 = 37-94%). EILs for four infestations averaged over all insect densities were 2.0-2.5 midges panicle^{-1} for the commercial cultivars (ICSV 1, ICSV 112, and CSH 1) compared with 55 to 189 midges panicle^{-1} for the midge-resistant cultivars (ICSV 197 and ICSV 745). Thus EILs for sorghum midge change with the level of host-plant resistance and these are crucial in taking appropriate decisions for pest management.

Sorghum head bug (*Calocoris angustatus*). Studies were conducted to estimate EILs for sorghum head bug on two resistant (IS 17610 and IS 21443) and two susceptible (IS 9692 and CSH 11) cultivars over two seasons, using different protection levels at the half-anthesis (HA), complete-anthesis (CA), milk (M), and dough (D) stages of panicle development. Experiments were laid out in a randomized block design with three replications for each cultivar. Plots were sprayed at the HA, HA+CA, HA+CA+M, or HA+CA+M+D stages with 0.025% demeton-S-methyl. Head bug numbers were recorded in five panicles in each plot 24 h before and after spraying. Grain yield was recorded at harvest. Relationships between bug numbers at different stages of panicle development with grain yield were estimated by regression analysis. EILs were computed on the basis of loss of grain yield due to one bug panicle^{-1} at the half-anthesis stage.

Maximum grain yield was obtained in CSH 11 and IS 9692 with four insecticide sprays, and with one and two sprays in IS 17610 and IS 21443, respectively. EILs varied from 0.04-0.30 bugs for CSH 11, 0.9-6.6 bugs for IS 9692, 2.7 bugs for IS 17610, and 0.3-5.1 bugs for IS 21443 at the half-anthesis stage. Head bug-resistant cultivars not only decrease the rate of bug population increase, but can also withstand greater head bug densities.

Inheritance of Resistance to Sorghum Midge

H.C. Sharma and J.W. Stenhouse

We studied the inheritance of resistance to sorghum midge by testcrossing resistant and susceptible pollen parents on two midge-resistant (PM 7061A and PM 7068A) and two midge-susceptible (ICSA 42 and 296A) female parental lines. Pollen parents included four midge-resistant (ICSV 745, PM 15908-3, PM 17422-3, and PM 17592-1) and five midge-susceptible (CS 3541, MR 750, MR 836, MR 844, and MR 923) lines. Five panicles were infested with 40 midges panicle^{-1} for 2 consecutive days in each plot under headcages. Percentage of midge damage was estimated from a sample of 500 spikelets drawn at random at maturity. Panicles were also rated visually for midge damage under headcage and natural infestation.

General combining ability (GCA) effects were greater than the specific combining ability (SCA) effects over seasons under headcage and natural infestation, both for % midge damage and visual damage rat-ing (except for damage rating under natural infestation during the postrainy season). For cultivar preference by the midge females, the SCA effects were greater than the GCA effects. GCA effects for the midge-resistant lines (PM 7061A and PM 7068A) were significant and negative (P<0.001) for midge-susceptibility, while those of the susceptible lines (ICSA 42 and 2926A) were positive (except for % damage during the rainy season). PM 7041A contributed towards nonpreference by midge females while ICSA 42 contributed significantly towards preference.

Table 17. Estimates of direct and indirect effects from path analysis of different characters on stem borer deadhearts (%) in sorghum, during postrainy and rainy seasons 1991-92, ICRISAT Center.

Character/ season		Seventh node length at maturity	Second node length at maturity	Second node girth at maturity	Time to 50% flowering	Deadhearts (%) (r)
Seventh node length	PR[1]	**-0.17**[2]	-0.25	-0.02	-0.03	-0.47
	R	**-0.36**	-0.04	-0.22	0.01	-0.54
Second node length	PR	-0.09	**-0.49**	0.05	-0.06	-0.59
	R	-0.27	**0.05**	-0.16	0.004	-0.38
Second node girth	PR	-0.02	0.11	**-0.22**	0.04	-0.09
	R	0.22	-0.02	**0.36**	-0.01	0.55
Time to 50% flowering	PR	0.05	0.35	-0.10	**0.09**	0.38
	R	0.10	-0.01	0.24	**-0.02**	0.31
Residual:		0.58(PR); 0.63(R)				

1. PR = postrainy season; R = rainy season.
2. Figures in bold are direct effects.

GCA effects of midge-resistant testers were significant and negative for midge susceptibility and cultivar preference while midge-susceptible testers in general showed positive GCA effects for midge susceptibility (except CS 3541 for % damage, and MR 750 for % midge damage and damage rating under cage during the postrainy season). SCA effects were not significant for midge susceptibility except for 296A x CS 3541.

Effect of Source of Pollen on Midge Emergence on Resistant and Susceptible Female Parents

H.C. Sharma

In order to develop sorghum hybrids with high levels of resistance to soghum midge, we studied midge emergence on midge-resistant (PM 7061A and B and 7061A and B) and midge-susceptible (ICSA and B 42 and 296A and B) female parents pollinated with a susceptible (Swarna) or a resistant (DJ 6514) genotype. The female parents and the B lines were sown in a randomized block design with two replications. Five panicles under headcage were infested with 40 midges in each genotypes with or without pollination. From 15 days after infestation (DAI), adult midges emerging from each panicle were counted on alternate days until 30 DAI.

The number of midges panicle^{-1} were slightly lower when the A lines were pollinated with DJ 6514 (762 midges panicle^{-1}) compared with Swarna (919 midges panicle^{-1}) during the 1991/92 postrainy season (Table 18). A significantly lower number of midges emerged when the A lines were not pollinated compared with those pollinated with Swarna. The number of midges emerging on B lines of the midge-resistant parents were very low compared to the midge-susceptible parents and the pollinated or unpollinated panicles of midge-resistant A lines.

Table 18. Effect of midge-resistant female parents and pollinators on midge emergence under headcage (40 midges panicle^{-1}) 1991-92 postrainy season, ICRISAT Center.

	Pollen source				
	Swarna	DJ 6514	Male sterile (A line)	Maintainer (B line)	Mean
ICSA 42	996 (31.5)[1]	617 (24.6)	354 (18.6)	1202 (34.7)	792 (27.3)
296A	1500 (38.6)	1564 (39.4)	1137 (33.6)	1182 (30.0)	1346 (35.4)
PM 7068A	1097 (32.0)	699 (26.3)	407 (19.8)	27 (4.1)	555 (20.8)
PM 7061A	84 (9.0)	168 (12.0)	247 (15.5)	17 (5.1)	132 (10.4)
Mean	919 (28.0)	762 (25.6)	574 (22.6)	687 (18.4)	714 (23.7)
SE for					
Genotypes					±(0.73)
Treatments					±(0.94)
Genotypes x treatments					±(1.78)
Except when comparing means with the same level of genotype					±(1.87)

1. Figures in parentheses are square root transformed values.

The source of pollen did not influence midge numbers on the midge-resistant female, PM 7061A. Undeveloped ovaries are known to affect the oviposition behavior of the sorghum midge. The differences in the number of emerging flies on the A/B pairs of midge-resistant lines may also be attributed to morphological and/or biochemical factors that affect oviposition behavior and/or larval development. These factors could be of direct relevance in sorghum resistance to midge.

Breeding Midge-resistant Seed Parents and Restorer Lines

Belum V.S. Reddy and H.C. Sharma

Seed parents. We continued backcrossing to convert PM 7068, PM 17467, PM 17682, and PM 19268 into male-sterile lines with A_1 (milo), A_2, A_3, and A_4 (Maldandi) cytoplasms; PM 17500-2-1 with A_1, A_3, and A_4 (Maldandi); and ICSV 89057 and ICSV 89058 with A_3, and A_4 (Maldandi) cytoplasms. We completed the 5th and 6th backcrosses during 1992.

Previously we generated new variability by crossing midge-resistant lines with elite milo (A_1) cytoplasm maintainer lines, and screened them for resistance to midge (ICRISAT Cereals Program Annual Report 1991, p. 53). The resulting selections (314 single cross F_6s, 111 three-way cross F_5s, and 23 four-way cross F_4s) were sown in the 1991 postrainy season at IC. However, discrimination was not possible because of low levels of pest infestation. Midge resistance scores collected in the 1991 rainy season at Dharwad were used to select among families for resistance. The resulting single cross F_7s, three-way cross F_6s, and four-way cross F_5s were screened in the 1992 rainy season. Pest pressure was high (CSH 1 received a score of 8 on to 1 to 9 scale where 1 = highly resistant, 9 = highly susceptible), and there was clear discrimination.

Comparision of the means of parental and selected samples families with those in the previous season (ICRISAT Cereals Program Annual Report 1991, p. 53) showed that selection for midge resistance was effective. The greater grain mass of the recent cycle of selections over control (Table 19) indicated an effective transfer of resistance to a higher grain mass background.

Correlations among the relevant traits (Table 20) indicated that (1) resistance to midge did not correlate with grain mass, indicating that the linkage between resistance and low grain mass

Table 19. Characteristics of midge-resistant progenies evaluated during rainy season 1992, ICRISAT Center.

Population or selected families	Size	Midge resistance score[1] Mean & SE	Range	100-grain mass (g) Mean & SE
SC F_7[2]				
Population	170	5.6±0.36	1 to 8	-
Sample	29	4.1±0.07	1 to 5	3.0±0.04
TC F_6				
Population	215	4.8±0.33	2 to 8	-
Sample	27	3.8±0.07	2 to 5	2.9±0.03
Control				
ICSV 197		2.0±0.00	1 to 4	2.1±0.001

1. Scored on a scale of 1 to 9, where 1 = highly resistant, 9 = highly susceptible, SEs are based on square root transormations.
2. SC = single cross; TC = three-way cross.

Table 20. Correlations between midge resistance and grain traits in selected families, ICRISAT Center, 1992 rainy season.

Generations/ families	Grain hardness vs midge score	Grain mass vs grain hardness	Grain mass vs midge score
SC F_7[1] (130)[2]	-0.13	0.42**[3]	-0.01
TC F_6 (206)	0.20**	0.43**	0.14

1. SC = single cross; TC = three-way cross.
2. Figures in parentheses indicate sample size.
3. ** = significant at P = 0.01.

has been broken down, and (2) resistance was negatively associated with grain hardness, but it was not strong.

To investigate the possibility of combining high levels of resistance and high grain mass, six selections in each of four groups based on grain mass (group 1: 3.3 g for 100-grain mass; group 2: 2.8 g; group 3: 2.4 g; and group 4: 1.7 g) having the same level of midge resistance (score 3.0 under field choice condition in the 1991 rainy season screenings) were evaluated in the 1991 postrainy season under no-choice/cage conditions.

There was significant variation for midge resistance score within groups 1, 2, and 4 (Table 21), indicating the potential for further selection advance for resistance even at higher grain mass levels.

We also evaluated 33 selections with maintainer line reactions for their grain yield and midge resistance in late sowings in the rainy season at IC. The lines were high yielding (2.1-3.2 t ha^{-1}), highly resistant (1.7 to 2.0 score; comparable to the resistant variety ICSV 745), and superior to the control 296B for both the traits. They varied in plant height and in flowering (Table 22).

We continued with testcrossing and backcrossing the above midge resistant maintainer lines into the milo male-sterile cytoplasm. We now have 175 progenies in various stages of backcrossing (BC_1: 55; BC_2: 95; BC_3: 10; and BC_4: 15).

Restorer lines. We screened 80 selected S_6 progenies under midge infestation in the 1991 postrainy season, together with 34 S_6 lines of the stem borer group (ICRISAT Cereals Program Annual Report 1991, p. 53). Lines from these materials are being screened in the 1992 postrainy season.

Table 21. Within grain mass groups variances[1] for midge resistance (score), ICRISAT Center, 1991 postrainy season.

Genotypes	Group 1	Group 2	Group 3	Group 4
Genotypes (5)[2]	2.6**[3]	0.7**	0.3	0.7**
Residual (12)	0.09	0.10	0.10	0.12

1. Based on square root transformed values.
2. Figures in parentheses are degrees of freedom.
3. ** significant at P = 0.01.

Table 22. Performance of midge resistant progenies evaluated[1] during the 1992 rainy season, ICRISAT Center.

Genotype	Grain yield (t ha^{-1})	Time to 50% flowering (d)	Plant height (m)	Midge score[2]
SPMD 2669	2.5	60	1.5	2.0
SPMD 2679	3.2	63	1.5	2.0
SPMD 2681	2.4	64	1.6	1.7
SPMD 2631	2.1	67	1.5	1.7
296B[3]	1.6	70	1.4	5.7
SE	±0.2	±1.0	±0.05	±(0.2)[4]
CV%	24	3	5	39

1. Randomized complete block design with three replications, BS 7, high fertility (N:86 P:40 K:0).
2. Midge score on 1 to 9 scale where 1 = highly resistant, 9 = highly susceptible.
3. Susceptible control.
4. Figure within parentheses is based on square root transformation values

Effect of Host Plant Resistance and Panicle Compactness on Population Dynamics of Sorghum Head Bug

H.C. Sharma

In order to study the role of host-plant resistance in the population dynamics of sorghum head bug, we monitored the population on a compact-panicled, bug-susceptible sorghum hybrid, CSH 5, and a bug-resistant, loose-panicled germplasm accession, IS 21443, in large plots (0.5 ha) over two sowing dates during the 1990-92 rainy seasons. Bug numbers were counted on alternate days from five panicles selected at random at each of five spots marked diagonally across the plot from panicle emergence to the hard-dough stage.

Although the differences in initial bug infestation were low, the bug popoulation increase in CSH 5 at 10-15 days after panicle emergence was much greater than in IS 21443 in the second sowing (Fig. 9). We attribute these differences in bug numbers on the open-panicled, bug-resistant line to low oviposition

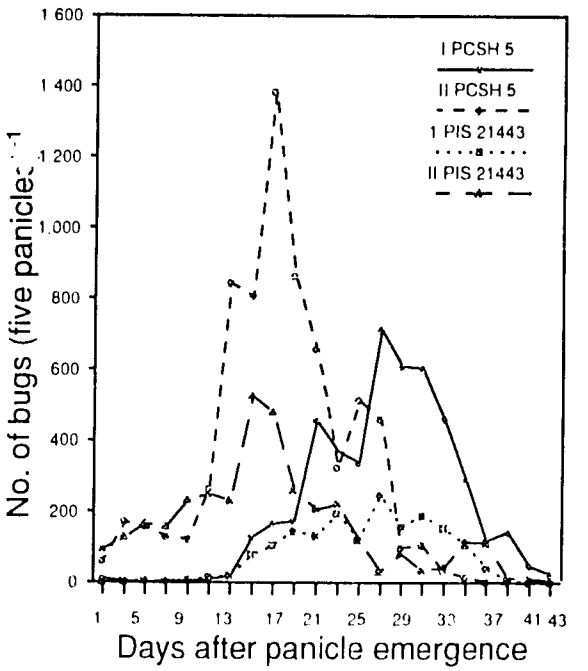

Figure 9. Buildup of head bug population on two sorghum genotypes sown on two dates, ICRISAT Center, rainy season, 1992.

and survival of nymphs, and exposure to natural enemies.

These results indicate that the sowing of a head bug resistant genotype can result in a 10-fold decrease in the rate of bug population multiplication and has significant implications in the reduction of bug densities over large areas.

Breeding Head Bug resistant Seed Parents

Belum V.S. Reddy and H.C. Sharma

Single crosses between Malisor 84-7, a head bug resistant line, and four elite B-lines (ICSB 13, ICSB 26, ICSB 38, and ICSB 42) were advanced and selected in F_2 for freedom from head bug damage and for Malisor 84-7 grain type (thick pericarp). A total of 48 F_3 progenies and the BC_1F_1s of ICSB 13, ICSB 38, and ICSB 42 F_1s to Malisor 84-7 (ICRISAT Cereals Program Annual Report 1991, p. 54) were evaluated and selected in the 1991 postrainy season. Progenies of 45 F_3 plants and 10 BC_1 F_1s are being evaluated further in the 1992 postrainy season.

Host Plant Resistance, Crop Diversity, and Natural Enemy Interactions

Seasonal Distribution of Neuroptera on Sorghum

S.J. Duffield

Biological control strategies depend on the identification of key natural enemies that effectively control pest populations. The larvae of Neuroptera are documented polyphagous predators and have been used extensively in biocontrol programs. The impact of naturally occuring populations of Neuroptera on *Helicoverpa armigera* (Hubner) on sorghum has not been studied. One of the factors that influences the effect of a natural enemy on pest populations in the field is the degree of synchrony it shows with its prey, in both time and space.

This study evaluates the distribution of lacewings (Neuroptera) on three cultivars of sorghum to determine their potential biocontrol potential against *H. armigera*. Sorghum cultivars were selected to provide a range of panicle types: semiloose (CSH 1), semicompact (CSH 9), and compact (SPV 104).

The most abundant lacewing stage recorded were the eggs, which were laid singly or in groups of up to 10. The abundance of the lacewing eggs showed a bimodal pattern on all of the cultivars, while *H. armigera* showed only a single peak (Fig. 10). The density of both lacewing and *H. armigera* eggs was less on the semiloose panicled cultivar (CSH 1) compared to the semicompact (CSH 9) and compact (SPV 104) cultivars. In all three cultivars, the majority of lacewing eggs were laid on the lower half of the sorghum plant (Fig. 11). The percentage of eggs laid in the panicle was greater in the semiloose (CSH 1 - 34%) cultivar than in the semicompact CSH 9 - 18%) and compact (SPV 104 - 9%) cultivars.

The temporal distribution of lacewing eggs failed to follow that of *H. armigera*, which suggests that lacewing oviposition is not related to changes in *H. armigera* egg density. Furthermore, *H. armigera* oviposit on the sorghum panicle only, but less than one-third of the neuroptera eggs were found at this location. As the majority of lacewing eggs are laid in the bottom half of the plant it also suggests that they are not primarily targeting *H. armigera*.

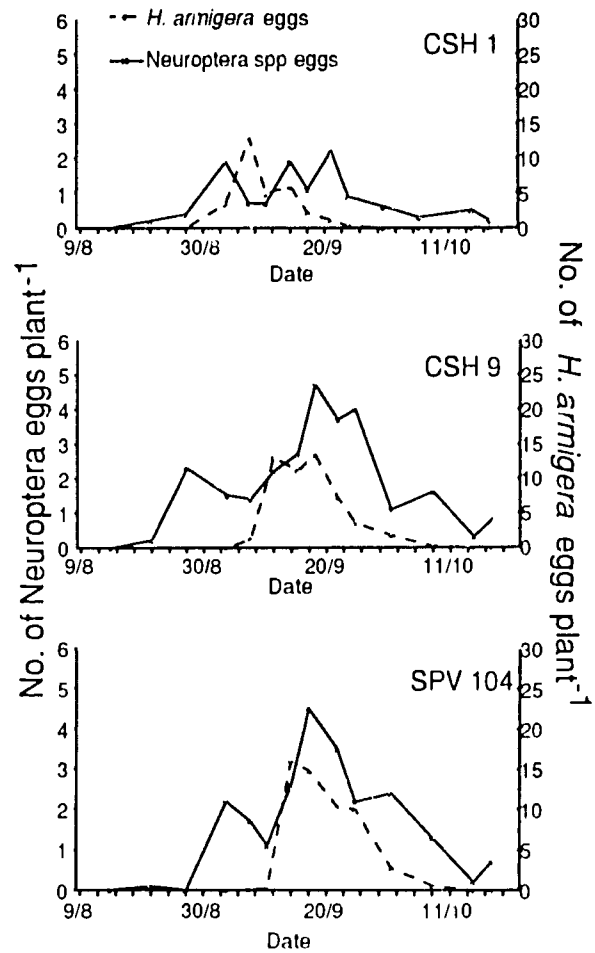

Figure 10. Temporal distribution of Neuropteran and H. armigera *eggs on sorghum.*

Despite the fact that lacewing oviposition is not a direct response to the density of *H. armigera*, lacewing density is relatively high at the time of *H. armigera* activity. Their effectiveness as predators of *H. armigera*, however, will depend largely on the polyphagy and mobility of the larvae in sorghum plants.

Genotype and Parasitoid Interactions in *Chilo partellus*

S.L. Taneja

In an effort to integrate host-plant resistance and biological control of spotted stem borer, we monitored the activity of a larval parasitoid, *Apantheles flavipes*, on *Chilo partellus* in two resistant (IS 2205 and ICSV 700) and two susceptible (ICSV 1 and CSH 11) sorghum genotypes infested with laboratory-reared larvae.

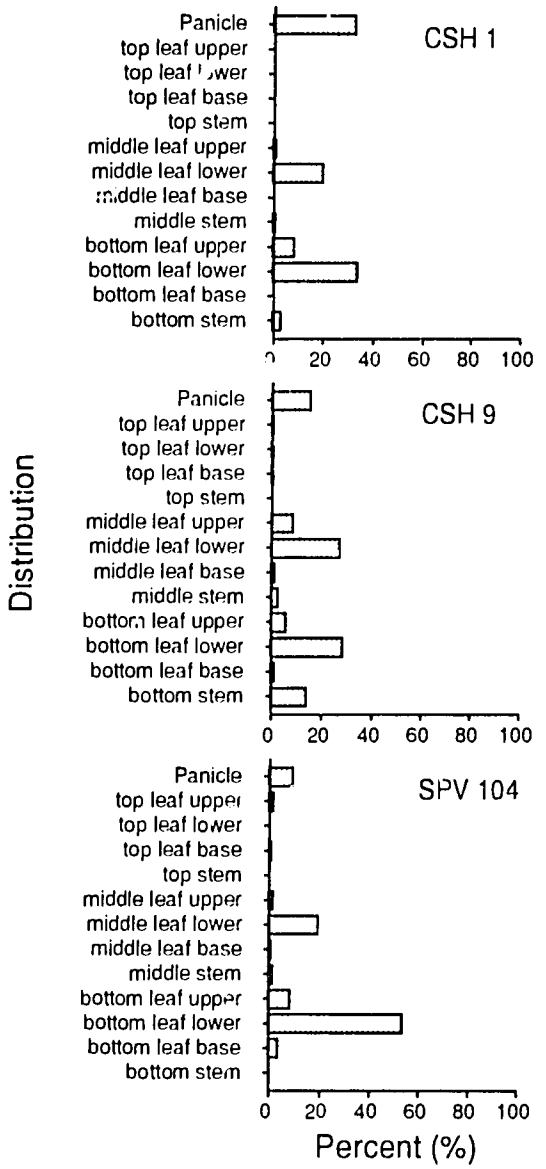

Figure 11. Spatial distribution of Neuropteran eggs on sorghum.

Infested plants were sampled at weekly intervals and the level of borer infestation and parasitism were recorded. Parasitism was negligible in larvae collected from the leaf whorls, while larvae in the stem were highly parasitised. The level of parasitism increased as the season progressed, reaching up to 60% in September. Larvae collected from susceptible genotypes recorded low parasitism (39 and 56%) compared to those from resistant genotypes (61 and 74%). The higher level of parasitism on borer-resistant genotypes is attributed to slower larval development and/or prolonged larval exposure. This experiment is being repeated in the postrainy season to determine the level of parasitism, peak parasitoid activity, and the effect of resistant genotypes on the level of parasitism.

Varietal Improvement

Breeding New Seed Parents

We initiated a program to improve milo cytoplasm seed parents for resistance to various pests and diseases, to diversify the cytoplasm of male-sterile lines, and to develop agronomically desirable high-yielding restorers on nonmilo cytoplasms - A_2, A_3, and Maldandi in A_4 (ICRISAT Cereals Program Annual Report 1991, p. 59). Aspects of this work carried out in 1992 are reported elsewhere in this report under appropriate headings. We report here those aspects not previously mentioned.

Breeding *Striga*-resistant Seed Parents

Belum V.S. Reddy

Breeding and conversion with milo cytoplasm. A number of crosses were made between high yielding (*Striga*-susceptible) B-lines and resistant (restorer) lines. The progenies have been screened at IC and at Punjabrao Krishi Vidyapeeth, Akola, in collaboration with the Indian Council of Agricultural Research since 1990.

Selections from the 1991 rainy season screening (ICRISAT Cereals Program Annual Report 1991, p. 62), including 208 from advanced generations, 11 F_6s from single crosses, 33 F_5s from three-way crosses, and 24 F_4s from four-way crosses, were advanced with selection for agronomic desirability and grain mass in the 1991 postrainy season. Testcrosses of the new progenies and backcrossing in the maintainer lines coupled with selection generated 56 lines from the advanced generation set; 172 from single crosses, 26 from three-way crosses, and 34 from four-way cross sources; 120 testcrosses; and 9 BC_1, 16 BC_2, and 67 BC_3 male-sterile lines.

These lines were screened at Akola and IC during the 1992 rainy season, in *Striga* sick plots using an augmented nursery design with two test plots sandwiched between two susceptible check plots of CSH 1. *Striga* incidence was low at IC (mean number of plants 9 and a range 0 to 39 in CSH 1 plots), and moderate at Akola (mean number of 32 with a range of 0 to 140 in CSH 1 plots). We selected lines with ≤ 5 *Striga* plants in the central row of the three-row test plots that had *Striga* populations in the adjacent two susceptible control plots greater than four times the number of its own *Striga* plants. This discrimination resulted in the following selections: 54 lines from advanced set; 211 from single cross; and 46 from three-way cross sources. Selected maintainer lines in various stages of conversion include 27 in BC_2, 8 in BC_3, 9 in BC_3, and 5 in BC_4. We also made 15 new testcrosses.

Selection response. A resistance index [RI(%)] was calculated to estimate the *Striga* infestation as

$$RI(\%) = \frac{S-(s_1+s_2)/2}{(s_1+s_2)/2} \times 100$$

where S is the number of *Striga* plants in the test entry, s_1, and s_2 in the two adjacent susceptible control plots. Percentage distribution of progenies among RI classes in various generations is given in Table 23. Comparison of RI values for IC across years indicated that the selection for resistance to *Striga* was effective, and that the response to reaction was maintained. By contrast, there was increased susceptibility in the Akola 1992 results, which may indicate that the Akola *Striga* strain is more aggressive than the IC *Striga* strain.

There was considerable variability for plant height, flowering, and grain mass among the resistant populations (Table 24).

Conversion with nonmilo cytoplasms. We confined backcrossing of *Striga*-resistant lines SAR 12, SAR 16, and SAR 34 to A_3 and A_4 (Maldandi) cytoplasms (ICRISAT Cereals Program Annual Report 1991, p. 60). We have now completed six backcrosses in the process of converting them into male-sterile lines with both the cytoplasms.

Introducing durra and bold lustrous grain type into milo cytoplasm male steriles. In previous years we crossed durra lines (5) and bold lustrous grain lines (18) to elite B-lines, and selected for dwarf and durra plant type with bold lustrous grain. A total of 26 single cross F_7s, 26 BC_1F_6s, 3 BC_2F_5s, 24 single cross F_4 progenies, and 64 maintainers and their BC_3 male steriles from the 1991 rainy season

Table 23. Percentage distribution of progenies bred for *Striga* resistance among RI(%)[1] in various generations, 1990-92, Akola, and ICRISAT Center.

Progenies year and location	RI (%) mean	Progenies/ Class (%) -100 to - 80	>-80	Total progenies
ADV.90P[2]	-81	82	18	222
ADV.91A	-94	96	4	78
ADV.92P	-95	89	11	56
ADV.92A	-77	69	32	52
SC $F_3$90P	-91	87	13	211
SC $F_5$91A	-93	93	7	214
SC $F_7$92P	-93	90	10	172
SC $F_7$92A	-84	74	26	165
TC $F_2$90P	-56	38	62	121
TC $F_4$91A	-81	65	35	23
TC $F_6$92P	-86	73	27	26
TC $F_6$92A	-86	76	24	21
FC $F_3$91A	-91	92	8	36
FC $F_5$92P	-90	79	21	34
FC $F_5$92A	-79	57	43	30

1. Resistance index.
2. ADV = advanced generation; SC = single cross; TC = three-way cross; FC = four-way cross; P = ICRISAT Center; A = Akola.

(ICRISAT Cereals Program Annual Report 1991, pp. 62-63) were grown in the 1991 postrainy season, with selection for bold lustrous grain with durra plant type. Also, testcrossing of additional progenies and backcrossing of the maintainers were carried out. The resulting materials were evaluated in the 1992 rainy season, and the following progenies were generated through selection and backcrossing: 25 lines yet to be testcrossed; and lines in various stages of conversion - 18 testcrosses, 20 BC_1, 22 BC_2, 25 BC_3, and 22 BC_4.

The advanced generation progenies and the maintainer lines in conversion were superior to 296B for grain mass, and included a range of variability for plant height and days to flowering (Table 25).

Table 24. Characteristics of *Striga*-resistant progenies evaluated during 1992 rainy season, ICRISAT Center.

	Plant height (m)		Time to 50% flowering (d)		100-grain mass (g)	
Progenies	Min	Max	Min	Max	Min	Max
ADV[1]	1.1	2.1	63	80	1.7	3.6
SC F_7	1.0	2.2	60	88	1.5	4.2
TC F_6	0.8	2.3	64	75	1.9	3.4
FC F_5	0.9	2.6	65	86	2.0	3.7
296B	1.0	1.0	68	68	2.8	2.8

1. ADV = advanced generation; SC = single cross; TC = three-way cross; FC = four-way cross.

Breeding non-milo cytoplasm restorer lines. In an effort to improve the restorer lines for alternative cytoplasms for grain yield and agronomic desirability, we had earlier identified 19 lines from the populations that restored fertility on A_2, 8 on A_3, and 35 on A_4 Maldandi (ICRISAT Cereals Program Annual Report 1991, pp. 63-64).

These lines were evaluated for grain size and grain yield in the 1991 postrainy season, and the resulting selections (50 of A_2, 36 of A_3, and 28 of

Table 25. Characteristics of selected durra derivatives during 1992 rainy season, ICRISAT Center.

	Plant height (m)		Time to 50% flowering (d)		100-grain mass (g)	
Progenies	Min	Max	Min	Max	Min	Max
Advanced[1]	1.0	2.6	58	82	2.7	4.0
Conversion[2]	1.1	2.1	56	80	2.8	4.3
296B	1.0	1.0	68	68	2.8	2.8

1. Advanced generation material derived from single, three-way, and backcrosses.
2. Lines identified as maintainers that are being converted into male-sterile lines.

A_4) were evaluated for grain yield and agronomic desirability in the 1992 rainy season. Testcrosses to their respective cytoplasms were made to confirm restoration. We now have 57 progenies and their testcrosses on A_2, 60 on A_3, and 30 on A_4 (Maldandi).

Introducing tillering ability into milo cytoplasm male-sterile lines. Three types of materials were developed: namely, selections from crosses between high-yielding maintainer lines and selected tillering lines; tillering Sudan grass and grain-grass maintainer lines that are under conversion; and the F_1s of maintainer lines crossed to the selected grain-grass lines (ICRISAT Cereals Program Annual Report 1991, p. 63). Selected lines from the first group were backcrossed to the respective milo cytoplasm lines. We have seven male-sterile lines in BC_5.

Two Sudan grass and two grain-grass lines selected earlier have been further backcrossed to the BC_4, to convert them into male-sterile lines.

The F_1s of the selected grain-grass lines failed to germinate.

Breeding early maturing seed parents. We initiated conversion of 12 early flowering lines (51-56 days to flower during rainy season at IC) as the available male-sterile lines flower in more than 60 days (ICRISAT Cereals Program Annual Report 1991, p. 64). We completed the third backcross while converting them into male-sterile lines with milo cytoplasm.

Isonuclear male-sterile lines. Five backcrosses to the sources of A_1 (milo), A_2, A_3, and A_4 (Maldandi) cytoplasms with the recurrent parents ICSB 11, ICSB 17, ICSB 28, ICSB 37, ICSB 38, and ICSB 42 and four backcrosses for ICSB 88001, ICSB 88004, and ICSB 88005, were completed by the end of the 1991 rainy season (ICRISAT Cereals Program Annual Report 1991, p. 64). Two more backcrosses have been made, completing the conversion of these maintainers into male-sterile lines with all four cytoplasms.

Development of isogenic lines. In continuation of our work to develop isogenic lines (ICRISAT Cereals Program Annual Report 1991, p. 64), we grew the fifth cycle materials in the 1991 postrainy season. These included 15 pairs of lines contrasting in height (tall and dwarf), 42 pairs for plant color (tan and nontan), 49 pairs for leaf lustre (glossy and nonglossy), and 35 pairs for presence and absence of trichomes. In both plant height and color, some pairs of lines were uniform, and additional contrasting pairs were selected from segregating pairs. For leaf lustre and trichomes, all the pairs were segregating and did not conform to their selected target. A total of 89 pairs contrasting in leaf lustre and 93 pairs in trichomes were selected.

All the above pairs were grown in the 1992 rainy season. The following were selected: 25 pairs contrasting in each of plant height (tall and short) and plant color (tan and nontan); 62 pairs contrasting in leaf lustre (glossy and nonglossy); and 98 pairs contrasting in leaf-epidermal appendages (trichomes present and absent).

Hybrid Development and Testing

Belum V.S. Reddy and J.W. Stenhouse

Hybrid evaluation has been de-emphasized at IC as part of a shift to improve parental lines (ICRISAT Cereals Program Annual Report 1991, p. 67). However, we evaluated some pointed hybrids for specific purposes.

1. Postrainy-season adaptation. The adaptive challenge involves response to the specific regime of temperature and daylength, and to declining soil moisture availability towards crop maturity. A total of 78 hybrids selected earlier for high biomass and bold grains were tested in the 1991 postrainy season in two separate trials at IC. Some of the hybrids produced grain yields significantly higher in Trial 1 (18-36%) and in Trial 2 (14 to 24%) than the control hybrid, CSH 12R (Table 26). They were also superior to the control hybrid for lodging and stay-greenness.

The stay-green line, E36-1 (ICSR 91034), restored fertility on milo cytoplasm, and all its hybrids were nonlodging and remained green after maturity, indicating that the stay-green trait was dominant.

2. Rainy-season adaptation. Hybrids selected for rainy-season adaptation at IC also perform well in many locations outside India, but their end uses were different in different parts of the semi-arid tropics (ICRISAT Cereals Program Annual Report 1991, p. 68). Accordingly, we summarize separately the results of the 1992 rainy season. We also report the results of two specific studies on general combining ability (GCA).

Table 26. Performance of selected hybrids from the advanced hybrid trials evaluated[1] at ICRISAT Center[2], postrainy season 1991.

Trial and genotype	Grain yield (t ha^{-1})	Time to 50% flowering (d)	Plant height (m)	Lodging score[3]
AHT-1				
ICSH 91210	5.7	59	2.2	1.7
ICSH 91209	5.2	59	2.3	1.7
ICSH 86686	4.9	62	1.9	1.7
ICSH 871015	5.6	60	2.4	1.3
Controls				
CSH-12R	4.1	61	2.3	2.7
M35-1	3.5	67	2.3	2.3
SE	±0.2	±0.7	±0.1	±(0.1)[4]
CV (%)	8	2	4	25
AHT-2				
ICSH 871035	4.9	57	2.3	1.3
ICSH 91218	4.8	58	2.3	1.0
ICSH 91222	5.2	57	2.2	1.0
ICSH 91225	4.9	59	2.3	1.3
Controls				
CSH-12R	4.2	61	2.2	4.0
M35-1	3.4	66	2.3	2.3
SE	±0.3	±0.8	±0.1	(0.08)
CV (%)	12	2	5	18

1. Randomized complete block design, three replications.
2. Location: BR 5 = Vertisol, high fertility (N86:P40:K0) sprayed.
3. Scored on a 1-5 scale, where 1 = no lodging, 5 = >80% lodging.
4. Figures within parentheses are based on square root transformations

A. Grain purpose. Two broad maturity groups - (1) early maturity (flowering <63 days), and (2) medium maturity (flowering ≥63 days) - are recognized, and tested in separate trials.

In advanced hybrid trials (AHT), we tested 7 early and 34 medium maturity hybrids at three locations (two at IC and one at Bhavanisagar). Three early hybrids (ICSH 90024, ICSH 90023 and ICSH 89051) produced grain yield 9 to 15% higher (numerically, but not statistically significant) than the control, CSH 6 (4.7 t ha^{-1}). None of the medium maturity hybrids yielded higher than the 296A-based control hybrid ICSH 153. However, the hybrids ICSH 91046 and ICSH 91122 produced grain yields (6.3 and 6.4 t ha^{-1}) equal to ICSH 153 (6.4 t ha^{-1}).

Preliminary hybrids (45) were tested at three locations (two at IC and one at Bhavanisagar). Three early hybrids had grain yields ranging from 5.6 to 5.9 t ha^{-1} and were significantly superior to the control hybrid CSH 6 (5.0 t ha^{-1}). Hybrids ICSH 92013 and ICSH 92033 had superior grain size, and ICSH 91162 was moderately resistant to stem borer (Table 27). Four medium maturity hybrids were on a par with the 296A-based

Table 27. Performance of selected sorghum hybrids from the preliminary hybrid trial (PHT) evaluated[1] over three Indian locations[2], rainy season 1992.

Genotype	Grain yield (t ha^{-1})	Time to 50% flowering (d)	Plant height (m)	100-grain mass (g)
ICSH 92013	5.9	62	2.0	3.3
ICSH 92033	5.9	61	2.1	3.0
ICSH 92001	5.3	62	2.2	2.8
ICSH 91162[3]	5.6	61	2.2	2.6
ICSH 91187[4]	6.4	67	2.4	3.0
ICSH 92025	6.3	65	2.5	3.1
ICSH 91188[4]	6.1	66	2.0	2.6
ICSH 92023	6.0	66	2.1	3.5
Controls				
CSH 6	5.0	59	1.9	2.9
ICSH 110	6.6	65	2.1	3.1
SE	±0.2	±0.4	±0.04	±0.1
CV%	7	2	6	3

1. 7x7 triple-lattice design, three replications,
2. Locations: BIL 7 = Vertisol high fertility (N86:P40:K0), sprayed, ICRISAT Center; BUS 7 = Vertisol, high fertility (N86:P40:K0), nonsprayed, ICRISAT Center; Bhavanisagar = Alfisol, high fertility (N80:P40:K40), sprayed, Bhavanisagar, Tamil Nadu.
3. Moderately resistant to midge.
4. Moderately resistant to stem borer.

control hybrid ICSH 110 for grain yield, and among them, ICSH 91188 was moderately resistant to midge (Table 27).

We selected 145 bold grain hybrids for further testing from a set of hybrids of the selected IC developed male-sterile lines (12) and restorer lines (22).

B. Dual purpose. We tested 20 hybrids in two locations (IC and Bhavanisagar). The controls were SPH 280, a postrainy season hybrid; ICSV 700, a stem borer-resistant variety; and IS 19674, a landrace known for high biomass and Brix's reading (sugars). Among the selected hybrids, five for grain yield and two for dry-fodder yield were significantly superior to the control IS 19674. All hybrids (except one) maintained sugar content on par with the control variety IS 19674 (Table 28). Flowering in these entries ranged from 67 to 76 days while SPH 280 flowered in 75 days.

Table 28. Performance of selected dual purpose sorghum hybrids evaluated[1] at two Indian locations[2], rainy season 1992.

Genotype	Yield (t ha^{-1}) Grain	Yield (t ha^{-1}) Fodder	Plant height (m)	Brix's[3] reading (%)
ICSH 92036	6.5	23.9	3.1	10.1
ICSH 92037	4.9	18.3	2.7	16.5
ICSH 92047	4.1	27.8	3.2	16.1
ICSH 92044	3.2	28.7	3.1	15.5
ICSH 92046	2.8	25.3	3.1	15.9
ICSH 92053	3.8	23.4	3.1	15.1
Controls				
SPH 280	3.0	22.1	2.9	16.6
ICSV 700	2.3	25.9	3.0	17.0
IS 19674	2.2	22.3	2.8	16.9
SE	±0.3	±1.3	±0.01	±0.7
CV (%)	11	7	6	9

1. 7x7 triple lattice design, three replications.
2. Locations: BIL 7 = Vertisol, high fertility (N86:P40:K0), sprayed, ICRISAT Center; Bhavanisagar = Alfisol, high fertility (N80:P40:K40), sprayed.
3. From location BIL 7 only.

C. Forage purpose. We tested 21 single-cross and 23 three-way hybrids at IC and Bhavanisagar. Seven single-cross and one three-way hybrids were selected, based on fresh fodder weight (at harvesting stage) (Table 29). They flowered from 58 to 76 days and had height ranging from 2.6 to 3.1 m.

D. General combining ability studies. A number of male-sterile lines and restorer lines have been developed at IC and used to produce high yielding hybrids with high specific combining ability. However registration of these lines requires data from a systematic evaluation of their performance in hybrid combination. For this purpose consequently, the select group of 20 restorers were

Table 29. Performance of selected sorghum forage hybrids evaluated[1] at two Indian locations[2], rainy season 1992.

Genotype	Yield (t ha^{-1}) Fresh fodder	Yield (t ha^{-1}) Grain	Tiller[3] (no.)	Ratoon-ability[4]
ICSH 92199	35.4	1.9	17	2.0
ICSH 92200	35.0	3.2	13	2.4
ICSH 92203	36.1	2.2	8	2.2
ICSH 92201	31.1	2.6	25	1.6
ICSH 92221[5]	34.2	3.1	15	1.9
ICSH 92216	29.8	2.6	16	2.7
ICSH 92215	34.6	1.2	14	3.2
ICSH 92217	24.8	2.7	18	1.0
Control				
IS 3359	25.8	0.8	24	2.7
SE	±1.7	±0.6	±1.4	±(0.16)[6]
CV (%)	8	34	13	34

1. 7x7 triple lattice design, three replications.
2. Locations: BIL 7 = Vertisol high fertility (N86:P40:K0), sprayed ICRISAT Center; Bhavanisagar = Alfisol, high fertility (N80:P40:K40), sprayed.
3. From Bhavanisagar only.
4. From BIL 7 only, scored on 1 to 5 scale where 1 = highly ratoonable, 5 = least ratoonable.
5. Three-way hybrid, others are single-cross hybrids.
6. Figure within parentheses is based on square root transformation values.

crossed to 4 common A-lines, and the 16 selected A-lines to common restorers. These groups of 80 and 64 hybrids were evaluated separately under high fertility. The data were subjected to line x tester analyses.

GCA estimates of the 20 restorers are given in Table 30. The restorers, ICSR 89018 and ICSR 174, were the most favored for earliness; ICSR 89004, ICSR 165, ICSR 38, and ICSR 160 for grain yield; and ICSR 165, ICSR 103, and ICSR 89018 for grain mass.

GCA estimates of the 16 elite A-lines are summarized in Table 31. Important male-sterile lines were ICSA 31 and ICSA 56 for earliness, ICSA 51, ICSA 31, ICSA 84, and ICSA 32 for grain yield, and ICSA 52 and ICSA 73 for grain mass.

Table 30. General combining ability estimates of the restorers, ICRISAT Center, rainy season 1992[1].

Restorer lines	Time to 50% flowering (d)	Plant height (m)	100-grain mass (g)	Grain yield (t ha^{-1})
ICSR 38	-0.8	-0.08	-0.23	0.49
ICSR 43	-1.5	-0.11	-0.24	0.39
ICSR 103	-1.2	-0.15	0.24	0.13
ICSR 108	2.4	0.17	0.01	-0.80
ICSR 143	0.8	0.10	0.06	0.07
ICSR 152	1.1	-0.04	-0.06	-0.09
ICSR 160	-0.0	0.12	-0.08	0.48
ICSR 165	8.7	0.82	0.61	0.50
ICSR 172	-1.0	-0.08	0.05	-0.21
ICSR 174	-2.6	0.08	0.17	-0.72
ICSR 89001	-0.2	-0.11	0.18	0.17
ICSR 89004	-0.2	0.06	-0.18	0.98
ICSR 89018	-4.0	-0.30	0.24	-0.35
ICSR 89019	0.9	-0.16	-0.22	-0.53
ICSR 89022	-1.3	-0.08	-0.44	-0.12
ICSR 89028	-0.3	-0.12	0.05	0.35
ICSR 89032	-0.5	-0.06	-0.12	-0.10
				0.31
SE	±0.04	±0.03	±0.05	±0.22

1. Randomized complete block design, three replications.

Genetic Diversification

Belum V.S. Reddy and K.E. Prasada Rao

As part of the drive to diversify the range of phenotypes represented in our breeding products and their genetic origins (ICRISAT Cereals Program Annual Report 1991, p. 75), we made several efforts to introduce new landraces into our breeding programs.

Some of the activities are mentioned elsewhere in this report. Here we report the progress made in three areas not covered in the earlier sections.

1. Genetic divergence and heterosis. Milo cytoplasm male-sterile lines and restorer lines developed at IC are mostly based on caudatum and kafir races. Since heterosis is proportional to the genetic distance between the parents involved in hybrids, a complete set of hybrids involving racially diverse parents was made (ICRISAT Cereals Program Annual Report 1991,

Table 31. General combining ability of the male-sterile lines, ICRISAT Center, rainy season 1992[1].

Male-sterile lines	Time to 50% flowering (d)	Plant height (m)	100-grain mass (g)	Grain yield (t ha^{-1})
ICSA 11	-2.0	0.03	0.09	-0.12
ICSA 31	-4.4	0.00	-0.05	0.52
ICSA 32	1.6	0.15	0.06	0.29
ICSA 38	3.7	0.00	-0.18	-0.29
ICSA 42	1.2	0.01	0.04	-0.22
ICSA 51	-0.4	0.14	0.01	1.06
ICSA 52	0.2	-0.01	0.54	-0.04
ICSA 56	-3.4	-0.10	-0.11	0.22
ICSA 73	-0.3	0.16	0.31	0.16
ICSA 84	1.1	0.19	0.08	0.29
ICSA 102	0.1	-0.02	0.05	0.12
ICSA 88005	-0.7	0.05	-0.16	-0.04
ICSA 88013	-1.7	-0.12	-0.05	-0.32
ICSA 89003	0.6	0.09	-0.03	-0.02
ICSA 89004	2.2	-0.28	-0.27	-0.77
ICSA 90001	2.5	-0.29	-0.30	-0.82
SE	±0.04	±0.02	±0.04	±0.20

1. Randomized complete block design, three replications.

p. 74). The evaluation involved the hybrids obtained by crossing five representative lines from each of the sorghum landraces (caudatum, durra, guinea, bicolor, and kafir) to six common male-sterile lines bred by IC. These hybrids along with their parents were evaluated in the 1991 postrainy and the 1992 rainy seasons. The results are shown in Table 32.

A. Phenology. Kafir and guinea restorer lines were late, but showed heterosis for earliness in both the seasons. By contrast, durra restorer lines were early in both the seasons, but they produced hybrids that flowered late in the rainy season, and early in the postrainy season. This may be due to the dominance of the temperature and day length sensitivity in durra hybrids.

B. Plant height. Durra and guinea restorer lines produced hybrids with greater height. On the other hand, caudatum and durra were superior to others for plant height when heterosis was considered as the basis.

C. Grain yield. Guinea restorer lines contributed to the highest grain-producing hybrids across the seasons followed by caudatum restorer lines. However, the order was reversed when judged on the extent of heterosis. The negative heterosis exhibited by durra and kafir hybrids in the postrainy season may be related to their sensitivity to low temperatures [minimum temperatures ranged from 7-15°C during the growth stage $(GS)_1$ and GS_2].

D. Yield components. The grain yield superiority of guinea and caudatum hybrids across the seasons was primarily due to increased grain number and grain mass contributed by the respective restorer lines.

E. Agronomic desirability. The superiority of the guinea over caudatum groups with respect to grain yield contrasted with the inferiority of the guinea lines for grain threshability and agronomic desirability. These data suggest it will be necessary to exploit broadly across these races in order to achieve sustained and acceptable advances in performance.

2. Terminal drought stress. In continuation of our work to breed for terminal drought stress with stay-green trait and bold grains (ICRISAT Cereals Program Annual Report 1991, p. 75), we selected 68 F_3s from three-way crosses and 47 S_2s from the populations during the 1991 postrainy season.

3. Large grain (ICSP LG) population. After completing the introduction of the desirable variability (ICRISAT Cereals Program Annual Report 1991, p. 75), we sowed the bulk (C_0-cycle 0) made by mixing 300 half-sibs and 40 fertile S_1s in a 2:1 ratio, during 1991 postrainy season, and initiated mass selection for bold grain in short-statured plant types, primarily among male-sterile open-pollinated plants. Prior to flowering, we removed plants with small glume size (which is related with small grain). We selected 200 half-sibs and 80 fertile S_1s, and made the bulk (C_1 bulk) by mixing them in a 2:1 ratio. The C_1 bulk was grown in the 1992 rainy season in isolation. We selected in the C_1 bulk 122 half-sibs and 189 fertile S_1s, and pooled them in a 2:1 ratio to form the C_2 bulk for further selection.

4. High tillering (ICSP HT) population. We completed the introduction of desirable variation (ICRISAT Cereals Program Annual Report 1991, pp. 75-76) and constituted the C_0 bulk of 800 half-sibs and 50 fertile S_1s pooled in a 4:1 ratio. This was sown in isolation at Bhavanisagar during the 1992 summer season. Uniculm plants were removed prior to anthesis, and random mating occurred among the tillering plants. We selected 280 half-sibs and 26 fertile S_1s with high tillering ability. Seed from these was pooled equally to form the C_1 bulk, which was grown in isolation in the 1992 rainy season at IC. Uniculum plants were removed prior to anthesis. At maturity, we selected 230 half-sibs and 143 fertile S_1s with high tillering ability and red/white grain, which were classed as brown midrib at milk stage. These were pooled in a 2:1 ratio to form the C_2 bulk for further selection.

5. B-population (ICSP B) with resistance to various factors. We introduced bold grain lines, and downy mildew, midge, and stem borer-resistant lines into US/B-C_6 population with the objective of developing a B population with variability for resistance to these major yield-reducing factors (ICRISAT Cereals Program Annual Report 1991, p. 76). The bulk thus obtained was sown during the 1992 postrainy season. Male steriles in the bulk were crossed to an additional set of eight dwarf stem borer resistant breeding lines that originated from three different parents. Three separate bulks were established from the selected 250 half-sibs, the

Table 32. Performance of the restorer lines belonging to different landraces and their hybrids in sorghum evaluated[1] at ICRISAT Center, 1991 postrainy and 1992 rainy seasons.

Character	Season	Material	Landrace groups					SE	CV(%)
			Kafir	Caudatum	Durra	Bicolor	Guinea		
Time to 50% flower (d)	PR	Restorers[2]	96	87	82	80	93	±0.60	3
		Hybrids[3]	91	87	82	83	88	±0.25	
		%Heterosis[4]	-6	0	0	4	-6		
	R	Restorers	66	64	63	63	67	±0.37	2
		Hybrids	64	62	71	62	64	±0.15	
		%Heterosis	-3	-3	11	-2	-5		
Plant height (m)	PR	Restorers	1.3	1.1	1.5	1.5	1.8	±0.03	8
		Hybrids	1.3	1.4	1.7	1.5	2.0	±0.01	
		%Heterosis	0	21	12	0	10		
	R	Restorers	1.8	1.6	2.3	2.2	3.2	±0.03	5
		Hybrids	2.0	2.1	3.1	2.3	3.2	±0.01	
		%Heterosis	10	24	26	4	0		
Yield (t ha^{-1})	PR	Restorers	1.1	1.1	1.6	1.6	1.2	±0.09	28
		Hybrids	0.7	1.4	0.8	1.7	1.9	±0.04	
		%Heterosis	-57	21	-100	6	37		
	R	Restorers	3.0	2.8	2.9	2.9	4.5	±0.21	18
		Hybrids	4.0	5.5	3.4	4.8	5.8	±0.09	
		%Heterosis	25	49	15	40	22		
Grain# (100s)	PR	Restorers	139	133	163	211	203	±0.37	29
		Hybrids	76	155	77	199	253	±0.15	
		%Heterosis	-83	14	-110	-6	20		
	R	Restorers	310	294	327	357	624	±0.64	18
		Hybrids	344	523	304	463	626	±0.26	
		%Heterosis	10	44	-7	23	0.4		
1000-grain mass (g)	PR	Restorers	23.0	26.1	29.5	21.5	17.5	±0.38	6
		Hybrids	24.6	26.4	27.7	25.6	22.0	±0.15	
		%Heterosis	7	1	-7	16	21		
	R	Restorers	29.4	29.0	27.4	24.2	21.7	±0.41	5
		Hybrids	35.1	32.4	33.6	31.8	27.6	±0.17	
		%Heterosis	16	11	19	24	21		
Threshability score	R	Restorers	2.67	2.93	3.47	3.33	2.87	±(0.05)	25
		Hybrids	2.38	2.36	2.69	3.12	3.07	±(0.02)	
		%Heterosis	-12	-24	-29	-7	7		
Plant aspect score	PR	Restorers	2.93	3.13	2.53	3.47	3.00	±(0.04)	16
		Hybrids	3.07	2.34	2.58	2.84	2.51	±(0.01)	
		%Heterosis	5	-34	2	-22	-20		
	R	Restorers	2.73	2.93	3.47	3.93	3.80	±(0.04)	15
		Hybrids	2.18	2.59	3.66	3.10	3.70	±(0.01)	
		%Heterosis	-25	-13	5	-27	-3		

1. Randomized complete block design with three replications, high fertility (N 86: P 40: K 0), Vertisol, sprayed BM 8A in the 1991 postrainy season, BIL 7A in the 1992 rainy season. 2. Mean of five restorers. 3. Mean of 30 hybrids obtained by crossing five lines in the given landrace to six common male-sterile lines. 4. Average superiority of hybrids over restorer lines. PR = Postrainy season. R = Rainy season. Threshability score on 1 to 5 scale where 1 = grain free from glumes upon threshing, 5 = >50% of the grain with glumes. Plant aspect score on 1 to 5 scale, where 1 = most desirable and 5 = least desirable plant and grain types. Figures in parentheses are based on square root transformation values.

100 fertile S_1s, and the crosses with stem borer resistant sources. The bulks were grown in isolation in the 1992 rainy season in a 2:1:2 ratio. We selected 250 dwarf bold grain half-sibs and 90 fertile S_1s. The seeds from these were mixed in a 3:1 ratio to form the bulk for the next random mating cycle.

Seedling Growth in Early-maturing Sorghum

H.F.W. Rattunde

Vigorous growth of sorghum seedlings may contribute significantly to maximizing yield and yield stability of early-maturing sorghum. The crop establishment phase can be a critical determinant of survival and productivity. Rapid early growth may enhance (1) avoidance/tolerance of soil crusting, (2) effective exploitation of available resources and weed suppression by rapid development of shoot and roots, and (3) avoidance of damage by shoot fly. Furthermore, rapid growth may be a key to maximizing productivity in early-maturing sorghum, where duration of growth would be a limiting factor. Even with ideal conditions for establishment, differences in seedling vigor were significantly related to yield of grain and stover in germplasm material and random-mating populations (ICRISAT Cereals Program Annual Report 1991, p. 59).

Recurrent selection for enhanced seedling growth in the US/R and RS/R populations was initiated in 1992 to exploit the variability observed for seedling vigor, and to test its potential for improving the productivity of early-maturing sorghum. Random full-sib progenies of US/R (n = 152) and RS/R (n = 137) random-mating populations were sown in micro-plots (hill of eight plants) with six replications. Selection for seedling vigor scores (visual) and shoot dry weight (destructive) can be completed by 36 days after emergence (DAE), enabling completion of one cycle per season. Seedling vigor was scored (1 low to 9 high) at 3, 7, and 14 DAE. Scores were averaged over dates because the genotype x date interaction was small. The micro-plots were cut at the soil level and dried to determine shoot dry weight at 36 DAE.

There is relatively little information, however, on relationships of seedling vigor to shoot and root characteristics of potential importance for yield and yield stability. Therefore, additional shoot and root characters were measured to indicate potential changes resulting from selection for seedling vigor and dry matter accumulation. The shoot measures included seedling height at 17 DAE, number of fully emerged leaves at 30 DAE, and length, width, and computed area of the seventh leaf. Roots were observed on two random plants per plot at thinning (11 DAE) by counting the number of secondary roots >1 cm and measuring the length of the longest root on each plant. Root volume was estimated by root length x root number. There was highly significant genetic variation for all measured and computed traits.

Seedling vigor scores and shoot dry weight were positively and strongly related to seedling height and leaf length, and more weakly related to leaf width (Table 33). Seedling vigor and dry weight were not related to the rate of leaf appearance. There were relatively strong correlations with seed weight, suggesting that seed energy reserves are also a determinant of early growth.

Shoot growth measures were weakly, but often significantly, related to greater root growth (Table 34). This suggests that greater shoot growth does not necessarily occur at the expense of root growth, but may even be associated with superior root development. The weak association indicates that there is considerable opportunity for combining high shoot and root growth. The impact of this on yield and yield stability of early-maturing sorghum remains to be determined in a range of environments.

Table 33. Phenotypic correlations of seedling vigor and shoot dry weight (36 DAE) with shoot and seed characteristics for US/R and RS/R full-sib progenies.

	Seedling vigor		Shoot dry weight	
Traits	US/R	RS/R	US/R	RS/R
Seedling height	0.92**[1]	0.91**	0.83**	0.81**
Leaf number	0.00	-0.01	0.02	0.02
Leaf length	0.69**	0.67**	0.59**	0.60**
Leaf width	0.35**	0.26**	0.30**	0.28**
Leaf area	0.56**	0.54**	0.48**	0.51**
Seed weight	0.52**	0.46**	0.47**	0.33**

1. ** significant at P<0.01.

Table 34. Phenotypic correlations of seedling vigor and shoot dry weight (36 DAE) with root characteristics for US/R and RS/R full-sib progenies.

	Seedling vigor		Shoot dry weight	
Traits	US/R	RS/R	US/R	RS/R
Root number	0.37**[1]	0.04	0.37**	0.03
Root length	0.43**	0.25**	0.41**	0.24**
Root volume	0.44**	0.16	0.43**	0.16

1. ** significant at $P < 0.01$.

Molecular Biology

Use of Proteins and DNA Markers for Characterizing Dwarfing Genes in Near-isogenic Lines of Sorghum

C.S. Busso and Santosh Gurtu

Protein markers. We examined the prospects for finding a unique protein marker for dwarfing genes in sorghum. We looked for differences in the protein banding patterns of three pairs of tall and dwarf near-isogenic sorghum lines. We compared banding patterns of soluble proteins from embryos of these lines using SDS-PAGE (denaturing conditions). About 50-60 bands were resolved on gels On an average, 30 bands were different between the tall and dwarf members of a pair; this was not expected with these near-isogenic lines. However, there were no consistent single-band differences between the tall and dwarf lines of different pairs.

For ease of interpretation, we looked for differences with fewer bands resolved in gels by using the buffer-PAGE system (nondenaturing gel electrophoresis). Even with this system no consistent differences between the tall and dwarf members of a pair were detected. Two-dimensional gel electrophoresis also failed to resolve any consistent differences between tall and dwarf lines.

RAPD markers. We also looked for consistent differences between the above dwarf and tall pairs derived from the ICSP 1B/R MFR population using the RAPD technique. We amplified the genomic DNA samples of each of the above six lines with a set of 56 commercially available primers (decamers-Operon Technologies, USA). We compared the bands (amplified DNA molecules) separated in polyacrylamide gels. Only the use of one primer, A4, resulted in differences between tall and dwarf lines in two pairs, but not in the third.

Genetic Transformation to Introduce Resistance Genes into Breeding Lines: In-vitro Regeneration of *Sorghum bicolor* Shoot Apices

Saleh Nahdi and J.M.J. de Wet

The prospects for *Agrobacterium*-mediated transformation in cereals has brightened with the recent success with maize and sorghum. Abilities to culture shoot apices and rapidly produce normal plants are the two prerequisites for successful transformation with *Agrobacterium*. We have successfully regenerated whole plants from shoot apices from 11 sorghum lines. Shoot meristems, isolated about 24 h after seed germination, were cultured on a modified medium containing MS mineral salts, B5 vitamins, supplemented with EDTA, glycine, L-aspargine, thiamin, ascorbic acid, niacinamide, alcium pantothenate, zeatin, BAP, charcoal, kinetin, and IAA. Ability to regenerate varied among genotypes from 91% (in line 296B) to 19% (ICSB 89). ICSR 111 and ICSR 165 also showed high regeneration capacity (73% and 68%, respectively). Plantlets developed from shoot apical meristems within 4-5 weeks without formation of any callus. Browning of young regenerated plants could be controlled by increasing the amount of activated charcoal and ascorbic acid in the medium. Plantlets were transferred successfully to soil. They appeared to have the normal phenotype, but no cytological examinations were undertaken. This regeneration system has potential for use in developing transformed sorghum plants.

Pearl Millet Research

Proviseur Peace Ebrah

55

Abiotic Stress

Selection for Drought Tolerance

F.R. Bidinger and V. Mahalakshmi

Threshing percentage as a selection criterion. Previous research on tolerance to terminal drought stress in pearl millet identified threshing percentage (ratio of the mass of the grain to the mass of the panicle) as a useful indicator of genotype tolerance/susceptibility to terminal stress:

1. Threshing percentage focuses directly on the interaction of the genotype and the stress by measuring only those growth/developmental processes that occur during the stress exposure.
2. It is a quantitative measure of the degree of success of an individual genotype in setting and filling grains under moisture stress - the processes affected by terminal stress - as the greater the reduction in either of these processes, the greater the reduction in threshing percentage.
3. It is easily and accurately measured, and characteristically has a coefficient of variation of half or less than that of grain yield under stress conditions.
4. It generally explains a significant proportion of differences in grain yield among genotypes under terminal stress. The combination of differences in threshing percentage, yield potential and drought escape frequently explains 80% or more of the variation for grain yield under terminal stress.

These features, plus the fact that there is generally very little variation in threshing percentage among advanced breeding materials in the absence of stress, make threshing percentage a promising candidate as a direct selection criterion for tolerance to terminal stress. We tested threshing percentage as a selection criterion in the composite EC 87, which was formed by merging two early composites, one with tolerance to terminal drought stress. A replicated set of 1000 S_1 progenies were grown under both terminal stress and a fully irrigated control in the drought nursery in the dry season of 1989. Selection in the terminal stress planting was done on the basis of threshing percentage and selection in the irrigated planting was done on the basis of grain yield. The best 300 progenies by each criterion were then evaluated for grain yield in the normal rainy season in both north India and at IC. Four varieties were made representing the best progeny in both the single-stage selection (threshing percentage or yield in the drought nursery) and the best progeny from the two-stage selection (threshing percentage or yield in the drought nursery plus grain yield in the rainy season). These were tested in a total of 12 environments in 1990 and 1991, which were grouped according to the season and location and whether or not they were stress or nonstress environments (Table 35). The objective of the tests were to compare the effects of selection for threshing percentage under stress vs selection for grain yield under nonstressed conditions (in both the one and two-stage selection systems) under both stressed and nonstressed test environments.

Results: single-stage selection scheme. Selection for threshing percentage under stress resulted in a significant improvement in this parameter in all test environments, whether stressed or not (Table 35). The difference in threshing percentage under terminal stress in the drought nursery evaluation between the varieties selected for threshing percentage and for yield was very large (68.2% vs 60.7%) and associated with a significant yield difference of nearly 20% in favor of the selection for threshing percentage under stress. Under stress conditions in the rainy season in northern India, there was a small (8%) nonsignificant advantage in favor of the threshing percentage selection. There were no yield differences in the absence of stress in the dry season, but there were small (6%) and again nonsignificant yield differences in favor of the selection for grain yield in the absence of stress in the rainy season locations (Table 35).

The fact that most yield differences are not significant is not surprising, as it is very difficult to obtain a large enough response in a single cycle of selection to obtain significant yield differences in pearl millet. There are clear trends in the data however, which if accepted as real because of their consistency, do indicate that selection for threshing percentage under a terminal stress is effective in improving tolerance to such a stress, particularly when the resulting material is tested in the same stress environment in which the selection is done. However, the results also

Previous Page Blank

Table 35. Mean grain yields and threshing percentages of varieties selected from EC 87 on the basis of threshing percentage under stress [TH%(S)] or yield in irrigated conditions [YLD(I)] in the dry season (single-stage selection), and on the basis of threshing percentage under stress in the dry season + grain yield in the rainy season, or yield under irrigation in the dry season + yield in the rainy season (two-stage selection scheme). Data are from trials conducted in 1990 and 1991.

	Yield (g m^{-2}) by selection criterion			Threshing % by selection criterion		
	TH% (S)	YLD (I)	$P <$[1]	TH% (S)	YLD (I)	$P <$[1]
Single-stage selection in drought nursery						
Drought nursery						
Terminal stress (2)[2]	191	157	0.03	68.2	60.7	0.0005
Irrigated (2)	387	382	NS[3]	81.1	77.6	0.006
Rainy season nonstress						
Southern India (3)	302	319	0.18	78.8	76.4	0.01
Northern India (3)	215	227	NS	72.5	68.2	0.005
Rainy season stress						
Northern India (2)	118	109	NS	68.8	65.9	0.08
Two-stage selection drought nursery and rainy season						
Drought nursery						
Terminal stress (2)	163	170	NS	61.2	64.5	0.12
Irrigated (2)	370	342	0.20	78.2	77.7	NS
Rainy season nonstress						
Southern India (3)	322	292	0.02	76.0	76.9	NS
Northern India (3)	240	259	0.18	70.0	69.6	NS
Rainy season stress						
Northern India (2)	124	111	NS	67.2	64.8	0.14

1. Probability that the varieties resulting from the two selection criterion are not different, based on single degree of freedom contrast.
2. Number of test environments.
3. NS = P >0.20.

suggest that there may be a penalty resulting from selection deliberately for threshing percentage under stress, in terms of yield improvement in nonstressed environments.

Results: two-stage selection scheme. Responses to selection in the two-stage scheme were much less consistent. There were small but contrasting differences in threshing percentage in the two stressed test environments between the two selection schemes, and no differences at all in threshing percentage in the absence of stress (Table 35). There were differences in grain yield of the order of 5-10% in a number of the test environments, but the pattern of advantage was inconsistent. For example, the variety selected for threshing percentage under stress outyielded the variety selected for yield under irrigation, when

tested in the nonstressed environments in the dry season and in southern India, but not in the nonstressed environments in northern India or in either of the stressed environments. Perhaps the inconsistency is simply a reflection of the large genotype x environment interaction that occurs in multilocational testing of material selected for grain yield in a limited number of locations, as the selection pressure for yield in the rainy season was much stronger (15 of 300 progenies = 5%) than the selection pressure applied in the dry season (300 of 1000 progenies = 30%).

Results: one-stage vs two-stage selection. The improvement in threshing percentage from selection was much less in the two-stage scheme than in the single-stage scheme under both the stress and non-stress environments (Table 35). Perhaps this is not too surprising as the selection intensity for threshing percentage in the initial stage of the two-stage scheme was mild (300 out of 1000 S_1 progenies = 30%) in comparison to the selection intensity for threshing percentage under stress in the single-stage scheme (15 out of 1000 progenies = 1.5%). This probably also explains why there was a positive yield response under stress in the drought nursery to selection for threshing percentage in the single-stage scheme and not in the two-stage scheme. The additional selection pressure for grain yield ability under rainy season conditions in the two-stage scheme, however, did appear to have an effect in the rainy season test locations, where the two-stage scheme selections of threshing percentage plus yield were at least numerically superior to the single-stage selections for threshing percentage alone.

Conclusions. The results of the single-stage selection scheme suggest that selection for threshing percentage under terminal drought can be effective in increasing tolerance and grain yield, under certain conditions. A high selection intensity is necessary, selection in the target environment appears to be more effective than selection in a different environment, and selection for threshing percentage may mean foregoing the opportunity to improve grain yield in the absence of stress. Therefore, the best procedure may be to practice selection for threshing percentage in finished varieties with an established yield potential, and, where possible, to practice selection in the area for which the variety has been bred. However, the latter point needs further quantification because it is operationally far easier to develop reliable selection conditions for drought tolerance in managed dry season environments than in the normal rainy season, even in arid locations.

Rajasthan Landrace Topcross Hybrids

V. Mahalakshmi, E. Weltzien R., and F.R. Bidinger

The rationale for topcross hybrids. The Cereals Program is working closely with the Rajasthan Agricultural University and the Central Arid Zone Research Institute to accelerate the development of new breeding materials with specific adaptation to the arid conditions of northwestern India. There has been only a limited adoption of high yielding varieties and hybrids in this area, despite their superior yield potential. Reasons for this vary, but do include the lack of a clear advantage of modern cultivars over the farmers' own landrace varieties under actual farm conditions in the arid zone, where adaptation to the environmental conditions is at least as important as yield potential as a determinant of actual yields.

The breeding of improved genetic materials for this area clearly must place heavy emphasis on adaptation, including use of local landraces as parents in the breeding program. Approaching the problem by attempting to transfer adaptation from the landraces to high yielding cultivars is likely to be difficult however, as little is known about the nature of that 'adaptation', either physiologically or genetically.

The current approach in the collaborative breeding programs is to target improvement of yielding ability of the landraces, without losing their adaptation to the arid environmental conditions. Recent research on topcross (male-sterile line x open-pollinated variety) hybrids has indicated that this approach may be an effective and rapid way of accomplishing this objective.

Comparison of topcross hybrids and landraces. We tested this hypothesis with a set of landrace-based topcross hybrids made by crossing 16 selected Rajasthan landrace varieties to an early flowering grain-type male-sterile line and a medium maturity dual purpose (grain plus fodder) male-sterile line. The resulting 32 topcross hybrids and their 16 pollinators were evaluated in a set of environments that included the arid zone of western Rajasthan, a more favorable environment at Hisar, and a managed terminal stress environment at IC in the dry season (Table 36).

With the exception of Hisar in 1989 which was irrigated, all rainy season experiments were rainfed (range 192 - 774 mm; Table 36) but with good management of plant population, weed control, and fertility (Table 36). The object was a specific test of adaptation to physical stress factors, unconfounded by the effects of poor crop management. The dry season test environments were intended to expose the test material to a severe terminal drought stress, which is the most damaging stress to grain yield. These tests were irrigated until just before flowering, and then left to fill what grain they could entirely on available soil moisture, under very high temperature and evaporative demand conditions.

The topcross hybrids made with the grain-type male-sterile flowered 4 to 8 days earlier and produced a higher grain yield than the landrace pollinators in each of the three groups of test environments (Table 37). Their yield advantage was due both to a higher yield potential, which is best expressed in the more favorable Hisar environment and associated with a considerably higher harvest index, and to the escape from drought stress provided by early flowering in the terminal stress environments and in some of the arid zone test locations. Their advantage in grain yield, however, was at the expense of fodder (stover) yield, for which they were the lowest yielding of the three groups of test materials (Table 37).

The dual purpose topcross hybrids had a similar time to flowering as the landraces, but produced both more grain and more fodder than the landraces in all three groups of test environments. The greater grain and stover yields were due primarily to a significant heterosis for total biomass production in the dual purpose topcross hybrids (in comparison to the landrace pollinators) but the dual purpose hybrids also had a greater harvest index in the favorable and terminal stress environments (data not shown). The dual purpose topcross hybrids produced lower grain yields that the grain-type hybrids, but significantly higher fodder yields in all test environments, as expected.

Table 36. Seasonal rainfall and mean grain and stover (fodder) yields for the individual test locations in the landrace topcross hybrid evaluation experiment.

	Seasonal rainfall (mm)	Grain yield ($g\ m^{-2}$)	Stover yield ($g\ m^{-2}$)
Arid zone environments			
Fatehpur 1989	220	29	168
Fatehpur 1990	-[1]	111	228
Fatehpur 1991	282	143	-[1]
Jodhpur 1989	210	108	245
Jodhpur 1990	774[2]	151	300
Jodhpur 1991	192	72	-[1]
Mean		102	235
Favorable environments			
Hisar 1989	154+150[3]	207	607
Hisar 1990	457	150	552
Hisar 1991	193	204	537
Mean		187	565
Terminal stress environments			
ICRISAT 1990	18+218[3]	141	351
ICRISAT 1991	88+155[3]	163	418
ICRISAT 1992	4+169[3]	126	341
Mean		143	370

1. Data not available.
2. Nearly 500 mm of this total fell in 1 week before planting.
3. Approximate irrigation applied (preflowering).

Conclusions. Even in the lowest yielding of the test environments - Fatehpur 1989 and Jodhpur 1991 - the yields of the topcross hybrids were equal or superior to those of the adapted landraces, suggesting that there was no loss of adaptation in the topcross hybrids to (at least) the moisture stress and high temperature conditions of the arid zone. Averaged over the six arid zone test environments, the grain-type and duel purpose topcross hybrids outyielded the landraces by 26% and 16%, respectively. In the two other sets of test environments, the topcross hybrid superiority for grain yield averaged 50% in the case of the grain-type topcross hybrids and 39% in the case of the dual purpose topcross hybrids. The latter also produced significantly greater fodder yields than the landraces, in exactly the same season length, in all test environment groups.

These results indicate that topcross hybrids based on locally adapted landraces are an efficient and low cost way to combine the

Table 37. Mean days to flowering and grain and stover (fodder) yields for the landrace, and grain and dual purpose topcross hybrid (TCH) groups, by different test environments. Data are from 1989, 1990, and 1991.

Environment	Days to flowering[1] (d)	Grain yield[1] ($g\ m^{-2}$)	Stover yield[1] ($g\ m^{-2}$)
Arid zone environments (6)[2]			
Landraces	55b	89c	230b
Grain-type TCH	52c	112a	225b
Dual purpose TCH	57a	103b	257a
CV (%)	5	35	34
Favorable environments (3)			
Landraces	55b	153c	582b
Grain-type TCH	49c	202b	520c
Dual purpose TCH	56a	213a	613a
CV (%)	4	21	23
Terminal stress environments (3)			
Landraces	57a	103c	377b
Grain-type TCH	49c	183a	327c
Dual purpose TCH	55b	144b	407a
CV (%)	4	23	17

1. Means followed by the same letter within each environment are not significantly different ($P < 0.05$) according to Duncan's multiple range test.
2. Number of tests in each environment class, except for stover yield in the arid zone test environment for which data are available for only four tests.

adaptation of the local landraces with an improved yield potential. The requirements for seed production of the topcross hybrids may be an obstacle to their use in some areas, but is less likely to be so in India where seed is produced in irrigated areas in southern India during the dry season. We believe that am increased effort in production of a range of topcross hybrids based on locally adapted Rajasthan landraces, with evaluation in both research station and on-farm trials, is justified to test these results more broadly in a range of arid zone environments.

Diseases

Pearl Millet Downy Mildew
(*Sclerospora graminicola*)

Weather and Downy Mildew Development

R. Bandyopadhyay

Information on disease spread is important in interpreting factors affecting development of epidemics in the field. Such information can also explain the erratic nature of downy mildew epidemics. Our objective in this study was to characterize the spread of downy mildew from a focus of infection in the field.

During the 1992 rainy season, we established a crop of the downy mildew-susceptible genotype Tift $23DA_1$ in a 0.25 ha square-shaped field. Seed was sown in rows 0.75 m apart and, following emergence of seedlings, the field was divided into 1700 contiguous plots (1.5 m x 1.0 m). On the day of seedling emergence, a focus of 45 infected plants (genotype 7042S), contained in 9 pots, was placed at the center of the field. The pots were watered daily at 1630 h, and plants were enclosed in polythene covers to provide the high humidity necessary for sporulation. The cover was removed 5-6 h later. The focus was removed 16 days after emergence. We recorded downy mildew incidence (number of infected plants) in each plot on a 4-7 day interval, beginning 5 days after focus establishment. We also monitored temperature, relative humidity (RH), wind speed, and wind direction at 30-minute intervals, using an automatic weather station.

Profuse sporulation occurred in the potted focus plants every night. Since *S. graminicola* has an incubation period of about 5-7 days, we expected downy mildew symptoms to appear in field plots within 7 days after emergence. However, the disease appearance was delayed by 7 days. Examination of the weather data for the first 14 days showed that although night temperatures (24-26°C) were congenial for infection, the RH during the first 7 days was below 90% between 0100 h and 0800 h when spore dispersal and deposition normally occurred. Increased RH (>90%) at 0100 to 0800 h during the following 3 days, due to rain, led to the appearance of disease, some 7 days later than expected.

Primary spread of downy mildew, recorded 17 days after emergence, occurred up to 34 m in the windward direction (47.5% incidence) and up to 17.5 m in the leeward direction (0.34% incidence). All plants in the field, except one, were infected during the next 2 weeks.

This study showed that nocturnal wind direction is important in determining the direction of disease spread, and that under favorable environmental conditions (temperature 24-26°C and RH >90% during late night and early morning) a severe downy mildew epidemic in a susceptible genotype can develop within 2-3 weeks resulting in almost complete destruction of the crop.

Effect of Temperature on In vivo Germination of Sporangia and Zoospores

V.C. Chalam[1], S.D. Singh, and K. Chandrasekhara Rao[1]

1. Research Scholar and Associate Professor, Department of Plant Pathology, Andhra Pradesh Agricultural University, Hyderabad, India.

We studied the effect of temperature on the germination of sporangia and zoospores on the adaxial surfaces of fully expanded second leaves of a resistant (IP 18293) and a susceptible (HB 3) genotype of pearl millet grown in pots. Freshly harvested sporangia suspended in water were sprayed on the leaves of 10 seedlings in two pots. Two such pots of each entry were incubated at each of five temperatures: 15°C, 20°C, 25°C, 30°C, and 35°C. The pots were covered with polythene bags to provide high relative humidity. The leaf samples were collected 2.5 h after inoculation and cleared. The observations on spore germination were taken under a fluorescence microscope.

The results showed that the sporangial germination (zoospore release) was highest at 20°C and 25°C on the leaf surfaces of both the susceptible and resistant genotypes. The lowest germination occurred at 35°C followed by 15°C. Zoospore germination was highest at 20°C, and decreased with the increase or decrease in temperature. Regression analysis revealed that the optimum temperature for sporangial and

zoospore germination was 23.3°C on both cultivars (R^2 = 0.93** and 0.80** for resistant genotypes, 0.93** and 0.91** for susceptible genotypes, for sporangia and zoospores, respectively, significant at $P \leq 0.01$)). These results have implications for the development of downy mildew under field conditions. Ambient temperatures declining below 20°C or rising above 30°C are likely to reduce germination of zoospores on the leaf surfaces, which in turn will decrease the incidence of downy mildew.

Genetic Diversity for Virulence and Aggressiveness in a Field Population of the Pathogen

R.P. Thakur

Occurrence of high genetic variation in *S. graminicola* populations has led to the selection of host-specific pathotypes (ICRISAT Cereals Program Annual Report 1990, p. 62), and demonstration of variation in pathogenicity of single-spore isolates from the field population of this pathogen at IC (ICRISAT Cereals Program Annual Report 1991, p. 30).

In a greenhouse experiment, we compared the virulence and aggressiveness of the five cultivar-specific pathotypes (NHB 3, BJ 104, MBH 110, 852B, and 700651) selected from the IC field population of the pathogen, on 14 pearl millet genotypes of varying resistance. A sixth pathotype, the IC field population, also was involved. A randomized complete block design in two replications was used. Potted seedlings (about 120 per replication), raised from seeds surface-sterilized with 2% NaOCl for 4-5 min, were spray inoculated at the two-leaf stage with an aqueous sporangial suspensions (1×10^5 sporangia mL^{-1}). Inoculated seedlings were incubated at 20°C and >90% relative humidity for 24 h and later shifted to the greenhouse at 20-25°C. Pathogenicity was measured as the ability of a pathotype to produce infection (symptom), virulence as the percentage of infected seedlings (% incidence), and aggressiveness as time from inoculation to symptom expression (latent period).

The six pathotypes were all pathogenic to all host genotypes tested except IP 18292 and IP 18293 (Table 38), but they varied in their levels of virulence and aggressiveness. The analyses of variance for downy mildew incidence and latent period revealed highly significant ($P \leq 0.001$) effects of host genotype, pathotype, and host genotype x pathotype interaction. All pathotypes were highly virulent on the susceptible control genotype 7042S-11 (66-100% incidence) but relatively less virulent on the resistant control ICMP 85410 (14-49% incidence). Significant variation in virulence was observed in different host genotype x pathotype combinations, indicating the strong host genotype-pathotype specificity. Similarly, the latent period varied from 4 to 14 days for different host genotype x pathotype combinations, indicating variability in aggressiveness. Generally, low virulence was associated with longer latent period and vice-versa. Genetic similarity, measured using cluster analysis, indicated three distinct groups among the six pathotypes. Pathotype-1 (NHB 3) was distinct from pathotype-4 (852B) and these two were distinct from the remaining four pathotypes, which were dissimilar among themselves.

These results clearly indicate the highly variable nature of *S. graminicola* population that is greatly influenced by host resistance factor(s). Pearl millet genotypes differed significantly in their degree of resistance to these six pathotypes. The host genotypes that showed a high degree of resistance to all six pathotypes (IP 18292, IP 18293, 7042R, and P 310-17) may represent effective sources of stable resistance to the ICRISAT field population of the pathogen.

Identification of Resistance

S.D. Singh

We tested 419 accessions from Zimbabwe for the identification of resistance. Initially, the accessions were tested in the 1989 Field Downy Mildew Nursery under severe disease pressure. One hundred thirty-six accessions either remained free of downy mildew or developed <10% downy mildew. These accessions were retested in the 1990 Postrainy Season Downy Mildew Nursery and further selections were made. This process of testing and selection was repeated in the 1990 rainy season and again in the 1991 postrainy season. Four accessions (IP 16438, IP 17116, IP 16762, and IP 16736) either remained free or developed <1% downy mildew in three successive screenings. These accessions were tested in a multilocational experiment at Patancheru, Aurangabad, Mysore, Jamnagar, and Bhavanisagar (India), and at

Table 38. Downy mildew incidence in 14 pearl millet cultivars inoculated with 6 pathotypes of *Sclerospora graminicola*.

	Downy mildew incidence (%)[1]						
Host genotype	Path-1 (NHB 3)	Path-2 (BJ 104)	Path-3 (MBH 110)	Path-4 (852B)	Path-5 (700651)	IC-field	Mean
P 7-4	13 (20)[2]	20 (21)	3 (10)	3 (10)	3 (11)	26 (31)	10 (17)
P 310-17	13 (21)	5 (13)	1 (6)	2 (8)	2 (9)	6 (13)	5 (12)
700651	72 (58)	51 (45)	5 (13)	15 (22)	6 (14)	28 (32)	29 (31)
7042R	5 (13)	7 (15)	<1 (3)	1 (5)	<1 (3)	4 (11)	3 (8)
852B	82 (65)	86 (68)	2 (9)	57 (49)	61 (52)	44 (42)	55 (47)
MBH 110	1 (3)	1 (5)	65 (54)	4 (11)	1 (7)	3 (9)	12 (15)
NHB 3	94 (76)	84 (67)	96 (79)	1 (6)	80 (64)	63 (52)	70 (58)
J 104	94 (76)	91 (72)	96 (79)	2 (7)	76 (61)	71 (57)	72 (59)
7042S	94 (76)	90 (71)	94 (76)	79 (63)	84 (67)	77 (61)	86 (69)
IP 18292	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
IP 18293	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
5141B	81 (64)	86 (68)	98 (82)	8 (16)	92 (78)	83 (66)	75 (62)
ICMP 85410	37 (37)	29 (33)	49 (44)	14 (21)	18 (25)	27 (32)	29 (32)
7042S-11	100 (90)	96 (79)	99 (86)	99 (75)	99 (85)	66 (54)	93 (78)
Mean	49 (43)	45 (40)	43 (39)	20 (21)	37 (34)	36 (33)	

SE: Host genotype (G) (±1.18); Pathotypes (P) (±0.77); G x P (±2.89)

1. Mean of two replications.
2. Figures in parentheses are arcsine-transformed values.

Bengou (Niger) and Cinzana (Mali). IP 16438 and IP 16762 showed 4% and 8% mean downy mildew severity, respectively, across locations. These are the first sources of downy mildew resistance identified from Zimbabwe.

Pearl Millet Ergot
(*Claviceps fusiformis*)

Effect of Cytoplasmic-Nuclear Male Sterility on Susceptibility to Ergot in Pearl Millet

K.N. Rai and R.P. Thakur

An earlier study indicated that cytoplasmic-nuclear male sterility increases the susceptibility to ergot of pearl millet inbred lines and hybrids. To assess the generality of this result, based on a wider range of parental lines (especially those with resistance to ergot) and their hybrids, we crossed two ergot-susceptible (ES) male-sterile lines [A-lines ICMA 1 (81A) and ICMA 2 (843A)], two ergot-resistant (ER) male-sterile lines (ICMA 91113 and ICMA 91115), and their counterpart maintainers [B-lines ICMB 1 (81B), ICMB 2 (843B), ICMB 91113, and ICMB 91115] with each of seven pollinators. The pollinators consisted of two ES restorer lines (R-lines H 77/833-2 and ICMR 87003) and two sets of ER sibbed bulks, with set 1 (ICMPES 33 and ICMPES 127) having moderate resistance levels and set 2 (ICMPES 2, ICMPES 29, and ICMPES 34) having high resistance levels. The resultant 56 hybrids and 15 parental lines were sown in randomized complete block design in three replications in the ergot nursery at IC during the 1991 and 1992 rainy seasons. Ten panicles in each plot were inoculated in each year to determine ergot reaction. Five panicles in each plot were bagged at the early boot stage in 1992 to determine selfed seed-set as a measure of the degree of male fertility.

The two ES R-lines had mean ergot severities of 54-61% compared with 10-20% for the

moderately resistant pollen parents and 1-4% for the highly resistant pollen parents (Table 39). The mean ergot severity of the two ES seed parents (76-79% for A-lines and 66-77% for B-lines) was much higher than the mean severity of the two ER seed parents (10-24% for A-lines and 2-7% for B-lines). Regardless of the ergot-resistance levels of seed parents, hybrids of A-lines made with each of the three groups of pollinators were more susceptible than the hybrids made on their counterpart B-lines. As the resistance levels of the parental lines increased, so did the resistance levels of their hybrids, but only in crosses with B-lines and ergot-resistant A-lines. Nevertheless, even the hybrids produced by crossing resistant A-lines with the highly resistant pollinator group had 15-26% ergot severity. Further, male fertility of these hybrids was poor (9% selfed seed-set). Hybrids of A lines had significantly much less selfed seed-set than the hybrids of B-lines, indicating that perhaps the poor fertility restoration of hybrids of A-lines is an important factor determining their greater susceptibility to ergot. It is likely, therefore, that breeding of highly resistant hybrid parents coupled with high male-fertility restoration of hybrids will help produce hybrids with high levels of ergot resistance. Whether these hybrids will have grain yields competitive to those not specifically bred for ergot resistance remains an open question.

Table 39. Ergot severity and selfed seed-set in pearl millet pollinators and their hybrids made on two ergot-susceptible (ES) A-lines [ICMA 1 (81A) and ICMA 2 (843A)], two ergot-resistant (ER) A-lines (ICMA 91113 and ICMA 91115), and their counterpart B-lines, ICRISAT Center.

Pollinators		Mean ergot severity and selfed seed-set in:				
			Hybrids of ES seed parents		Hybrids of ER seed parents	
Type	Number	Pollinators	A	B	A	B
Mean ergot severity (%), 1991 rainy season						
ES R-lines	2	54 (45)[1]	91 (73)	83 (67)	74 (61)	57 (49)
ER bulk - set 1	2	19 (25)	87 (70)	53 (47)	66 (55)	14 (21)
ER bulk - set 2	3	1 (4)	79 (64)	47 (43)	15 (21)	3 (9)
SE(D)		±(4.2)[2]	±(3.8)[3]	±(2.9)[4]	±(2.4)[5]	±(2.7)[6]
Mean ergot severity (%), 1992 rainy season						
ES R-lines	2	61 (52)	93 (76)	87 (70)	86 (70)	67 (57)
ER bulk - set 1	2	10 (17)	84 (67)	54 (47)	70 (58)	19 (25)
ER bulk - set 2	3	4 (8)	83 (66)	48 (44)	26 (29)	5 (12)
SE(D)		±(5.6)	±(4.2)	±(3.2)	±(2.6)	±(3.0)
Mean selfed seed-set (%), 1992 rainy season						
ES R-lines	2	51 (46)	43 (39)	88 (70)	45 (42)	82 (67)
ER bulk - set 1	2	69 (57)	3 (6)	89 (71)	2 (7)	88 (70)
ER bulk - set 2	3	68 (57)	27 (30)	85 (68)	9 (12)	86 (69)
SE(D)		±(5.5)	±(5.0)	±(3.9)	±(3.2)	±(3.5)

1. Figures in parentheses are on arcsin scale.
2. Applicable for comparison of the difference between pollinator groups in first and second rows.
3. Applicable for comparison of the difference between pollinator groups in third row and either of the first two rows.
4. Applicable for comparison of the difference between the first two rows and any of the columns in these rows for hybrids.
5. Applicable for comparison of the difference in any of the hybrid columns in the third row
6. Applicable for comparison of the difference between the third row and any of the first two rows for any columns of the hybrids.

Varietal Improvement

A High-tillering Male-sterile Line of Pearl Millet

K.N. Rai

High-tillering ability continues to be an important objective in most of the pearl millet seed parents breeding programs in India. The two highest-tillering male-sterile lines (5054A and 3383A), developed at the Indian Agricultural Research Institute, New Delhi, which have been extensively used for hybrid breeding, have low grain yield, small seed size, and are susceptible to downy mildew. We have recently developed a high-tillering male-sterile line (ICMA 89111) from a cross between ICMB 2 (843B) and a progeny derived from a cross between Gero New Strain and Saria Synthetic. The evaluation of these three male-sterile lines, as part of a larger experiment conducted in three environments during the 1990 rainy season, showed that ICMA 89111 had 64% higher grain yield, 66% higher seed mass, and 22% more panicles plant^{-1} than the better of the other two male-sterile lines, and flowered 5 days later than them (Table 40). A greenhouse seedling inoculation test showed that ICMA 89111 was highly resistant to downy mildew (4.6% disease incidence as compared to 15.5% in 5054A and 52.1% in 3383A).

Hybrids made by crossing a common set of six diverse pollinators on each of the three male-sterile lines were evaluated in the same three environ-ments as the male-sterile lines. On average, the hybrids of ICMA 89111 had 16% higher grain yield and 33% more grain mass than hybrids of the other two male-sterile lines (Table 41). Hybrids of all three male-sterile lines, however, had similar numbers of panicles plant^{-1}. Hybrids of ICMA 89111 were about 20 cm taller and flowered 2-3 days later than those of the other two male-sterile lines.

These results indicate that ICMA 89111 is a promising new male-sterile line for breeding high-tillering hybrids with a higher grain yield potential, larger grain, and higher levels of downy mildew resistance than was possible with 5054A and 3383A.

Table 40. Characteristics of three high-tillering pearl millet male-sterile lines, rainy season 1990[1].

Character	Male-sterile lines			
	ICMA 89111	5054A	3383A	SE
Grain yield (t ha^{-1})	1.8	1.1	1.1	±0.01
Plant height (m)	1.20	1.33	1.19	±0.002
Time to 50% flowering (d)	55	50	50	±0.4
Panicles plant^{-1} (no.)	6.7	5.1	5.5	±0.3
1000-grain mass (g)	7.8	4.6	4.7	±0.2
Downy mildew (%)[2]	4.6	15.5	52.1	
	(12.2)[3]	(23.0)	(46.2)	±(1.37)

1. Mean of three environments: ICRISAT Center (18 Jun sowing in a Vertisol and 24 Jul sowing in an Alfisol) and Hisar (11 Jul sowing in an Entisol), India.
2. Greenhouse screening data. Performance of controls: 81A (32.4%); NHB 3 (96.2%); 700651 (10.8%).
3. Arcsin scale.

Table 41. Mean performance of hybrids on three high-tillering male-sterile lines in pearl millet, rainy season 1990[1].

Character	Mean of six hybrids on			
	ICMA 89111	5054A	3383A	SE
Grain yield (t ha^{-1})	2.9	2.5	2.4	±0.06
Plant height (m)	2.00	1.82	1.75	±0.013
Time to 50% flowering (d)	49	47	46	±0.01
Panicles $plant^{-1}$ (no.)	3.9	4.2	4.0	±0.12
1000-grain mass (g)	10.4	7.6	7.8	±0.08

1. Mean of three environments: ICRISAT Center (18 Jun sowing in a Vertisol and 24 Jul sowing in an Alfisol) and Hisar (11 Jul sowing in an Entisol), India.

A New Source of Cytoplasmic-nuclear Male Sterility in Pearl Millet

K.N. Rai and C.T. Hash

The search for new sources of cytoplasmic-nuclear male sterility (cms) is an important aspect of the cytoplasmic diversification of pearl millet seed parents at IC. During the 1985 dry season, at least 18 of the 1337 half-sib progenies of the Early Gene Pool (EGP), constituted as a backup population for ICRISAT's Early Composite, segregated for low frequencies of male-sterile plants. The cross of one half-sib progeny (EGP 261) with J 104 (restorer of the A_1 cytoplasm) produced a predominantly male-sterile hybrid, indicating that the cytoplasm of EGP 261 might be different from A_1. The subsequent backcross progenies developed by using J 104 as a recurrent parent continued to be male-sterile. A hybrid developed from a cross between the sterile F_1 progeny and ICMP 423 (a highly downy mildew resistant pollen parent of the A_1-based hybrid ICMH 423, which was released in 1987 for cultivation in India) was found partially male sterile in an observation nursery during the 1986 rainy season. In summer 1988, the BC_2F_1 was fully male sterile. Five additional backcrosses with ICMP 423 produced a male-sterile line that was contributed as ICMA 90111 to the All India Coordinated Pearl Millet Improvement Projects (AICPMIP) trial during the 1990 rainy season.

The relationship between the cytoplasm of EGP 261 and Tift $23A_1$ was studied during the 1991 rainy season at IC by evaluating the pollen fertility restoration of 27 pairs of hybrids made by crossing a common set of 27 pollinators on $81A_1$ (which has Tift $23A_1$ cytoplasm) and ICMA 90111. Pollen-shed of hybrids was taken as a measure of their fertility, and the lack of it as a measure of their sterility, based on visual rating of plots having generally >30 plants. The hybrids were classified as F (all plants shed pollen), F/S (majority of the plants shed pollen), S/F (majority of plants did not shed pollen), and S (all plants did not shed pollen).

Eleven pollen parents produced hybrids with F rating on $81A_1$, whereas only three of these produced hybrids with F rating on ICMA 90111 (Table 42). In contrast, 17 pollen parents produced hybrids with S rating on ICMA 90111, whereas only 10 of these produced hybrids with S rating on $81A_1$. A total of 23 hybrids on ICMA 90111 had S or S/F ratings, in comparison to only 14 such hybrids on $81A_1$.

These preliminary results suggest that the cytoplasm of EGP 261 may be different from A_1. Development of isonuclear A-lines is currently underway that will finally enable us to confirm these results through the evaluation of fertility restoration patterns of isonuclear hybrids. In the meantime, RFLP analysis of mitochondrial DNA shows EGP 261 cytoplasm to be different not only from A_1 but also from A_2, A_3, A_v, and A_m sources (see Sivaramakrishnan et al., pp. 83-85 of this report).

Table 42. Pollen-shed ratings of 27 pairs of pearl millet hybrids made on male-sterile lines $81A_1$ and ICMA 90111, ICRISAT Center, rainy season 1991.

Pollen-shed rating[1] of hybrids on		
$81A_1$	ICMA 90111	Number of pollen parents
F	F	3
F	F/S	1
F	S/F	3
F	S	4
F/S	S/F	2
S/F	S/F	1
S/F	S	3
S	S	10

1. F = all plants shed pollen; F/S = majority of plants shed pollen; S/F = majority of plants did not shed pollen; S = all plants did not shed pollen.

Development and Yield Evaluation of Pearl Millet B-Composites

K.N. Rai

High grain yield and downy mildew resistance, short plant height, good tillering, large grain size, and appropriate maturity are some of the important characters for which combined selection is done in the seed parents breeding project of pearl millet at IC. Several advance generation nonrestorer (B) lines combining most of these traits have been converted into male-sterile (A) lines. However, a very large number of recently developed potential B-lines lack some of these traits while excelling in others. These were used to develop trait-specific B-Composites. For instance, 324 early-maturing lines were random mated three times to develop an Early B-Composite (EBC), and 100 high-tillering lines were random mated three times to develop a High-Tillering B-Composite (HTBC). Similarly, 47 smut-resistant B-lines, derived from crosses between ICMB 2 (843B) and 7 smut-resistant stocks, were random mated twice to develop a Smut-Resistant B-Composite (SRBC).

The three B-Composites (EBC, HTBC, and SRBC), three advanced composites that have been under recurrent selection and possess the corresponding specific traits [(e.g., Bold-Seeded Early Composite (BSEC), High-Tillering Population 88 (HiTiP 88), and Early Smut-Resistant Composite II (ESRC II)], and two composite crosses (ESRC II x SRBC and EC II x EBC) and their parental populations, were evaluated in the 1992 rainy season in four environments (early and late sowings at IC, Bhavanisagar, and Hisar) to evaluate their relative performance.

On the average, two interpopulation hybrids (ESRC II x SRBC and EC II x EBC) were among the top three highest-yielding entries, although the difference between these hybrids and their parental populations was not significant (Table 43). BSEC was the highest-yielding (3.0 t ha^{-1}) and had the largest grain mass (12.4 g 1000^{-1}) among the advanced composites. The two B-Composites (SRBC and EBC) had grain yield, grain mass, tillering ability, and flowering similar to those of BSEC. HiTiP 88 was the lowest-yielding composite (2.6 t ha^{-1}) with the smallest grain mass (7.8 g 1000^{-1}). Its high-tillering ability was similar to that of HTBC and ICMV 91818 (an open-pollinated variety from HiTiP x BSEC), but the latter two entries had significantly larger seeds. Surprisingly, EC II was the highest-tillering composite (3.2 panicles $plant^{-1}$). Highly significant ($P<0.01$) population x environment interactions were observed for all the traits. Thus, while BSEC was the highest-yielding entry in the 29 Jun sowing environment at IC, in the other three environments there was no significant difference between BSEC and EBC. HTBC had significantly higher grain yield than HiTiP 88 in both sowings at IC. At Hisar and Bhavanisagar, however, there was no significant difference between the two composites. SRBC and ESRC II had comparable grain yields in all four environments.

These results suggest that the grain yield potential of random-mated bulks of the three B-composites is comparable to the advanced composites of corresponding characteristics. Also, it seems unlikely that ESRC II and EC II will make any significant contribution to upgrading the productivity levels of SRBC and EBC, respectively. Evaluation of the S_1 bulk performance and the magnitude of genetic variability should provide additional information required to further examine the relative potential of these composites and composite crosses for breeding high-yielding inbred lines.

Table 43. Grain yield and other characteristics of pearl millet composites and composite crosses, rainy season 1992[1].

Composite/ composite cross[2]	Grain yield (t ha^{-1})	Time to 50% flowering (d)	Plant height (m)	No. of panicles plant^{-1}	1000-grain mass (g)
ESRC II x SRBC	3.1	45	1.9	2.1	11.0
BSEC	3.0	46	2.0	2.2	12.4
EC II x EBC	3.0	46	2.0	2.1	11.9
SRBC	2.9	47	1.8	2.2	11.9
ESRC II	2.8	45	2.0	2.0	10.4
EBC	2.8	45	1.9	2.1	12.5
HTBC	2.8	47	1.9	2.9	10.5
EC II	2.7	48	2.1	3.2	11.4
ICMV 91818	2.7	44	1.9	2.7	9.8
HiTiP 88	2.6	48	2.1	2.7	7.8
SE	±0.08	±0.3	±0.02	±0.12	±0.14

1. Mean of four environments: ICRISAT Center (15 and 29 Jun sowings), Bhavanisagar, and Hisar, India.
2. ESRC II = Early Smut-Resistant Composite II-C1; SRBC = Smut-Resistant B-Composite; BSEC = Bold-Seeded Early Composite-C5; EC II = Early Composite II-C3; EBC = Early B-Composite; HTBC = High-Tillering B-Composite; HiTiP 88 = High-Tillering Population 88; ICMV 91818 = an open-pollinated variety from HiTiP x BSEC.

Grain Yield and Genetic Variability in Topcross Pollinators

B.S. Talukdar and C.T. Hash

In pearl millet hybrid seed production plots, 10 to 33% of the area is sown with the pollinators. Economic returns from this area, harvested for grain, are low because in single-cross hybrids, the pollinators are low-yielding highly inbred lines. By contrast, topcross pollinators are less inbred open-pollinated varieties that may offer higher grain yield. Furthermore, inbred pollinators are generally considered to be more homogeneous in phenology than topcross pollinators, which may result in nicking problems (poor matching of flowering of male and female parents) with changes of daylength and temperature of seed production environments. There is the potential that heterogeneity of a topcross pollinator may compromise the description necessary for seed certification, e.g., in plant height. The objectives of the present investigation were, therefore, to study grain yield levels and genetic variability in certain seed production traits in an elite topcross pollinator.

Three experiments were involved. In the first, inbred pollinators and their hybrids, and topcross pollinators and their hybrids, were grown in a replicated trial in the 1992 rainy season. In the second experiment, the topcross pollinator ICMR 312 was evaluated in an early variety trial across eight environments in India in the 1992 rainy season. In the third experiment, 50 S_1 progenies from each of two pollinators (ICMR 312 and ICMP 451) and ICRC II were evaluated for dry panicle yield, time to 50% flowering, and plant height during the 1992 rainy season at IC. Mean, range, and genetic coefficient of variation (taken as a measure of genetic variation) were estimated for these.

Mean grain yield of the inbred pollinators was 60% (1246 kg ha^{-1}) and topcross pollinators was 90% (2149 kg ha^{-1}) of the ICMH 451 control. In the second experiment the topcross pollinator ICMR 312 was found to yield 100% of control WC-C75 across eight locations in India. In this multilocational trial, the genotype x location interaction was statistically significant. At two of the lowest yielding locations, WC-C75 was significantly superior to ICMR 312. In one of the high yielding locations, ICMR 312 was significantly

Table 44. Estimates of mean, range, and genetic coefficient of variance (GCV) for three characters in progenies from pollinators in rainy season 1992, ICRISAT Center.

	Panicle yield (t ha^{-1})			Time to 50% flowering (d)			Plant height (cm)		
Pollinator	Mean	Range	GCV(%)	Mean	Range	GCV(%)	Mean	Range	GCV(%)
ICMR 312	2.4±0.24	1.1-3.4	69	50±1.3	40-58	93	144±5.92	127-167	75
ICMP 451	2.6±0.28	1.2-4.0	74	54±1.6	46-60	58	154±4.82	132-182	84
ICRC II	2.8±0.25	1.4-4.4	87	58±1.3	48-67	88	177±7.90	147-225	84

superior to WC-C75. In the remaining five locations these two entries did not differ significantly.

Genetic variation for time to 50% flowering was substantially higher in ICMR 312 compared to ICMP 451 (Table 44). For plant height, however, genetic coefficient of variance was comparable in the two pollinators. Thus, selection to alter time to 50% flowering is likely to be more effective in ICMR 312 than in ICMP 451. The topcross pollinator ICMR 312 appears to be higher yielding and more variable in flowering time, thus improving the probability of good nicking in seed production plots. This result also indicates that certain topcross pollinators can be genetically homogeneous for some traits such as plant height and genetically heterogeneous for other traits such as flowering time.

It may be concluded that topcross pollinators can be bred with high yield (as high as WC-C75) and greater genetic heterogeneity than ICMP 451 for useful traits while at the same time maintaining relative homogeneity for traits to facilitate seed certification.

Stability and Heritability for Downy Mildew Resistance in Two Pearl Millet Pollinators

B.S. Talukdar and S.D. Singh

The objectives of the present study were (1) to evaluate downy mildew resistance of ICMR 312 and ICMP 451 compared to WC-C75 across three pathogen isolates in the greenhouse and in two field downy mildew nurseries at IC, and (2) to study heritability for this trait using the Patancheru isolate.

In the first experiment five entries, ICMR 312, ICMP 451, P7, HB 3, and WC-C75, were subjected to a seedling downy mildew screen in the greenhouse using pathogen isolates from Patancheru, Mysore, and Rajasthan. P7 is a stable resistant control and WC-C75 is a cultivar which has demonstrated durable resistance to downy mildew in India. HB 3 is highly susceptible and was used as an indicator of downy mildew pressure. In the second experiment, 50 random S_1 progenies from each of ICMR 312, ICMP 451, and ICRC II were evaluated in a replicated trial in the seedling downy mildew screen with the Patancheru isolate. ICRC II was used as the control where selection for downy mildew resistance was found effective in earlier studies. Mean disease incidence, standard error, and broad-sense heritability were estimated.

Results (Table 45) indicate that ICMP 451 is potentially vulnerable to downy mildew in India. However, the inoculum load, environmental conditions, etc., in hybrid seed production fields may not yet be as favorable for the pathogen as in the present study. By contrast, the downy mildew resistance of ICMR 312 in this evaluation was at least as good as the stable resistant control P7 and durable resistant control WC-C75.

The heritability estimate for downy mildew incidence was as high in ICMR 312 (0.72) as in ICRC II (0.71). The heritability estimate was lower in ICMP 451 (0.41). This suggests that, if needed, selection for downy mildew resistance is likely to be more effective in ICMR 312 than in ICMP 451, where progress from selection is expected to be limited.

It may be concluded that, while being highly resistant, the pollinator ICMR 312 still possesses highly heritable variability for resistance to downy

Table 45. Mean downy mildew incidence (%) for the pollinators and three controls when evaluated in the greenhouse against three Indian isolates[1] and in the field in two disease nurseries[1] in India in 1992.

	Downy mildew incidence (%)				
	Greenhouse screen			Field disease nurseries	
	Isolate				
Genotype	PTC	MYS	RAJ	PTC	MYS
Pollinators					
ICMR 312	13.8	10.9	9.6	0.0	3.3
ICMP 451	74.2	9.5	92.4	3.5	24.5
Controls					
P7	44.7	39.0	8.1	0.0	7.6
WC-C75	40.5	11.5	5.4	0.0	2.9
HB 3	96.8	96.3	91.5	88.7	89.9
Mean	36.9	19.9	33.5	7.0	10.3
SE	±4.9	±2.3	±2.0	±1.6	±4.3
CV(%)	32.6	28.6	14.74	0.17	3.1

1. PTC = Patancheru, India; MYS = Mysore, India; RAJ = Rajasthan, India

mildew. Considering the past experience, where resistance in several commercially grown cultivars became ineffective in a very short span of time, one can expect that there may be a need to improve upon the level of resistance in a pollinator in the future. Under such circumstances, ICMR 312 should provide adequate scope for improvement through selection.

Farmers' Selections Among Pearl Millet Cultivars in Western Rajasthan

E. Weltzien R., M.L. Whitaker[1], M.M. Anders[1], K.G. Kshirsagar[1], and U. Voortman[2]

1. Resource Management Program, ICRISAT.
2. University of Hohenhein, Stuttgart, Germany.

This year, a study was initiated to improve our understanding of farmers' preferences for varietal characteristics in pearl millet, and constraints to pearl millet production in western Rajasthan. The project is a collaborative effort involving researchers, government and nongovernment development agencies from Rajasthan, and ICRISAT scientists. We are using on-farm trials, formal surveys, individual interviews, and group discussions involving matrix ranking and other participatory rural appraisal methods to gain a better understanding of these issues.

In addition we invited farmers, who had participated in this study in their own villages, to make selections from a broader range of varieties grown in a research station trial at the Central Arid Zone Research Institute, Jodhpur, in western Rajasthan. One group of six farmers came from Nunwa, Ajmer district, in eastern Rajasthan, where rainfall is relatively higher and more reliable, and the soils more productive. The other group of eight farmers came from Aagolaie, 45 km west of Jodhpur, in western Rajasthan, where rainfall is low and sandy soils prevail. The two groups visited on different days, but were given the same varietal choices and general instructions.

Farmers were asked to select single rows of cultivars that they thought would be useful for them and other farmers in their area. Each farmer was given 10 labels with an identification number. They were asked to select 10 individual rows by attaching a label to the end of each selected row. The trial was sown with four row plots, and the farmers could tie labels to both ends of each row. They thus had the opportunity to give one variety more then one label. The trial had 42 entries, including the three cultivars used in the on-farm trials. Other entries were landrace populations, improved landrace varieties, new cooperatively bred varieties from Rajasthan (presently in AICPMIP testing), as well as standard control varieties that had been released earlier in India. Farmers were given one replication of the trial for making their selections. Afterwards, we discussed their choices, observations, and crop management considerations in detail.

For presentation of results (Fig. 12), we grouped all the selected cultivars into five groups: A - medium maturity varieties with large panicles, thick stems, and low tillering potential, e.g., ICMV 155; B - early maturity varieties with large panicles, large grain, and with low tillering potential, e.g., ICTP 8203; C - high-tillering varieties, newly bred in Rajasthan from populations composed mostly of breeding material of Indian origin of medium-early maturity

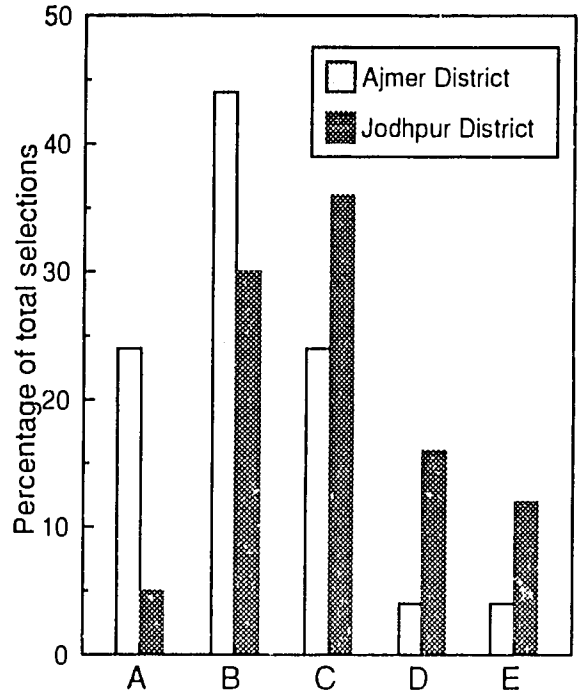

Figure 12. Selections made by farmers from Ajmer and Jodhpur districts, among five groups of pearl millet varieties grown on station at Jodhpur, as percentage of total selections made by each group of farmers.

A: Medium maturity varieties
B: Early maturity varieties
C: High tillering varieties
D: Extra early hybrid , HHB 67
E: Improved landraces

D - HHB 67, an extra-early maturing hybrid with thin stems and high basal tillering potential, small panicles, and large grain; and E - derivatives from landrace populations from western Rajasthan improved by mass selection in Rajasthan.

The farmer preferences differred between the two groups. Farmers from the higher rainfall area, Ajmer district, more frequently selected groups A and B, varieties with large panicles, low tillering potential, and good responsiveness to favorable growing conditions. In contrast, farmers from the drier Jodhpur district more frequently selected groups C, D, and E that had higher tillering, thin-stemmed varieties, and included landrace derivatives. The earlier large grain varieties (group 3) were attractive to 30% of these farmers, who later indicated they intended to use these varieties in higher fertility fields. These selections and the following group discussions indicated very clearly the importance of earliness as a criterion for acceptability of a new variety in the drier areas of western Rajasthan. Farmers explained their preference for higher tillering genotypes mostly through their interest in better fodder quality, and their perception that this trait makes a variety more adaptable to varying growing conditions.

Estimates of Components of Phenotypic Variation

E. Weltzien R.

The partitioning of phenotypic variation of performance trial data for major selection criteria is an exploratory tool for plant breeders. Such estimates of genotypic, genotype x environment interactions, and error variance components are the basis for estimates of operational heritabilities and expected genetic gains from selection. They are essential for optimizing allocation of resources for selection experiments. For pearl millet, no reports that partition genotype x environment interactions into genotype x year, genotype x location, and genotype x year x locations variance components are available.

The parameter estimates reported here are derived from a trial that compared an unselected set of 104 landrace accessions from northern India with 17 standard control entries. The trial was grown in 1988 and 1989 at IC, Hisar (Haryana), Fatehpur (Rajasthan), and Jodhpur (Rajasthan) during the rainy season. At Hisar the trial was irrigated at sowing time in both years, and in 1989 received two subsequent irrigations. At all other sites it was sown under rainfed conditions. Trial means for grain yield ranged from 15 g m^{-2} under drought conditions to 178 g m^{-2} under good rainfall, as well as irrigated conditions. Data were combined for analyses across all four locations and also across the two arid zone sites in Rajasthan. In both analyses, significant genotypic components of variation of a similar level of significance were expressed (Table 46). This component was somewhat higher than the error variance component when estimated across four locations, whereas in the Rajasthan subset it was lower than the corresponding error variance component. For both scenarios no significant genotype x year interaction was found. The genotype x location interaction was significant when the four very

Table 46. Components of phenotypic variation for grain yield of 104 pearl millet landrace accessions and 17 control entries, tested at four locations in India, 1988 and 1989.

Estimate of component of variation[1]	All four locations	Two Rajasthan locations
s^2_g	361±154	212±119
s^2_{gl}	208±71	n.s.[2]
s^2_{gy}	191±99	164±131
s^2_{gly}	407±36	533±94
s^2_e	315	313

1. s^2_g = genotypic component; s^2_{gl} = genotype x environment interaction component; s^2_{gy} = genotype x year interaction component; s^2_{gly} = genotype x location x year interaction component; s^2_e = error variance.
2. Mean square not significant.

different locations were considered, indicating different varietal responses to the highly productive locations, IC and Hisar, compared with the arid zone locations, Fatehpur and Jodhpur. For both cases the largest component of the genotype x environment interaction was the three-way genotype x location x year interaction. For the arid zone environments, it was roughly 2.5 times larger than the genotypic component of variance. This indicates differential varietal responses in each of the individual testing environments within the arid zone subset, probably reflecting the large spatial and seasonal variation under which the testing was done.

Thus, in the arid zone genotype x environment interactions do not appear to be simple functions of either year or location influences, for the material tested in these trials. The entries in this trial represent mostly local landrace accessions from Rajasthan, with 50% originating in the dry western part of this state. Assuming that these landraces were selected and maintained by farmers in their locality for several generations, the landraces possibly were selected for good local adaptation, which may have contributed to the high three-way interaction. Further analysis of this data, studies of environment effects and interactions, and similar analyses with different genetic material are necessary. However, these data indicate that multi-environmental testing of breeding material is necessary to realize satisfactory gains from selection, because the results from single test environments may be conditional. An improved understanding of the environmental and genetic factors conditioning growth and development of pearl millet in stress and nonstress environments will help to achieve focused genetic improvements.

Formation of Two Gene Pools with High Vegetative Growth Rate

E. Weltzien R. and P.J. Lynch[1]

1. Department of Agronomy, Iowa State University, Ames, Iowa, USA.

Most of the increases in dry weight of the pearl millet plant that occur beyond about 10 days after flowering reflect increases in dry weight of reproductive structures rather than increases in vegetative dry weight. This observation, previously made at IC, led to the development of rapid and inexpensive method for estimating vegetative growth rate on a large number of pearl millet genotypes. Using this method, genetic variation for vegetative growth rate was identified. We then sought to create two medium maturity gene pools with high grain yield and high vegetative growth rate by introgressing germplasm with high vegetative growth into an elite pearl millet population.

Gene pool development. The formation of the high vegetative growth rate gene pools, called HiGroP and SenPop, began in the dry season 1988, when four landraces, two accessions of wild [subsp *monodii* (Maire) Brunken], and two accessions of weedy [subsp *stenostachyum* (Klotzsch ex A. Br. and Bouche) Brunken] pearl millet, collected in India and Africa, were crossed to selfed progenies from the cross ICMV 87901 x ICMV 82132. In the postrainy season 1988-89, the F_1s from wild and weedy subspecies matings were backcrossed to the cultivated parent, and the F_1s involving landraces were random mated. In the dry season 1989, seeds from the random matings and BC_1F_1s were space-planted and

Table 47. Mean vegetative growth rate, time to 50% flowering, and grain yield for the midparent, HiGroP C_0, and SenPop C_0, combined across ICRISAT Center, Hisar, and Bhavanisagar, rainy season 1991.

Entry	Vegetative growth rate ($g\ m^{-2}\ d^{-1}$)	Time to 50% flowering (d)	Grain yield ($g\ m^{-2}$)
Midparent[1]	14.4	50.4	248.0
HiGroP C_0	17.1*[2]	53.3*	221.1
SenPop C_0	15.8	58.1*	242.8
CV (%)	34	5	21
SE	±1.6	±1.6	±43

1. For the mating ICMV 87901 x ICMV 82132.
2. * significant at P = 0.05.

selfed to form S_1 lines. In the rainy season 1989, 38 S_1 lines from each landrace mating and from each wild and weedy subspecies BC_1 mating, along with 20 controls, were evaluated in a 18x18 simple lattice design at IC. The 20 S_1 lines from this trial that had the highest vegetative growth rates, and which had acceptable grain yields and maturities, were recombined to initiate the HiGroP gene pool. A composite of seed was made from the recombined progenies and designated HiGroP C_0.

The best of the eight matings on the basis of the means of its 38 BC_1S_1 lines for growth rate, grain yield, and maturity was a BC_1 mating involving a weedy accession from Senegal. The 20 BC_1S_1 lines with the highest vegetative growth rates from this mating were intermated to form the initial bulk (C_0) of the SenPop gene pool, by compositing seed of the recombined progenies. In the rainy season 1991, the HiGroP and SenPop C_0 populations, along with ICMV 87901 x ICMV 82132, were evaluated in four replications of a randomized complete block experiment, grown at Bhavanisagar (11°N), IC (17°N), and Hisar (29°N). The traits measured were time to 50% flowering (TF), grain yield, and vegetative growth rate. Vegetative growth rate was estimated by the formula: (plant dry weight at TF+10 days)/(TF+10).

Results. The midparent value of ICMV 87901 x ICMV 82132 is the expected mean of the base population into which genes from the exotic parents, used to form HiGroP and SenPop, were introgressed. Comparison of the C_0 means for HiGroP and SenPop with the midparent value indicate that both of the gene pools had a greater vegetative growth rate than the midparent value (Table 47; 2.7 $g\ m^{-2}\ day^{-1}$ or 19% of midparent value for HiGroP, and a nonsignificant 10% for SenPop). For both HiGroP and SenPop time to 50% flowering increased significantly and grain yield decreased compared to the midparent value. The greater increase in vegetative growth rate for HiGroP than for SenPop may reflect the greater number and perhaps genetic diversity of donor sources, and the more intense selection used in its formation.

The Inheritance of Vegetative Growth Rate and Related Traits in Pearl Millet

P.J. Lynch[1] *and E. Weltzien R.*

1. Department of Agronomy, Iowa State University, Ames, Iowa, USA.

We conducted a generation means analysis to determine the significance and relative importance of five genetic parameters that could be operational in the inheritance of vegetative growth rate in pearl millet. This will provide pearl millet breeders with information useful for devising the most efficient breeding method for selecting for increased vegetative growth rate in pearl millet.

Materials and methods. The five populations of pearl millet used to initiate this study were: (a) EC C6; (b) a bulk of the self-pollinated progeny from the variety cross ICMV 87901 x ICMV 82132; and (c) IP 3226, IP 3175, and IP 6098; ICRISAT landrace accessions collected in western and central Rajasthan in India, and in Niger, respectively. Diallel matings (without reciprocals) among the five parents, the F_1 matings selfed and random mated, the parent populations random mated and selfed, and 8(9) controls were evaluated during the rainy seasons 1990 and 1991 at IC. All matings were produced via full-sib progenies in one season, bulking equal volumes of seed from all panicles pollinated within a mating. The experiment was laid out as a

Table 48. Percentage of the sum of squares among generations due to various genetic effects, for a number of traits of five pearl millet populations populations evaluated at ICRISAT Center, rainy seasons 1990 and 1991.

Genetic effect	TF[1]	GR1	GR2	SY	BM	HI	PH
Additive (a)	30	39	5	5	18	46	44
Dominance (d)	7	7	29	29	29	7	4
Heterotic (h)	27	16	11	11	12	30	19
Additive x additive epistatic (aa)	28	28	43	44	36	12	25
Residual	9	10	12	11	5	5	8

1. TF = time to 50% flowering (days after emergence); GR1 = growth rate measured as dry matter accumulated at TF + 10 days per day (g m^{-2} d^{-1}); GR2 = growth rate measured as straw yield at maturity divided by TF + 10 days (g m^{-2} d^{-1}); SY = straw yield at maturity (g m^{-2}), BM = above ground dry matter at maturity (g m^{-2}); HI = harvest index (%); PH = plant height (cm).

randomized complete block design with three replications.

Statistical analysis. The analysis was conducted upon the means of the population generations within each year and across years, following Eberhart and Gardner (1966. A general model for genetic effects. Biometrics 22:864-881). In this model each generation mean for a trait (Y) is written as a function of the cumulative additive (a), dominance (d), heterotic (h), and additive x additive epistatic (aa) genetic effects. The genetic parameters that contribute significantly to a trait and the sums of squares associated with each genetic parameter are determined by successively fitting more complex models to the data via least squares regression. The mean squares due to fitting each genetic parameter are (1) tested for significance and (2) compared with the generations sums of squares for a trait. The generations sum of squares not accounted for by the fully fitted genetic model is termed residual, and it represents effects involving epistatic dominance and linkage effects.

Results. Significant differences occurred among generations for all seven traits. Additive genetic effects were significant for all traits except vegetative growth rate estimated at maturity (GR2). Dominance and heterotic effects were significant for all traits except vegetative growth rate estimated at 10 days after flowering (GR1), and straw yield (SY). Additive x additive epistasis effects were significant for all traits except GR1. Residual effects were significant for time to 50% flowering (TF) and harvest index (HI).

The model accounted for a high proportion of the generations sums of squares, ranged from 88% for GR2 to 95% for biomass (BM) and harvest index (HI) (Table 48). Additive effects accounted for the largest proportion of the generations sums of squares for all the traits except GR2, SY, and BM for which additive x additive epistatic effects were of greatest importance. For each of the seven traits, a greater proportion of the generation sums of squares was accounted for by the sum of additive genetic effects plus additive x additive epistatic effects (48% to 69% of the generations sums of squares) than by the sum of dominance plus heterotic genetic effects (23% to 42% of the generations sums of squares).

These results suggest that any breeding method that selects for additive effects should be suitable for improvement of vegetative growth rate in pearl millet. However, because dominance genetic effects for GR2 were important, maximum improvement for this trait will be realized only if the breeding method used to improve vegetative growth rate also selects upon dominance types of genetic effects. However, since only one test location was used, this result should be interpreted with caution.

Recurrent Selection for Vegetative Growth Rate in Pearl Millet

P.J. Lynch[1] *and E. Weltzien R.*

1. Department of Agronomy, Iowa State University, Ames, Iowa, USA.

Selection for increased vegetative growth rate in pearl millet may result in greater grain and stover yields for this crop. A rapid method for estimating vegetative growth rate is available and the primary gene pool of pearl millet possesses genetic variation for this quantitatively inherited trait. We conducted one cycle of S_1 progeny recurrent selection for increased vegetative growth rate in the HiGroP and SenPop gene pools.

Recurrent selection procedure. In the 1990 rainy season, 134 random S_1 progenies from the C_0 of each gene pool plus 10 control entries were evaluated in a 12x12 lattice design at IC and Hisar in India. During the 1990/91 postrainy season, 20 S_1 lines with high vegetative growth rates, acceptable grain yields, and flowering dates from each gene pool were recombined to form the C_1. In the 1991 dry season, S_1 progenies were derived for evaluation of progress.

Evaluation of progress from selection. In the 1991 rainy season, 46 random S_1 lines from each of the C_0 and the C_1 of HiGroP and SenPop, and 10 control cultivars, were evaluated in a 13x13 simple lattice design at IC and a triple lattice design at Hisar. The traits measured in each plot for both experiments were time to 50% flowering (TF), vegetative growth rate at 10 days after flowering (GR1), and grain yield (GY). Operational heritabilities were estimated on an entry-mean basis.

Results. When grown at IC, cycle means for TF, GY, and GR1 in both gene pools were not significantly different (Table 49), although TF was earlier and GY was increased. Vegetative growth rate in HiGroP, however, was reduced (2.5% of the C_0 mean). In SenPop, TF, GY, and GR1 were decreased (by 2, 6, and 4%, respectively, of the C_0 mean).

When grown at Hisar, significant progress was measured in both gene pools (Table 49). In HiGroP, TF was significantly reduced by 4.3 days (7% of the C_0 mean), and GY and GR1 were significantly increased by 5% and 11% of the C_0 mean, respectively. For SenPop, TF was significantly reduced by 7.2 days (11% of the C_0 mean) and GY was significantly increased by 62 g m^{-1} (38% of the C_0 mean). At the 8% level of significance, GR1 in SenPop increased 1.1 g m^{-2} day^{-1} (7% of the C_0 mean).

At both sites, heritability estimates for TF were high (80-90%) and for GY and GR1 they were moderate (ca. 45%). Heritability estimates at Hisar were larger and more often significant than at IC. Thus, progress from selection for increased vegetative growth rate should be greater at Hisar than at IC. These results demonstrate that recurrent selection for increased vegetative growth rate indeed can be successful, and that simultaneous improvement also can be made for time to flower and grain yield.

Recurrent Selection in Pearl Millet for Improving Stand Establishment at High Temperature

P. J. Lynch[1]

1. Department of Agronomy, Iowa State University, Ames, Iowa, USA.

Inadequate stand establishment is a major constraint to attaining high grain and fodder yields of pearl millet in the semi-arid tropics. One cause of inadequate stands for pearl millet is seedling mortality related to the effect of high temperature.

Two cycles of recurrent selection for tolerance to high temperature during emergence were conducted in the HiGroP and SenPop gene pools, using a laboratory screening procedure developed at IC. The cycles of selection, along with controls, were evaluated to measure the efficacy of the laboratory screening procedure.

Development of genetic materials. In each of the two cycles of selection, 100 progenies from a gene pool or cycle of selection, plus controls, were tested three times. Emergence percentage was averaged across these three repetitions, and the 10 half-sib (in HiGroP) or full-sib (in SenPop) progenies with the highest average emergence percentage were recombined. Progress from selection was evaluated using seed produced in one season. Seed lots were passed over 2.8 mm

Table 49. Means of S_1 lines from HiGroP and SenPop C_0 and C_1 for time to 50% flowering, grain yield, and vegetative growth rate evaluated at ICRISAT Center and Hisar, India, rainy season 1991.

	ICRISAT Center			Hisar		
Gene pool	Time to 50% flowering (d)	Grain yield ($g\ m^{-2}$)	Growth rate ($g\ m^{-2}\ d^{-1}$)	Time to 50% flowering (d)	Grain yield ($g\ m^{-2}$)	Growth rate ($g\ m^{-2}\ d^{-1}$)
HiGroP						
C_0	54.3	211.5	8.1	62.1	181.8	15.7
C_1	53.8	216.3	7.9	57.8*[2]	208.5**[3]	17.4*
% of C_0	-1.0	2.3	-2.5	6.9	14.6	10.9
h2[1]	77.2	37.9	43.6	93.9	57.2	54.6
SenPop						
C_0	55.7	228.9	8.4	66.6	161.6	16.1
C_1	54.4	215.5	8.1	59.4**	223.6**	17.2+[4]
% of C_0	-2.3	-5.9	-3.5	10.8	38.4	7.2
h2[1]	72.7	12.5	-20.6	91.5	65.3	48.5

1. Broad-sense heritability (%) in C_1 populations on an entry-mean basis.
2. * significant at P = 0.05.
3. ** significant at P = 0.01.
4. + significant at P = 0.08.

and 2.1 mm sieves, and seeds retained on the 2.1 mm sieve were bulked for evaluation experiments.

Emergence selection procedure. The screening procedure for determining percentage emergence under heat stress used a steel tank holding 100 pots of 7.5 cm diameter, and 10 infrared heat lamps mounted on an adjustable rack suspended above the tank. To mimic the diurnal variation of soil temperatures in the field, lamps were turned on from 0700 to 1400 h. Temperature at 2 cm below the soil surface was adjusted from 30 to 50°C, with a mean of 45°C, by raising or lowering the lamp rack. The tank was filled with about 2 cm of water, which kept the soil moist during the screening period. Each screening cycle began at 1000 h on day 1, and final emergence counts were made at 1400 h on day 5 after sowing.

Progress from selection. HiGroP (HG C_0) and SenPop (SP C_0) cycle zero, HiGroP cycle one (HGE C_1) and two (HGE C_2), SenPoP cycle one (SPE C_1) and two (SPE C_2), and nine controls were tested using the procedure described above. The experiment was repeated three times and each repeat contained three replications, arranged as a completely randomized design. Progress from selection was assessed for significance via single degree of freedom orthogonal comparisons of cycle means. Heritabilities for emergence percentages were calculated for each selection cycle on an entry mean basis using variance components estimated from individual selection experiments. Significant genetic variation was considered to exist when the estimate of s^2_g was greater than two times its standard error.

Results. Emergence ranged from 13.8 to 43.8% with a mean of 30.7% (Table 50). Neither of the increases in percentage emergence within HiGroP or SenPop was significant from C_0 to C_2. However, the increase in percentage emergence from C_0 to C_2 was highly significant when HiGroP and SenPop populations were averaged (7.4% per cycle).

To identify causes for this lack of clear response to selection, we examined means,

Table 50. Mean emergence (%) at 45°C for population cycle bulks of HiGroP and SenPop selected for improved emergence at 45°C, in laboratory evaluation experiments conducted at ICRISAT Center in 1991.

Entry	Emergence (%)
HiGroP	
HG C_0	22.6
HGE C_1	43.8
HGE C_2	37.5
SenPop	
SP C_0	27.9
SPE C_1	29.1
SPE C_2	42.7
Controls	
HHB 67	13.8
ICMH 423	31.3
EC C6	31.9
ICMV 82132	19.1
ICMV 87901	27.6
ICMV 84400	36.5
VC F_2[1]	18.9
WRaiPop 88	41.2
WC-C75	31.8
Mean	30.4
SE	8.2
CV (%)	56.3

1 F_2 of variety cross ICMV 87901 x ICMV 82132

variances, and heritabilities from the individual selection experiments (Table 51). The emergence-testing procedure seemed to increase emergence in both gene pools, i.e., 36, 53, and 72% emergence for the tested progenies of HG C_0, HGE C_1, and HGE C_2, respectively, and 41, 56, and 77% emergence for the tested progenies of SP C_0, SPE C_1, and SPE C_2, respectively. Significant genetic variation was present in all cycles of selection for both testing procedures in both gene pools. However, it appears to decrease in the advanced cycles of selection, possibly caused by small effective population sites. Heritabilities varied between 39% and 75% for percentage of emergence.

The lack of precision in estimating the effect of heat on a genotype, as indicated by high

Table 51. Estimates of emergence percentage parameters[1] for HiGroP and SenPop selection experiments conducted at 45°C with the emergence testing procedure.

Experiment	X_c	X_p	s^2_g	h^2	s^2_e	CV
HiGroP C_0	58	36	251±38	69	340	38
HiGroP C_1	44	53	142±31	53	377	52
HiGroP C_2	62	72	57±18	39	265	71
SenPop C_0	56	41	385±35	67	584	42
SenPop C_1	39	56	111±25	51	318	35
SenPop C_2	73	77	122±16	75	119	77

1. Parameters: X_c = mean of controls; X_p = mean of progenies; s^2_g = genetic variance; h^2 = broad-sense entry- mean heritability; s^2_e = error variance; CV = coefficient of variation (%).

coefficients of variation (CV) and fluctuating estimates of heritability in the cycles of selection, and the small physical size of the apparatus used for testing, limit the effectiveness of this selection procedure. This study does, however, demonstrate that selection can increase the ability of pearl millet seedlings to emerge under high temperatures in the absence of drought stress.

Expression of Heterosis in Topcross Hybrids

F. R. Bidinger

The demonstration that it is possible to obtain a significant amount of heterosis in topcross (male-sterile line x open-pollinated variety) hybrids in pearl millet, even with modern high yielding varieties as topcross pollinators (ICRISAT Cereals Program Annual Report 1990, pp. 58-61), has prompted further investigation of the expression and predictability of this heterosis. We initiated a series of experiments by crossing individual topcross pollinators or high yielding varieties on 18 currently available male-sterile lines from the All India Coordinated Pearl Millet Improvement Project and ICRISAT. The resulting topcross hybrids, plus the pollinator, are being tested over a broad range of environments, both high and low yielding, with supporting crop measurements designed to determine if the

expression of heterosis is consistent, and thus predictable, across the whole range of test environments and male-sterile lines. We have now completed the first set of experiments from this research, which involved a topcross pollinator bred from the Bold Seeded Early Composite - BSEC TCP1.

Results. Mean heterosis for grain yield across all test environments ranged from 25% in topcross hybrids on ICMA 88004 and ICMA 2 (843A), to 46% in topcross hybrids on ICMA 87001 (Table 52). This somewhat higher level of heterosis than previously reported is probably due to the fact that BSEC TCP1 has a very narrow genetic base, and is not very high yielding as a variety. However, the magnitude of heterosis for grain yield for individual topcross hybrids varied considerably among test environments (Table 52), as did the relationships between heterosis for grain yield and heterosis for individual components of grain yield (panicle number, grains panicle^{-1}, etc.). Initial correlation studies thus did not show strong across-environment relationships between heterosis for grain yield and heterosis for individual yield components, suggesting that grain yield heterosis is not simply predictable in terms of yield component heterosis.

Further analysis of the data, however, indicated that the existence of a significant relationship between heterosis for grain yield and for individual yield or growth components depended on the expression of the component in question in the topcross pollinator, BSEC TCP1. Specifically, the relationship appeared to depend in large measure on whether the expression of the component in the pollinator was close to 'optimal' (no relationship of component heterosis and yield heterosis) or below 'optimal' (significant relationship between heterosis for the component and heterosis for grain yield). This appeared to be the case regardless of whether the expression of the component in BSEC TCP1 varied with the test environment or was always optimal or nonoptimal. For example, in the environments where BSEC TCP1 flowered early (40 days from emergence) there was a significant relationship between heterosis for time to flowering and heterosis for grain yield; but where BSEC TCP1 flowered later (e.g., 50 days), there was little significant relationship (Fig. 13). Similarly, where BSEC TCP1 had an average individual grain mass below 9 mg grain^{-1}, positive heterosis for grain mass was associated with positive heterosis for grain yield (Fig. 14). Conversely, where BSEC TCP1 had a large individual grain mass, heterosis for this component was negatively related to heterosis for grain yield (i.e., an increase in individual grain mass in hybrid combination resulted in a decrease in hybrid grain yield, probably because an increase in individual grain mass was associated with a reduced grain number). And finally, where BSEC TCP1 always maintained an optimal value of a component, such as harvest index, heterosis for this component was not related to heterosis for grain yield in any environment.

Table 52. Means and ranges for heterosis for grain yield in combinations of BSEC TCP1 and 18 different male-sterile lines, across nine different test environments in India.

Male-sterile line	Heterosis (%)[1] Mean	Range
MS 5054A	35	17 - 55
MS 5141A	32	-19 - 59
Pb 111A	35	25 - 64
PT 732A	33	09 - 101
833A	35	-07 - 69
ICMA 841 (841A)	31	16 - 48
ICMA 3 (842A)	27	01 - 59
ICMA 2 (843A)	25	02 - 42
852A	44	-05 - 117
862A	36	-01 - 66
863A	29	-03 - 54
AKM 1163	30	-14 - 56
ICMA 87001	46	13 - 85
ICMA 88001	39	19 - 54
ICMA 88004	25	-11 - 38
ICMA 88006	39	-03 - 49
ICMA 89111	30	-05 - 107
(AKM 1163 x ICMB 89111)	38	17 - 56

1. Yield advantage over BSEC TCP1.

Conclusions. The above results make it clear that the effect of heterosis in individual components of growth or yield on grain yield in topcross combinations will depend not on the genotype of the topcross pollinator, but on its phenotype in a particular environment. Simply, grain yield heterosis in relation to individual trait heterosis is

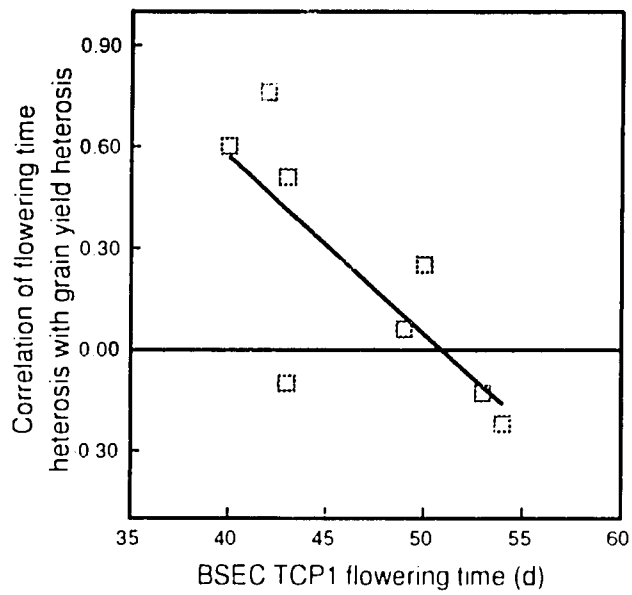

Figure 13. Association of heterosis for grain yield and heterosis for time to flowering in 18 different topcross hybrid combinations of BSEC TCP1 (ordinate) as a function of time to flowering in BSEC TCP1 itself (abscissa). Data are eight different test environments.

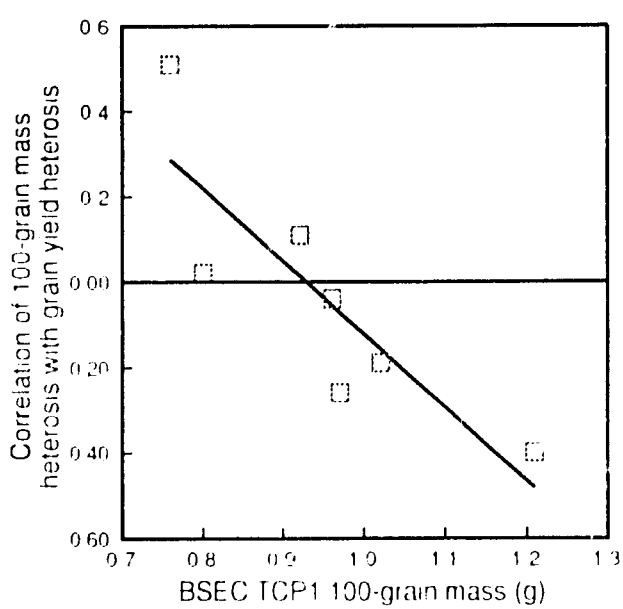

Figure 14. Association of heterosis for grain yield and heterosis for individual grain mass in 18 different topcross combinations of BSEC TCP1 (ordinate) as a function of the individual grain mass of BSEC TCP1 itself (abscissa). Data are seven different test environments.

subject to genotype x environment interaction in topcross hybrids. However, our results do indicate that the apparent genotype x environment interaction for the relationship of yield heterosis and trait heterosis can be simply explained in terms of the effect of environment on the expression of the trait in question in the topcross pollinator. This suggests that the exploitation of heterosis for a given topcross pollinator will be location specific. Different male-sterile lines will have to be used in different environments to maximize heterosis for grain yield for a given topcross pollinator. The choice of appropriate male-sterile lines for a specific environment, however, can be rationally made from a knowledge of the phenotype of the pollinator in the specific environment.

QTL Mapping of Downy Mildew Resistance Genes in Pearl Millet

E.S. Jones[1], J.R. Witcombe[1], C.T. Hash, S.D. Singh, M.D. Gale[2], and Chunji Liu[2]

1 University of Wales, Bangor, Gwynedd, UK.
2 Cambridge Laboratory, Norwich, UK.

Most agronomically important traits are under the control of polygenes or have low heritabilities so that their phenotype is continuously distributed. The number of genes involved and their individual or interactive effects are therefore difficult to determine using conventional Mendelian genetics, making their manipulation in plant breeding programs more difficult than for simply inherited traits. Now, using genetic linkage maps based on restriction fragment length polymorphisms (RFLP), the genome can be broken down into small components so that each 'piece' can be examined for it's contribution towards a particular trait and complex traits can be resolved into their individual genetic components. This process is termed quantitative trait loci (QTL) mapping.

The Cambridge Laboratory, Norwich, UK, has constructed RFLP maps for pearl millet using F_2 progeny from crosses made at IC between inbred lines differing in their susceptibility to pearl millet downy mildew (*Sclerospora graminicola*). Cross one is (LGD-1-B-10)-1 x ICMP 85410, and cross two is P7-3 x 7042(S)-1. Screens against downy mildew have been carried out at both Bangor, UK, and IC using F_4 bulks, each derived from single mapped F_2 plants. The QTL

Table 53. Distribution of quantitative trait loci (QTLs) contributing to resistance to Indian and African populations of pearl millet downy mildew in two mapping populations of pearl millet. Presence of a QTL on a linkage group is indicated by the contribution (%) of that QTL to the variation in downy mildew reaction in the mapping population x pathogen population x disease screen combination. Two of the linkage groups (indicated by a '?') can not be cross-compared because of the current lack of common probes.

Mapping population	Pathogen population	Linkage group 1	2	3	4	5	?	?
(LGD-1-B-10)-1 x ICMP 85410								
	ICRISAT Center, India[1]	44	18, 10			10		
	Maduguri, Nigeria[1]			49, 52				
P7-3 x 7042(S)-1								
	ICRISAT Center, India[2]	62	18, 13					
	ICRISAT Center, India[3]	20	24, 14					
	ICRISAT Center, India[1]	55	33					
	Baboni, Mali[1]			15			19	
	Bengou, Niger[1]			17			19	

1. Screening conducted in the greenhouse at Bangor, U.K.
2. Screening conducted in the field at ICRISAT Center, India.
3. Screening conducted in the greenhouse at ICRISAT Center, India.

mapping was carried out in Bangor using interval mapping and regression analysis at individual probe loci. A QTL is found when, at a particular RFLP probe locus, the progeny with the resistant parent RFLP pattern generally have the resistant phenotype and those with the susceptible parent RFLP pattern generally have the susceptible phenotype. The higher the correlation between genotype and phenotype, the closer the RFLP locus is likely to be linked to the resistance gene or genes.

QTL mapping has so far revealed several QTLs (probably genes, though they could be tightly linked clusters of genes) for resistance against Indian and African pathogen populations (Table 53). In the first cross, (LGD-1-B-10)-1 x ICMP 85410, the four QTLs (one major and three minor) for resistance against the IC pathogen population were on different linkage groups than the two (both major QTLs) found against the Nigerian pathogen population. Because the three minor QTLs effective against the ICRISAT pathogen population do not convey horizontal resistance (i.e., non race-specific resistance), they are most likely to be specific to virulent pathotypes present as a small proportion of the pathogen population. This hypothesis is soon to be tested by screening the mapped progenies in this cross against pathotypes derived from single zoospores.

In the second cross, P7-3 x 7042(S)-1, the same major QTL found in the first cross for resistance against the IC pathogen population was again revealed. In the screens carried out in India, two minor QTLs were also found against the IC pathogen population, but only one of

these was detected in the screens at Bangor. This could be due to statistical chance or changes in the pathogen population from 1989 (when the oospore material being used in Bangor was collected) to 1991 (when the screens in India were carried out).

Two QTLs found for resistance against pathogen populations from Niger and Mali were on the same linkage groups and in the same position as each other, but were independent of the QTLs found in this cross against the IC pathogen population. Unfortunately, because of the small number of common probes between the RFLP maps of these two mapping populations, it is not yet possible to conclude whether the QTLs detected in this second cross have any relationship to those found in the first cross against the Nigerian pathogen population.

These results indicate the emerging potential for using RFLPs in breeding for downy mildew resistance in pearl millet. We should soon be able to use this technology to select simultaneously for resistance against Indian and African populations of this most important pearl millet pathogen.

The projects in Norwich and Bangor have been funded by the Plant Sciences Research Programme of the ODA.

Molecular Biology

Progress in the Construction and Application of a RFLP-based Genetic Map for Pearl Millet

C.J. Lui[1], J.R. Witcombe[2], T.S. Pittaway[1], M. Nash[1], C.T. Hash, C.S. Busso, and M.D. Gale[1]

1. Center for Plant Science Research (PSR), Colney Lane, Norwich NR4 7UJ, UK.
2. Center for Arid Zone Studies, Bangor, Gwynedd LL57 2UW, Wales, UK.

We employed three different crosses to construct a RFLP-based genetic map for pearl millet. In the first cross, 180 probes from a PstI genomic library have been placed on the linkage map based on an F_2 population of 150 progenies derived from a single F_1 plant of the cross (LGD-1-B-10)-1 x ICMP 85410. Very few clones, including those with more than one copy, detected more than one locus. These latter duplicated loci appeared to be randomly distributed in this genome. About 40% of these probes were placed on a single linkage group. Analysis of two further crosses, P7-3 x 7042(S)-1 and 700651-1 x J 104, identified a possible breakpoint in the middle of this large linkage group, indicating that translocated chromosomes were involved in the first cross.

Both F_2 populations from the second and the third crosses were derived from bulked F_1 seeds. It was commonly observed that more than two alleles were segregating at any given locus in these populations, making segregation analysis difficult. This demonstrates the importance of using a single F_1 plant to produce a mapping population, especially in a highly polymorphic outbreeding species like pearl millet. In a species where it is difficult to produce sufficient F_2 seeds from a single F_1 plant, the progeny from each F_1 plant should be analyzed separately.

Even before the genetic map is completed, molecular markers can help resolve questions of importance to pearl millet breeders. Analysis at PSR of 19 diverse pearl millet genotypes (15 inbreds and 4 F_1 hybrids) with 200 single or low-copy genomic DNA probes shows that pearl millet is extremely polymorphic. RFLP is due, in large part, to base-pair mutations rather than deletion or insertion events. Comparisons of ICMB 841 and 81B (ICMB 1) with their putative parents clearly show that their published pedigrees (residual variability within a seed lot of 5141B and induced mutation in Tift $23D_2B$, respectively) are incomplete. Both now appear to have been selected from outcrosses of their putative parents to unknown sources of downy mildew resistance. This confirms long-standing speculation of millet breeders at IC. Preliminary comparisons among the four F_1 hybrids and their parental lines suggest that heterozygosity level may be a useful predictor of performance in pearl millet hybrid cultivars. This map is also being used to identify markers for genes conferring host plant resistance to downy mildew (*S. graminicola*) (see Jones et al. pp. 80-82 of this report) and those controlling photoperiod insensitivity, early maturity, plant height, and grain yield components. In addition, the application of this map to estimate the rate of genetic recombination during male and female gametogenesis is also pursued jointly with PSR. For this, all the required plant materials were produced at IC and seeds were carried to PSR for RFLP analysis.

Molecular Characterization of Cytoplasmic Male-sterile Lines of Pearl Millet

S. Sivaramakrishnan, R. Rajeshwari[1], N.C. Subrahmanyam[1], R.L. Smith[2], V. Sujata, and K.N. Rai

1. School of Life Sciences, University of Hyderabad, Hyderabad 500 134, India.
2. Plant Science Lab, Department of Agronomy, University of Florida, Gainesville, FL 32611, USA.

We continued to characterize RFLP of mtDNA of various cytoplasmic male-sterile (cms) sources in pearl millet. Preliminary results of this study have appeared in the ICRISAT Cereals Program Annual Report 1990 (pp. 67-69). We used four homologous pearl millet mtDNA clones that were PstI fragments: three of these contained the coxI and rrn18-rrn5 genes, and the fourth fragment was associated with reversion of sterility to fertility in A_1 cytoplasm. Mitochondrial DNAs were extracted from the various cms A-lines and their maintainer B-lines. Southern blot hybridization of mtDNA digested with different restriction enzymes (PstI, BamHI, XhoI, and SmaI) and probed with pearl millet mtDNA clones could bring out

polymorphisms among the different male-steriles and their respective maintainer lines. The dendrogram constructed on the basis of similarity indices among various cms pairs revealed two distinct groups (Fig. 15). The cms lines 5141A, ICMA 1 (81A), and ICMA 2 (843A) formed a distinct cluster, reflecting their origin from a common source of cytoplasm represented by Tift 23A, and were classified as A_1 type. A spontaneous source of cytoplasmic male sterility, PMC 30A, identified from a Botswana accession, was also found to have characteristics similar to the A_1 group. The rest of the male-sterile lines forming the non-A_1 group clustered together. Three subgroups were also identified in this latter group.

Further differences among the A-lines were revealed by Southern blot hybridization to maize mtDNA probes. The dendrogram based on similarity indices generated from hybridization patterns of mtDNA digested with PstI, BamHI, and XhoI, and probed with the maize atp6 gene probe revealed relationships among the various A-lines of pearl millet (Fig. 16). Four distinct groups of cytoplasms, and four subgroups within

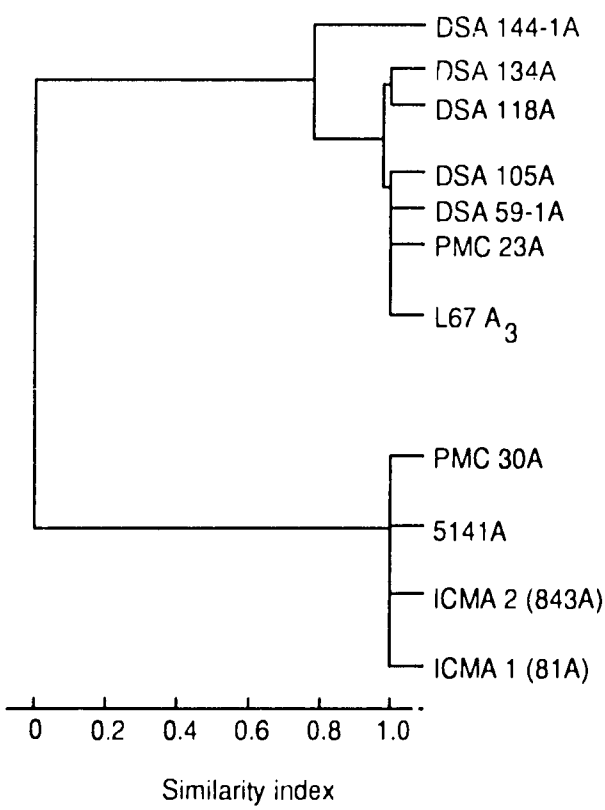

Figure 15. Dendrogram of 11 cytoplasmic male-sterile lines of Pennisetum glaucum *(L.) R.Br. based on homologous mtDNA clones.*

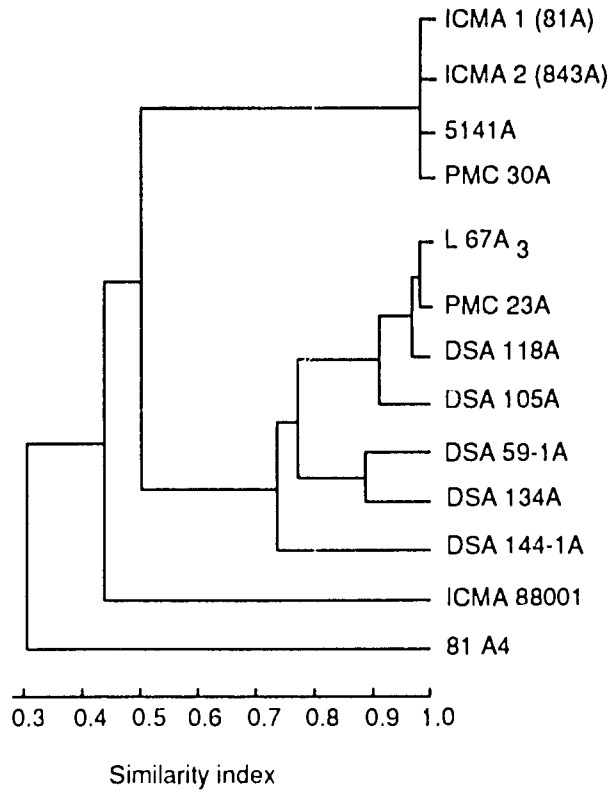

Figure 16. Dendrogram of 13 cytoplasmic male-sterile lines of Pennisetum glaucum *(L.) R.Br. based on mtDNA digested with 3 restriction enzymes and probed with maize atp6 clone.*

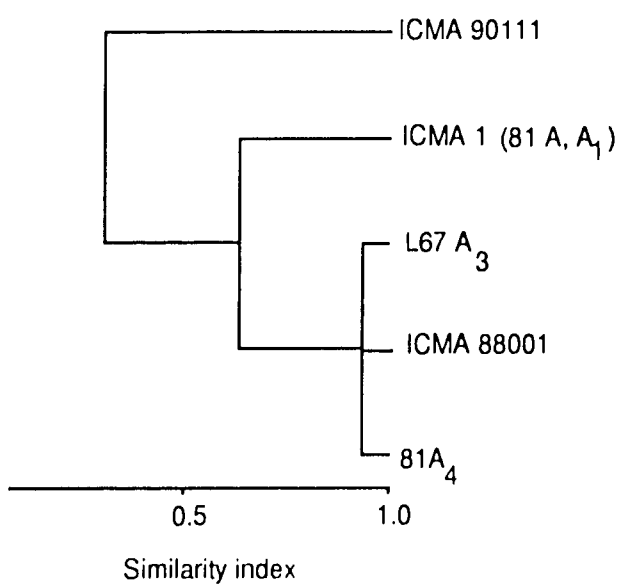

Figure 17. Dendrogram of cytoplasmic male-sterile lines of Pennisetum glaucum *(L) R.Br. based on restriction of mtDNA with six restriction enzymes and probed with maize coxI gene.*

the largest group were identified on the dendrogram. The A_1 group of cytoplasms identified earlier with the homologous probes also formed a cluster with the atp6 gene probe. The A_3 cytoplasm, represented by L67A, again formed a cluster along with PMC 23A, DSA 118A, DSA 105A, DSA 59-1A, DSA 134A, and DSA 144-1A. Four subgroups were detectable within this cluster, suggesting some minor variation in this group Cytoplasms of $81A_4$ and ICMA 88001 were distinct from each other as well as from the rest of the A-lines in this study. The atp9 probe differentiated the A-line $81A_4$, having its cytoplasm derived from *Pennisetum glaucum* subsp *monodii*. The hybridization also indicated that rearrangements (resulting in chimeric forms) of the atp6 gene may be involved in male sterility in a few of the pearl millet A-lines.

The above studies were extended to further characterize a new source of cytoplasm identified from the Early Gene Pool and incorporated into ICMA 90111 (see K.N. Rai and C.T. Hash, pp. 67-68 of this report). It formed a distinct group when tested with several restriction enzymes and maize mtDNA probes. The dendrogram based on similarity indices generated from the hybridization patterns of mtDNA digested with six restriction enzymes and probed with maize cox. gene probe revealed the uniqueness of ICMA 90111 (Fig. 17).

Technology Exchange

Previous Page Blank

Human Resource Development

Postdoctoral Fellows

Scientists who have completed the PhD degree within the last 2 years are considered for postdoctoral fellowships. They work with senior research scientists on specific research problems related to ICRISAT's activities.

Simon J. Duffield, from UK, joined the Cereals Entomology Unit in May to conduct IPM-related research with emphasis on cultivar, pest, and parasitoid interactions in sorghum/pigeonpea-based systems.

Jose A. Sifuentes, from Mexico, completed his 2-year term in June 1992. His research on inheritance of resistance to leaf blight (*Exserohilum turcicum*) in sorghum involving two resistant (A 2267-2 and ICSB 26) and four susceptible genotypes (ICSB 13, IS 18442, 296B, and ICSV 359) indicated that resistance was governed by a single dominant gene and the resistance gene may be different in the two resistant genotypes.

Alan Thomas, from the UK, returned home to accept a research position after 14 months work in Cereals Physiology on the effects of high soil surface temperatures on millet seedlings and the physiologic basis of genetic resistance to such heat stress.

Frauke Wehmann, from Germany, completed her term in February 1992. Her research involved multilocational screening to determine basic genetic parameters of shoot fly, stem borer, and midge resistance in sorghum.

Research Fellows

Scientists with MSc, PhD, or equivalent degrees and employed as research leaders in a national program for at least 5 years are considered for research fellowships.

Ali Abdulla Al-Shurai, from the Republic of Yemen, visited the Pearl Millet Breeding Unit for 6 weeks to acquaint himself with procedures and germplasm used in the population improvement and genetic diversification projects.

Hasan Mohamed Dahrooj, from the Republic of Yemen, visited the Sorghum Breeding Unit from 17 Aug to 10 Oct to familiarize himself with various aspects of sorghum breeding.

Berhane Biru Gonfa, from Nazreth, Ethiopia, joined the Cereals Physiology/Production Agronomy (RMP) Units for a 3-month period to gain experience with instrumentation and methodologies used in crop physiology research.

Mohammed Ali Hubaishan, from Yemen, spent 6 weeks in Cereals Entomology. His main project was on insect rearing on artificial diets. He conducted experiments on the effect of photoperiod on the oviposition of the spotted stem borer, *Chilo partellus*.

Zachee Ngoko, Maize Pathologist, Institute of Agronomic Research, Cameroon, spent 7 weeks in Cereals Pathology. He worked and acquainted himself with various aspects of pathogen variability, disease epidemiology, and disease management, including development and operation of field, laboratory, and greenhouse-screening techniques.

Mohammed Ahmed Saeed, from Taiz Agricultural Research Station, and **Abdulla Abdulwahed Saif**, from Agricultural Research Authority and Extension Area, Republic of Yemen, spent 2 months (17 Aug to 10 Oct) to familiarize themselves with various aspects of sorghum breeding and sorghum research in general.

Research Scholars

MSc or PhD students who complete the course work at selected universities and conduct thesis research at ICRISAT on problems related to ongoing projects are designated as research scholars. They are supervised by ICRISAT senior scientists approved by the universities as their research guides.

Tag E.B.M. Abdalla, from Sudan, completed his MSc thesis research on "Recovery resistance in grain sorghum to spotted stem borer, *Chilo partelius*". He returned to Sudan in February to

Previous Page Blank

complete the thesis write-up and submission to his university.

V. Celia Chalam, a PhD student from India, continued her thesis research on "Studies on the mechanism(s) of resistance to downy mildew disease in pearl millet genotypes".

Elasha Abdelhay Elasha, from Sudan, began MSc thesis research on the effects of differential secondary root development in postrainy sorghum on crop growth and yield, with Cereals Physiology.

Mohamed A. Farah, from Somalia, completed his MSc thesis research on "Seasonal variation in Somalian sorghum germplasm to shoot fly resistance" and obtained his degree from the Andhra Pradesh Agricultural University, Hyderabad, in October.

K.G. Kausalya, a PhD student from India joined the Cereals Entomology Unit in April to study insect-host plant-parasitoid interactions with relevance to sorghum midge.

Lene Sigsgaard, from Denmark, joined Cereals Entomology in October on a 4-month prestudy tour. Her research, entitled "Natural regulation of *Helicoverpa armigera* in sorghum-pigeonpea intercropping" will be part of a PhD from the Royal Veterinary and Agricultural University, Copenhagen, Denmark, and is funded by the Danish Foreign Ministry.

Korlipara Vijayalakshmi, from India, continued her MSc thesis research on "Study of interrelationship of important traits contributing to resistance to shoot fly in sorghum".

In-service Trainees

These are technician or research assistant-level research staff from NARSs who require specialized training for a full season (6 months). They also acquire special knowledge and skills through short training courses (1-2 weeks) in a particular discipline.

T.D. Tsion, from Ethiopia, spent 2 days in the Molecular Biology Unit to learn the technique of SDS Polyacrylamide Gel Electrophoresis.

Participants from several countries in the 6-month in-service training course of the Human Resource Development Program (HRDP) spent 2-week periods in the following Research Units: Pearl Millet Breeding (2), Sorghum Breeding (15), Cereals Entomology (11), and Cereals Pathology (15). They received training in field and laboratory techniques and research methodology.

Apprentices

These are students seeking short-term specialized training in a particular discipline.

P. Arti and **A. Annapurna**, from the National Research Center for Sorghum, Hyderabad, spent 1 month (11 May-10 Jun) to learn Polyacrylamide Gel Electrophoresis and Isoelectric focusing techniques.

Katrin Geers, from Belgium, spent 1 month (12 Aug - 9 Sep) with the Sorghum Breeding Unit to familiarize herself with sorghum breeding techniques.

Ortrun Gronski, from Germany, finalized her 3-month stay in the Genetic Diversification Project of the Pearl Millet Breeding Unit during January, working with a seedling heat tolerance (emergence) screening technique, and studying grain color expression in relation to seed anatomy of pearl millet.

Pieternella Martina Remeeus, from the Netherlands, arrived in September in the Sorghum Breeding Unit for 6 months and will be involved in screening and evaluating sorghum introgression lines for resistance to shoot fly.

Adriana Maria van der Steen, from the Netherlands, arrived in September for 6 months in the Genetic Diversification Project of the Pearl Millet Breeding Unit to learn various selection methods in pearl millet breeding and to participate in a genetic study of grain color.

Uwe Voortman, from Germany, spent 4 months with the Genetic Diversification Project of the Pearl Millet Breeding Unit and the Economics Unit participating in a study of farmers' preferences for pearl millet varietal characteristics in Rajasthan.

Network Activities

Cereals and Legumes Asia Network (CLAN)

C.L.L. Gowda

The Cereals and Legumes Asia Network (CLAN) was formed in April 1992 to facilitate interchange of germplasm, information, and technology among scientists in Asian countries. It amalgamates the activities of the erstwhile Asian Grain Legumes Network (AGLN) and the Asian component of the Cooperative Cereals Research Network (CCRN). CLAN is a network of scientists and research administrators in Asian countries, and associated regional and international institutes, who have shown willingness to work together to solve production constraints of ICRISAT mandate crops (sorghum, pearl millet, chickpea, pigeonpea, and groundnut).

The overall objective of CLAN is to enhance technology exchange on ICRISAT mandate crops and related resource management strategies.

Specific objectives of CLAN. The specific objectives of CLAN include the following:

- To strengthen linkages and enhance exchange of germplasm, breeding material, information, and technology among network members;
- To facilitate collaborative research among members to address and solve high priority production constraints at national and regional levels;
- To assist in improving research and extension capabilities of member countries; and
- To enhance coordination of regional research on ICRISAT mandate crops.

CLAN envisages bilateral work plans for collaborative research between NARS and ICRISAT. The work plans will be prepared for each country based on the need, priority, and capability of the country; they will be reviewed periodically to monitor progress and make plans.

The multilateral element in the CLAN structure is through activities that link all the network members, such as meetings, workshops, monitoring tours, training courses, and working groups. The Working Groups are formed by specialists from NARS, ICRISAT, and other speciality research institutes who have committed to work together to address and find solutions to high priority regional problems. The multilateral links also enhance interaction and information exchange among scientists.

CLAN will work in concert with donor agencies and international and regional institutes having common interest and possessing expertise in disciplinary research to help strengthen basic backup research in CLAN member countries.

The activities of CLAN are coordinated by the Coordination Unit located at, and supported by, ICRISAT Center.

International Sorghum Variety and Hybrid Adaptation Trial 1991 (ISVHAT 91).

G. Alagarswamy

We organized ISVHAT 91 with two objectives: (1) to ensure that improved sorghum varieties and hybrids are available to NARS scientists; and (2) to provide an opportunity for NARS scientists to test the adaptability of their improved sorghum cultivars. There were 26 entries (9 hybrids and 17 varieties), including 14 from IC, 10 from ICRISAT regional programs, 2 from the All India Coordinated Sorghum Improvement Project (AICSIP), and local control cultivar.

The trial was sent to 57 locations (28 in Asia, 21 in Africa, 5 in the Americas, and 3 other locations), and was sown in all except 7 of those locations (2 in Asia, 3 in Africa, and 2 other locations). To date, we have received data from 31 locations (16 in Asia, 12 in Africa, and 3 in the Americas). Data from 8 locations were incomplete. Complete data from 23 locations (12 in Asia, 8 in Africa, and 3 in the Americas) were analyzed and are summarized here.

The trial locations represented a very wide range of physical and climatic environments: latitudes of 8°S to 31°N; from 7 to 1560 m above mean sea level; the growing season average maximum temperature ranged from 27.4 to 35.4°C, and minimum temperature from 16.3 to 25.8°C.

The mean grain yield data across locations and regression coefficients are given in Table 54. Hybrids as a group had a higher yield (4.7 t ha^{-1}) than the varieties (3.9 t ha^{-1}). A hybrid was the top yielding entry in 16 out of the 23 locations.

IC-bred hybrids ICSH 89034,ICSH 871001, and ICSH 89123 yielded significantly more than the location mean yield in 9, 11, and 13 locations, respectively, and they were also among the highest yielding 20% of entries in 10, 8, and 9 locations, respectively. However, hybrid ICSH 871001 had the highest mean yield across all sites, and also ranked among the lowest 20% yielders in three locations. The control hybrid ICSH 110 yielded more than the location mean yield in 17 out of 23 locations. However, this difference was significant only in nine locations. The AICSIP hybrid SPH 468 ranked fifth in overall mean (4.7 t ha^{-1}), and had a grain yield higher than the location mean yield in 17 locations.

The days to 50% flowering of the top five ranking entries ranged from 61 to 66 and the height varied from 1.8 to 2.1 m. There was a general association between mean grain yield and regression coefficient, with the higher yielding entries also being the most responsive to more favorable conditions. The hybrids ICSH 89123, ICSH 89074 and ICSH 110 were relatively high yielders with regression coefficients of 1.07, and did not fall among the lowest yielding 20% of entries at any site.

There was a substantial entry x location interaction, with significant changes in the rank order of the entries at different locations. The AICSIP hybrid SPH 468 was among the top five high yielding entries in Pakistan, Indonesia, Thailand, Cameroon, Mali, and Egypt. The AICSIP variety SPV 669 was also among the top five high yielding entries in Thailand, Myanmar, Cameroon, Egypt, and Mexico.

Variety IS 23496 from SADC was among the top five high yielding entries in Thailand and in Guatemala. The variety KAT/83369 from EARCAL was among the top five high yielding entries in three locations in Myanmar. Grain yield of SPH 468, SPV 699, IS 23496, and KAT/83369 were significantly greater than the respective local check cultivar in each of the countries listed above.

The ISVHAT has provided an opportunity for cooperators to assess the yield performance of their advanced breeding lines over a wide range of agroecological conditions. Cultivars bred by Indian NARS scientists have performed well in several of the locations. The results of ISVHAT 91 indicated that the participation of AICSIP in these international trials is beginning to have a global impact.

Acknowledgements. The following NARS scientists conducted the trial in their countries. K. Richard (Cameroon), G. Bazante (Ecuador), Osman O. El-Nagouly, Fatthy I. El Attar and M.S. Abdel Fallah (Egypt), O.A. Martinez (Guatemala), R.H. Patel (India), S. Rosemarkam, Sholihin, and Subandi (Indonesia), Toe Aung, Daw Kyin Sein, Daw San Yee, and U Maw Kyi (Myanmar), J.W. Clark (Niger), M. Afzal, D. Hussain, A. Shakoor (Pakistan), and K. Lertprasertrat, T. Pothisoong, and Prasit Jaisil (Thailand).

Table 54. Mean grain yield of the cultivars and response coefficients across 23 locations.

Cultivar[1]	Origin[2]	Grain Yield (t ha^{-1})	A[3]	B	C	Response Coefficient[4]
ICSH 871001	IC	5.0	83	35	13	1.18
ICSH 89123	IC	4.8	87	39	0	1.07
ICSH 89034	IC	4.8	83	43	0	1.07
SPH 468	AICSIP	4.7	74	35	13	1.17
ICSH 89051	IC	4.7	74	30	4	1.11
ICSH 90002	IC	4.6	70	39	9	1.03
ICSH 89020	IC	4.5	70	26	9	1.04
ICSH 88065	IC	4.5	70	43	17	0.78
SPV 669	AICSIP	4.4	57	17	9	1.09
ICSV 111	WASIP	4.3	70	9	4	0.80
ICSV 88032	IC	4.3	70	13	17	0.92
ICSV 88002	IC	4.2	43	22	17	1.11
ICSV 89102	IC	4.2	61	0	4	1.02
ICSV 88013	IC	4.2	48	13	4	0.94
ICSV 89106	IC	4.1	39	9	9	1.08
ICSV-LM 86513	LASIP	4.0	30	4	17	0.99
ICSV 401	WASIP	3.9	35	4	17	0.99
KAT/83369	EARCAL	3.9	43	17	26	0.97
ISIAP Dorado	LASIP	3.9	30	0	13	1.12
IS 23509	SADC	3.6	26	22	43	0.74
IS 23496	SADC	3.5	26	9	48	1.05
IS 8193	EARCAL	3.2	22	4	57	0.89
5 DX 160	EARCAL	3.0	13	4	65	0.91
IS 9302	EARCAL	2.9	4	0	65	0.81
Controls						
ICSH 110	IC	4.7	74	39	0	1.07
ICSV 112	IC	4.4	70	22	17	1.05
Mean		4.2				

1 Cultivar names preceding the numerals, that end with H are hybrids and others are varieties

2 IC = ICRISAT Center; AICSIP = All India Coordinated Sorghum Improvment Project (India); EARCAL = Eastern Africa Regional Cereals and Legumes Network; WASIP = West African Sorghum Improvement Program, Kano; SADC = Southern African Development Community, Sorghum Improvement Program, LASIP = Latin American Sorghum Improvement Program.

3 A = Percentage of locations where the cultivar yielded more than location mean yield.
B = Percentage of locations where the cultivar yielded within top 20% yielders
C = Percentage of locations where the cultivar yielded within bottom 20% yielders.

4. All response coefficients are significant at P = 0.01.

Workshops, Field Days, and Meetings

Sorghum and Pearl Millet Production Seed Producers Field Day at ICRISAT Center

The Cereals Program hosted a field day at IC on 11 and 12 Mar, which was attended by the Indian national program coordinators for sorghum and pearl millet and 55 representatives from 26 private and 4 public seed production agencies in India. Morning field visits were followed by general discussion sessions each afternoon, with March 11 being devoted to sorghum and March 12 to pearl millet. The major purpose of the field visits was to demonstrate new hybrid parental lines and breeding materials of sorghum and pearl millet which will be available to NARS scientists. Emphasis was given to work on the transfer of resistance for important biotic constraints to male-sterile and restorer parents and to further diversify the elite genetic base of these material. The availability of alternative cytoplasmic male-sterility systems in elite maintainer genotypes was highlighted as were ICRISAT's germplasm collections of sorghum and pearl millet. Dis-cussions focused on emerging technologies including the use of RFLP-based genetic linkage map information in breeding programs, and the possibility of producing three-way hybrids having reduced seed production costs combined with high grain yield potential and acceptable uniformity.

The number of seed samples supplied in response to requests directly attributable to this field day exceeded 1000 for sorghum and 2000 for pearl millet. This contributed substantially to the increase in number of seed samples distributed by the Cereals Program in 1992 compared to 1991. Pearl millet materials that were particularly popular with participants included F_4 progenies derived from restorer line x restorer line crosses, new male-sterile lines, and advanced B-lines.

Participants were reminded of the necessity for feedback information on the use and performance of ICRISAT supplied material as an essential component in the assessment of ICRISAT's impact.

Sorghum Field Day - Bhavanisagar

A Field Day for the scientists of Tamil Nadu Agricultural University (TNAU) was held on 24 Sep at Bhavanisagar, India. Eighteen scientists attended the Field Day. They selected mostly dual purpose sorghum varieties/hybrids and forage hybrids, and discussed specific areas of collaboration between ICRISAT and TNAU.

National Sorghum Scientists Field Day

A Field Day for national sorghum scientists was held on 29 and 30 Sep at IC and was attended by 24 scientists from the National Sorghum Program. A range of materials - seed parents and varieties - were selected by the national scientists. During the discussion session that followed, scientists from IC and Indian NARS discussed areas of research thrust in sorghum. NARS scientists appreciated the discussion and the usefulness of the materials, particularly in the area of seed parents.

Cereals Program In-house Review (IHR) 1992

The In-house Review for the Cereals Program of ICRISAT Center was held on 30 Nov-4 Dec 1992. As indicated earlier, there was strong participation of scientists from across the Institute, and it was targeted to review the current research project portfolio in the context of the future research environment manipulated in the Medium Term Plan.

The IHR process involved the following components:

- Analysis of the commodity and research environments regionally - designed to crystallize the current status, priority needs and opportunities, and strengths and weaknesses.
- The MTP dimension - an overview of the MTP planning process and of the thematic nature of the Cereals Program plan for 1994/98.
- Review of the current research project portfolio - done against a background of regional needs and opportunities and the future research directions of the MTP. There was in-depth review of ICRISAT Center projects, and authoritative summaries of related research at other ICRISAT Centers. Discussion was designed to focus on the adequacy of current

knowledge and research, identification of specific needs and directions to achieve the MTP thematic objectives, and analysis of the comparative advantage of ICRISAT in each area of research.

- Review of the broader issues of R&D programming - an analysis of generic issues such as natural resource management, genetic resources and biotechnology in crop improvement, crop quality, and technology exchange.
- Integrative analysis of research needs and opportunities in major areas of crop improvement - in yield potential and stability, abiotic constraints and adaptive mechanisms, and biotic constraints and crop protection.

The outcome of the IHR was a series of recommendations for research management in these areas, which will guide the process of planning during 1993 of the research project portfolio for 1994/98.

Seed Distribution

We supplied 13 273 sorghum seed samples in response to requests from various institutions and national programs during 1992 (Table 55). Asia received 56% of samples followed by Africa (38%), and America (5%). Australia, Europe, and West Indies regions received only 1% of samples.

We supplied 8679 seed samples of pearl millet during 1992 (Table 56), a 66% increase over 1991. This increase is largely accounted for by supplies of breeding lines to public and private research workers in India following a field day for seed producers, and supply of RFLP mapping populations to ODA-funded collaborators in the UK. In addition, we provided to these UK collaborators 658 dried tissue samples for DNA extraction.

In sorghum, we supplied 65 kg of breeder seed of three lines ICSR 38 (MR 750), ICSV 112 (SPV 475), and ICSV 1 (SPV 351) to 11 seed-producing agencies (3 public and 8 private) in India.

In pearl millet, the amount of breeder seed supplied during 1992 was marginally higher (15%) than in 1991. We supplied 1476 kg of breeder seed of 11 hybrid parents and 5 open-pollinated varieties (Table 57). Hybrid parents accounted for 71% of the total breeder seed supplied, with the parental lines of ICMH 451 (i.e., ICMA 1, ICMB 1, and ICMP 451) comprising more than half of this. Among the open-pollinated varieties, MP 124 (ICTP 8203) accounted for the largest share of breeder seed supplied. In 1992 we also supplied seed of ICMV 155 and WC-C75 (200 kg each) to the Ministry of Agriculture, Government of India, for use in the final year of minikit testing of ICMV 155.

Table 55. Sorghum seed samples supplied from ICRISAT Center to national programs and other organizations worldwide during 1992.

Region/country	No. of samples				
	Breeder seed	Breeding lines	Trials and nurseries		Total
			Sets	Entries	
Asia					
China	0	235	4	102	337
CIS (formerly USSR)	0	212	0	0	212
India	11	4547	57	1244	5802
Indonesia	0	131	3	78	209
Myanmar	0	72	6	114	186
Nepal	0	72	3	78	150
Pakistan	0	50	8	150	200
Philippines	0	39	0	0	39
Thailand	0	117	5	115	232
Vietnam	0	24	1	26	50
Total	11	5499	87	1907	7417
Americas					
Argentina	0	0	1	24	24
Brazil	0	0	1	15	15
Colombia	0	290	0	0	290
El Salvador	0	0	1	24	24
Guatemala	0	0	1	12	12
Honduras	0	0	1	15	15
Mexico	0	40	3	60	100
Puerto Rico	0	0	1	15	15
Nicaragua	0	0	1	12	12
Peru	0	54	0	0	54
USA	0	28	2	30	58
Total	0	412	12	207	619
Australia	0	8	1	24	32
Total	0	8	1	24	32
Europe					
Denmark	0	2	0	0	2
Netherlands	0	1	0	0	1
Germany	0	11	0	0	11
Italy	0	25	0	0	25
Switzerland	0	4	0	0	4
UK	0	29	0	0	29
Total	0	72	0	0	72

(Continued)

Table 55. Continued...

Region/country	No. of samples				
	Breeder seed	Breeding lines	Trials and nurseries		Total
			Sets	Entries	
Northern Africa and Western Asia					
Egypt	0	862	2	38	900
Iran	0	157	3	78	235
Libya	0	48	2	52	100
Saudi Arabia	0	48	2	52	100
Syria	0	278	1	12	290
Yemen	0	48	7	144	192
Total	0	1441	17	376	1817
Eastern Africa					
Ethiopia	0	16	7	149	165
Kenya	0	168	7	129	297
Rwanda	0	0	1	25	25
Sudan	0	589	2	38	627
Total	0	773	17	341	1114
West and Central Africa					
Benin	0	0	1	25	25
Burkina Faso	0	54	3	70	100
Cameroon	0	24	3	62	6
Central African Republic	0	30	0	0	30
Chad	0	8	0	0	8
Ghana	0	0	3	69	69
Mali	0	72	18	363	459
Niger	0	48	5	88	136
Nigeria	0	544	14	320	864
Senegal	0	1	0	0	1
Togo	0	0	2	0	1
Zaire	0	24	1	26	50
Total	0	805	50	1071	1876
Southern Africa					
Zambia	0	0	1	15	15
Zimbabwe	0	48	9	201	249
Total	0	48	10	216	264
Others					
West Indies	0	36	1	26	62
Total	0	36	1	26	62
Grand total	11	9094	195	4168	13273

Table 56. Pearl millet seed samples supplied from ICRISAT Center to national programs and other organizations worldwide during 1992.

Region/country	No. of samples				
	Breeder seed	Breeding lines	Trials and nurseries		Total
			Sets	Entries	
Southern and Eastern Asia					
India	595	4251	83	2233	7079
Indonesia	0	0	4	60	60
Japan	0	0	2	30	30
Pakistan	0	26	0	0	26
Thailand	0	0	1	19	19
Total	595	4277	90	2342	7214
Northern Africa and Western Asia					
Egypt	0	4	0	0	4
Oman	0	2	0	0	2
United Arab Emirates	0	2	0	0	2
Yemen	0	72	0	0	72
Total	0	80	0	0	80
Eastern Africa					
Ethiopia	0	9	0	0	9
Kenya	0	36	6	131	167
Sudan	0	50	1	19	69
Uganda	0	0	1	19	19
Total	0	95	8	169	264
Southern Africa					
Zambia	0	0	1	12	12
Zimbabwe	0	10	0	0	10
Total	0	10	1	12	22
West and Central Africa					
Burkina Faso	0	6	0	0	6
Central African Republic	0	6	0	0	6
Cote d'Ivoire	0	3	0	0	3
Ghana	0	9	0	0	9
Niger	0	2	3	72	74
Nigeria	0	6	0	0	6
Total	0	32	3	72	104

(Continued)

Table 56. Continued ...

Region/country	No. of samples				
	Breeder seed	Breeding lines	Trials and nurseries		Total
			Sets	Entries	
Others					
Brazil	0	5	0	0	5
France	0	4	0	0	4
Germany	0	6	0	0	6
Jamaica	0	5	0	0	5
Mexico	0	2	1	19	21
UK	0	773	1	12	785
USA	0	71	0	0	71
Zaire	0	0	4	98	98
Total	0	866	6	129	995
Grand total	595	5360	108	2724	8679

Table 57. Breeder seed of pearl millet hybrid parents and open-pollinated varieties supplied from ICRISAT Center to seed production agencies in India during 1992.

Genotype	Quantity (kg)	Number of agencies
Hybrid parents		
ICMA 1 (81A)	358.5	63
ICMB 1 (81B)	172.5	63
ICMA 2 (843A)	92.5	28
ICMB 2 (843B)	45.5	28
ICMA 4 (834A)	2.0	1
ICMB 4 (834B)	1.0	1
ICMA 841 (841A)	157.0	45
ICMB 841 (841B)	77.0	45
ICMP 423	14.0	11
ICMP 451	122 5	52
ICMP 501	1.0	1
Open-pollinated varieties		
ICMV 1 (WC-C75)	84.0	35
ICMV 4 (ICMS 7703)	17.0	7
ICMV 155 (ICMV 84400)	127.0	38
ICMV 87901	3.5	2
MP 124 (ICTP 8203)	200.5	60
Total	1475.5	

Eastern Africa Regional Cereals and Legumes Program (EARCAL)

Eastern Africa Regional Cereals and Legumes Program (EARCAL)

Sorghum Research

Evaluation of Sorghum for Adaptation to Agroecological Environments

S.Z. Mukuru, S.B. King, and F.R. Bidinger

Heat and drought stress environments. We evaluated elite sorghum lines in the two EARSAM Preliminary Sorghum Yield Trials (EPSYT-1 and EPSYT-2) for adaptation and grain yield under rainfed and irrigated conditions during the short rainy (SR) season (Oct 91-Feb 92) and long rainy (LR) season (Apr-Jun) at Kiboko, Kenya. We also evaluated 64 experimental sorghum hybrids and varieties during the long rainy season under the same growing conditions.

Rainfall in both seasons was low and erratic, totaling 285 mm in the SR and 15[illegible] mm in the LR (Fig. 18). All the rainfall during the LR was received in the first month of the season (Apr) and this resulted in severe and prolonged terminal drought stress. Because of this, several entries in the rainfed trials failed to head or produced chaffy heads with poorly filled grains. In contrast, terminal drought stress was mild in SR and several entries in the rainfed trials produced high grain yields. The performance of the various trials evaluated in both the seasons is presented in Table 58. The irrigated trials in both seasons produced the highest grain yield followed by rainfed trials in the short rainy season. The rainfed trials in the LR season produced the lowest yields because of the severity of terminal drought stress that occurred in the trials. Plant heights of entries in the LR season rainfed trials were also significantly reduced.

Threshing percentage of entries in the irrigated trials was high with a narrow range (67-92%) while that of the rainfed trials, particularly those in the LR season, was very low with a broad range (16-80%). We found the relationship between grain yield and threshing percentage to be very strong in rainfed trials, indicating that a high threshing percentage was a major determinant of high grain yield in the rainfed trials. In the rainfed trials, there was no significant association between grain yield and time to 50% flowering, which indicated that drought escape was not an important factor in the differences in grain yield among genotypes in the rainfed trials.

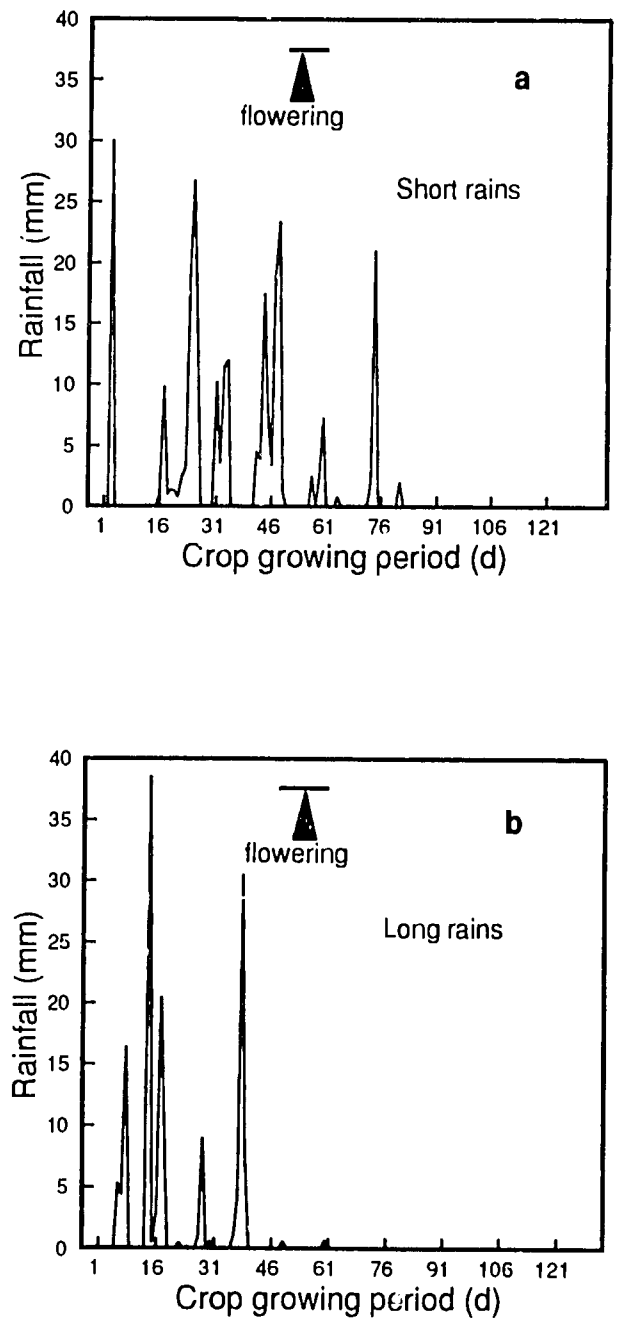

Figure 18. Rainfall received during the crop season in (a) the 1991 short rainy season, and (b) in the 1992 long rainy season at Kiboko. The means and ranges in flowering dates are indicated above the figures.

Previous Page Blank

Table 58. Mean performance of EARSAM Preliminary Sorghum Yield Trials (EPSYT-1 and 2) and the experimental sorghum hybrid trial evaluated under rainfed and irrigated conditions during the short rainy (SR) season (Oct 1991-Feb 1992) and long rainy (LR) season (Apr-Jun 1992) at Kiboko, Kenya.

	Rainfed		Irrigated	
	SR	LR	SR	LR
EPSYT-1[1]				
Mean grain yield (t ha^{-1})	3.8	1.1	6.5	6.8
CV (%) (Yield)	23	60	20	18
Mean time to flowering (days)	55	55	57	53
Mean plant height (m)	1.7	1.5	1.8	1.8
Mean threshing percentage (%)	70	61	80	81
EPSYT-2[1]				
Mean grain yield (t ha^{-1})	3.1	1.6	6.7	6.9
CV (%) (Yield)	21	53	18	16
Mean time to flowering (days)	55	54	58	54
Mean plant height (m)	1.8	1.5	1.8	1.8
Mean threshing percentage (%)	70	60	78	80
Experimental sorghum hybrid trial[2]				
Mean grain yield (t ha^{-1})	-	1.0	-	6.1
CV (%) (Yield)	-	56	-	23
Mean time to flowering (days)	-	54	-	52
Mean plant height (m)	-	1.5	-	1.8
Mean threshing percentage (%)	-	49	-	79

1. 7x7 triple lattice design, three replications, plot size = 3.75 m^2.
2. 8x8 simple lattice design, two replications, plot size = 3.75 m^2.

We selected 10 genotypes from EPSYT-1, 11 from EPSYT-2, and 8 from the hybrid trials that produced high grain yields under rainfed conditions in both seasons. We are re-evaluating the selected genotypes under rainfed conditions at Kiboko during the 1992/93 short rainy season to confirm their adaptation and productivity under drought stress.

We also evaluated F_2 segregating progenies derived from crosses involving several drought-tolerant sorghum genotypes under rainfed conditions at Kiboko. We selected over 40 F_2 individual genotypes with desirable agronomic as well as drought-tolerant traits, and advanced them to the F_3 generation.

Wet and humid environments. We evaluated 49 selected elite sorghum germplasm and breeding lines and 64 experimental sorghum hybrids and varieties during the long rainy season (Apr-Jul) for grain yield and adaptation under wet and humid conditions at Alupe, western Kenya. These trials received high and well-distributed rainfall (786 mm) during the season. The high rainfall and humid conditions at Alupe were favorable for disease development and spread, subjecting entries to high disease pressure, mainly anthracnose and leaf blight.

The mean grain yields of entries ranged from 1.4 to 7.4 t ha^{-1}, with a location mean of 5.1 t ha^{-1} for germplasm and breeding lines, while for the experimental sorghum hybrids mean grain yields ranged from 0.4 to 7.5 t ha^{-1} with a mean of 3.9 t ha^{-1}. Anthracnose and leaf blight scores ranged from 2 to 9 for the lines and 4 to 9 for the hybrids on a scale of 1 to 9 (where 1 = highly resistant

and 9 = highly susceptible). We selected five germplasm and breeding lines [IS 8193, Ent # 64, IS 23526, Bushamba, and 3227 (IS 12611 x SC 108-3)-4-4-8] and four experimental sorghum hybrids (ICSA 15 x KAT/369, SDSH 161, 391A x PGRC/E # 69420, and ICSA 88005 x KAT 369), which produced grain yields above 6.0 t ha^{-1} with high to moderate levels of resistance to anthracnose and leaf blight.

We also screened several F_2 segregating progenies at Alupe that were derived from crosses between adapted high yielding cultivars and leaf disease resistant introductions. We selected over 30 individual F_2s with desirable agronomic qualities and resistance to anthracnose and leaf blight, and advanced them to the F_3 generation.

Cool highland environments. We evaluated F_2 progenies at Kabete (1800 m asl) and Lanet (1900 m asl). These F_2 progenies were derived from crosses between cold-tolerant germplasm and KAT 369, a cold-susceptible lowland improved cultivar with good grain quality. We selected 120 cold-tolerant individual genotypes with good grain quality and advanced them to the F_3 generation.

Finger Millet Research

Survey of Finger Millet Diseases in Uganda and Kenya

S.Z. Mukuru, S. Pande, and S.B. King

We conducted a survey of finger millet (*Eleusine coracana*) diseases during January and February in farmers' fields in southwestern Uganda (125 fields), western Kenya (62 fields), and eastern Kenya (106 fields). Neck and finger blast caused by *Pyricularia grisea* was very common and probably caused yield losses in 272 fields. The foliar phase of this disease was severe in only 33 fields, however.

Tar leaf spot (*Phyllachora eleusines*) was commonly found in farmers' fields in southwestern Uganda and western Kenya, but it was less common in eastern Kenya.

Leaf blight (*Helminthosporium nodulosum*) was widespread in both countries, but symptoms were rarely severe. *H. nodulosum* was frequently isolated from blackened fingers and necks.

Cylindrosporium leaf spot (*Cylindrosporium* sp) was found frequently in Uganda and western Kenya but severity was low. Foot rot (*Sclerotium rolfsii*) was rarely found (Uganda only), as were virus-like symptoms (Kiboko only). Bacterial diseases were not observed.

This survey confirms that blast is the most important disease of finger millet, with finger and neck blast phases more severe than the leaf phase.

During the same survey, weeds (*Eleusine indica, E. africana,* and other *E.* spp) closely resembling finger millet were found to be a serious problem in many fields, especially in Uganda. It is very difficult to distinguish these weeds from finger millet before flowering; some farmers even abandon their finger millet due to heavy infestation. These weeds showed disease symptoms, sometimes severe, typical of blast symptoms on finger millet.

Development of a Screening Technique for Blast Disease Resistance

S. Pande and S.Z. Mukuru

We developed a simple field technique to screen finger millet for resistance to blast disease (*Pyricularia grisea*) at Kiboko, EARCAL's major field research site in Kenya, where natural levels of blast disease are generally too low for effective resistance screening of late-maturing germplasm lines. Essential components of the technique are: (1) application of inoculum in the form of powdered, infected plant debris to the leaves of test plants at about 1 month after emergence, and (2) increasing relative humidity and moisture in the resistance screening nursery by applying sprinkler irrigation twice daily (1 h each time) on rain-free days.

We compared four treatments at Kiboko during the 1991/92 short rains season in the process of developing the screening technique: (1) application of both inoculum and irrigation; (2) application of inoculum only; (3) application of irrigation only; and (4) application of neither inoculum nor irrigation (control). The treatment that included application of both inoculum and irrigation gave adequate levels of disease for screening at Kiboko, whereas treatments involving only inoculum or only irrigation resulted in high levels of disease only in highly susceptible materials (e.g., KNE 479, KNE 755, and KNE 808) (Table 39). The line KNE 739, which gives a susceptible blast reaction at Alupe and Kakamega, where natural

Table 59. Incidence of blast in susceptible and resistant finger millet lines under different combinations of inoculation and irrigation.

Entries	Blast incidence[1]			
	I+S[2]	I	S	C
Susceptible lines				
KNE 479	9	9	9	6
KNE 755	9	8	9	6
KNE 808	9	7	5	6
KNE 739	9	4	3	3
Resistant lines				
KNE 884	3	2	3	2
KNE 842	3	2	3	2

1. Blast score on 1-9 scale where 1 = highly resistant, and 9 = highly susceptible.
2. I+S = inoculum and sprinkler irrigation; I = inoculum; S = sprinkler irrigation; and C = control (neither inoculum nor irrigation).

levels of blast are high almost every season, also gave a highly susceptible reaction when both inoculum and irrigation were applied, but only a moderate level of disease developed in this line when either only inoculum or only irrigation were applied. Lines that give a resistant reaction at Alupe and Kakamega (e.g., KNE 842 and KNE 844) also showed resistance in the treatment that included both inoculum and irrigation.

This screening technique should be especially useful at locations where natural blast disease levels are low, but where crop improvement research activities for finger millet are concentrated.

Screening for Blast Resistance

S. Pande and S.Z. Mukuru

We screened 1000 introduced finger millet germplasm lines from the Genetic Resources Unit (GRU) at ICRISAT Center, 271 lines from SADC/ICRISAT, Zimbabwe, and 129 germplasm lines from Uganda for blast resistance and for other desirable agronomic traits at Kiboko during the short rainy season (Oct 91-Feb 91). We used the resistance screening technique described above to increase the level of blast infestation in the nursery.

A large percentage of the germplasm lines from GRU were very early, highly susceptible to blast, and poorly adapted. Lines from SADC/ICRISAT were very generally late with high yield potential but highly susceptible to blast. The germplasm lines from Uganda were equally late with high yield potential, but less susceptible to blast. We selected 121 germplasm lines with desirable agronomic traits and with blast score ≤ 6 (on a scale of 1-9 where 1 = highly resistant and 9 = highly susceptible). The selected lines were re-screened for blast resistance and adaptation at Kiboko and Alupe in replicated nurseries during the long rainy season (Apr-Jun). The expression of most of the lines was good at Kiboko but poor at Alupe - most were late, poorly adapted and susceptible to blast. We identified 34 lines with good yield potential and stable blast resistance at both locations (blast score ≤ 4).

Collateral Hosts of *Pyricularia grisea*

S. Pande, S.Z. Mukuru, and S.B. King

We during the survey of finger millet diseases in Kenya and Uganda, we observed leaf, neck, and finger blast symptoms typical of those caused by *Pyricularia grisea* on finger millet on other *Eleusine* species, *E. indica* and *E. africana*, and crows foot grass (*Dactyloctenium aegyptium*), which were growing as weeds in finger millet fields. In addition, typical blast symptoms were also observed at Kiboko in areas of year round soil moisture on three wild species of *Eleusine*, two species of *Cynadon*, one species of *Panicum*, and on several other grasses, including crows foot grass.

We conducted two cross inoculation tests among these grass species and finger millet. One involved inoculating the various grasses with two isolates of *P. grisea* from *E. coracana*. In this case, typical blast symptoms formed in both the leaves and panicles of nine species (*Eleusine coracana, E. jaegeri, E. indica, E. africana, E. multiflora, D. aegyptium, Digitaria macroblephara, D. sclarum*, and *Setaria verticillata*) and what appeared to be a hypersensitive reaction was found in two species (*Cynadon dactylon* and *C. plectostachyum*). A questionable response was observed in *Pennisetum massaicum* and no blast symptoms developed in three species (*Eragrostis superba, Panicum maximum, and Rottboellia exaltata*).

In the second cross inoculation test, five grass species, *E. africana, E. coracana, D. aegyptium,*

D. macroblephara, and *S. verticillata*, were each inoculated with *P. grisea* isolates obtained from each of the five grass species. Each of the five isolates were able to produce typical blast symptoms in each of the five grass species, except for unclear symptom expression on *E. africana* inoculated with *P. grisea* from *D. aegyptium*, and on *D. aegyptium* inoculated with *P. grisea* from *E. coracana*.

These results suggest that a number of grasses occur in and near finger millet fields in Kenya and Uganda that could serve as sources of *P. grisea* inoculum for finger millet, and as a bridge for inoculum maintenance between seasons and inoculum increase within seasons.

Virus Disease in Finger Millet

S.B. King and S.Z. Mukuru

We observed symptoms of a virus-like disease at a high frequency in the EARSAM Finger Millet Head Blast Disease Resistance Nursery at the Regional Research Center of the Kenya Agricultural Research Institute, Kakamega, Western Province, Kenya, during the months of July and August. The mean incidence of plants with symptoms among the 81 entries in the trial ranged from 15 to 95%, with 58 entries having $\geq$50% incidence and only 6 entries (KNE 382, KNE 792, KNE 810, KNE 1103, and KNE 1116, and the released variety KAT/FM 1) having $\leq$25% incidence.

Symptoms were most noticeable on leaf blades just before heading, and were characterized by a distinct mottling ranging from a cream to pale-green color interspersed with a green color of about the same intensity as that found in healthy leaves. Affected leaves were usually narrower than healthy leaves and they were sometimes wrinkled.

Generally, at least 50% of the foliage of affected plants was mottled. Symptoms resembled those of 'mosaic disease' of finger millet in India. Data on incidence suggest that there are genetic differences among lines for their reaction to infection.

Virus-like symptoms on finger millet in Kenya are usually limited to a few plants, as was the case in the same nursery grown at Kiboko and Alupe in 1992. We intend to monitor the incidence of this disease in 1993 and, if found, will send ELISA plates treated with sap from affected plants to IC to determine if a seriological relationship exists between mosaic of finger millet in eastern Africa and the mosaic in India.

EARSAM Regional Cooperative Trials and Nurseries

Sorghum

We organized and distributed to our cooperators the following trials: EARSAM Preliminary Sorghum Yield Trials (EPSYT), EARSAM Sorghum Ergot Resistance Nursery (ESERN), EARSAM Sugarcane Aphid Resistance Nursery (ESARN), EARSAM Sorghum Leaf Disease Resistance Nursery (ESLDRN), and EARSAM Sorghum *Striga* Resistance Nursery (ESSRN). These were evaluated or screened for resistance during the 1992 rainy season by our cooperators, at locations in appropriate agroecological environments in eastern Africa.

The EARSAM Preliminary Sorghum Yield Trials consisted of three different trials, for evaluation at locations in drought-stressed (ESPYT-1), wet and humid (ESPYT-2), and cool highland (ESPYT-3) environments. EPSYT-1 and 2, which consisted of 49 elite entries each, were distributed to 5 and 13 locations, respectively and EPSYT-3, which consisted of 36 elite entries, was distributed to 9 locations. The majority of the entries in these trials came from NARS programs, with the rest from ICRISAT.

We have received and analyzed data of EPSYT-1 from three locations, EPSYT-2 from six locations, and EPSYT-3 from four locations. Locations in the cool highland environment at which EPSYT-3 was evaluated produced the highest grain yields, averaging 3.8 t ha^{-1}, followed by the EPSYT-2 locations in the wet and humid environment with average yields of 3.0 t ha^{-1} (Tables 60 and 61, respectively). As expected, locations in the drought-stressed environments where EPSYT-1 was evaluated produced the lowest grain yields, averaging 2.0 t ha^{-1}. Coefficients of variation ranged from 17% at Kabete for EPSYT-3 to 60% at Kiboko LR for EPSYT-1.

Grain yields of selected high yielding entries in EPSYT-2 and EPSYT-3 trials are presented in Tables 62 and 63, respectively. Averaged across the locations, the highest-yielding entry in EPSYT-1 was PGRC/E # 69420 (2.8 t ha^{-1}) followed by LARSVYT 13, IS 23 '96, and Marimanti Collection 10. In EPSYT-2, 3227 (IS 12611 x SC 108-3)-4-4-8 was the highest-yielding entry (3.6 t ha^{-1}) across locations, followed by PGRC/E # 216740,

Table 60. Mean grain yields, coefficient of variation for yield, mean time to 50% flowering, mean plant height, and mean threshing percentage of entries in EARSAM Preliminary Sorghum Yield Trial (EPSYT-3) evaluated[1] at Lanet (LA), Njoro (NJ), and Kabete (KT) locations in Kenya and Mahwa (MH) in Burundi, rainy seasons, 1992.

	LA	NJ	KT	MH	Mean
Grain yields (t ha^{-1})	6.9	5.7	5.1	1.7	3.8
CV(%)	17	31	31	24	-
Time to 50% flowering (d)	104	130	75	99	102
Plant height (m)	2.3	2.3	2.5	1.9	2.3
Threshing percentage (%)	83	72	83	62	75

1. 6x6 triple lattice design, three replications, plot size = 3.75 m^2 at Lanet, Njoro, and Mahwa, and 7.5 m^2 at Kabete

Table 61. Mean grain yield, coefficient of variation for yield, mean time to 50% flowering, and mean threshing percentage of entries in EARSAM Preliminary Sorghum Yield Trial (EPSYT-2) evaluated[1] at Kiboko and Alupe locations in Kenya, Ilonga and Ukiriguru in Tanzania, Serere in Uganda, and Imbo in Burundi, rainy seasons, 1992.

	Kiboko LR 91	Alupe	Ilonga	Ukiriguru	Serere	Imbo	Mean
Grain yield (t ha^{-1})	4.1	5.1	2.7	1.2	1.8	2.8	3.0
CV%	21	27	22	29	35	39	-
Time to 50% flowering (d)	178	178	161	122	170	171	164
Threshing percentage (%)	70	76	78	74	55	62	69

1. 7x7 triple lattice design, three replications, plot size = 3.75 m^2

Bushamba, and IS 23526. The highest-yielding entry in EPSYT-3 was Cyatanobe (6.0 t ha^{-1}) followed by IS 25545, BM 27, and MB 29. There was substantial entry x location interaction for grain yield, with re-ranking of entries at the different locations.

We have not yet received data of most of the resistance screening nurseries. Analyzed results of these nurseries will be reported in our 1993 Annual Report.

Table 62. Mean grain yields (t ha^{-1}) of selected high yielding entries in the EARSAM Preliminary Sorghum Yield Trial (EPSYT-2) evaluated[1] at Kiboko (KB), short rains 1991, and Alupe (AL) locations in Kenya, Ilonga (IL) and Ukiriguru (UK) in Tanzania, Serere (SE) in Uganda, and Imbo (IM) in Burundi, rainy season, 1992.

Entries	KB	AL	IL	UK	SE	IM	Mean
3227(IS 12611 x SC 108-3)-4-4-8	4.6	6.3	2.8	2.0	3.0	2.9	3.6
PGRC/E # 216740	5.3	7.4	2.6	1.3	2.1	2.8	3.6
Bushamba	3.4	6.7	3.5	1.3	4.6	1.9	3.6
IS 23526	5.5	7.0	2.5	0.9	1.4	3.6	3.5
KAT/369-10	3.9	5.9	3.2	1.1	2.6	3.4	3.3
IS 23509	4.6	5.4	3.2	1.5	2.6	2.6	3.3
ENT # 15 SADC	5.2	5.2	3.5	1.7	1.2	2.8	3.3
KCJ ENT # 78	4.3	6.2	2.5	1.4	2.4	2.8	3.3
ENT # 17	4.4	5.8	2.9	1.1	2.3	2.9	3.2
Jidapandwanonii	3.2	4.9	3.7	1.2	4.2	2.1	3.2
Gambella 1107	5.6	5.0	2.8	1.3	1.5	3.2	3.2
IS 8193	2.8	7.4	3.4	1.1	2.5	1.6	3.1
Controls							
5 D x 160	2.6	5.2	4.1	1.2	4.3	2.8	3.2
Seredo	3.8	5.8	2.3	1.4	3.6	3.4	3.4
ICSV 112	4.4	3.6	3.1	1.4	1.7	2.9	2.8
Location mean (49 entries)	4.1	5.1	2.7	1.2	1.8	2.8	3.0
SE	±0.50	±0.79	±0.35	±0.21	±0.37	±0.62	±0.21
CV (%)	21	27	22	29	35	39	

1. 7x7 triple lattice design, three replications, plot size = 3.75 m^2.

Finger Millet

We organized EARSAM Advanced Finger Millet Yield Trial (EAFMYT) and EARSAM Finger Millet Head Blast Disease Resistance Nursery (EFMHBDRN) and distributed them to our cooperators for evaluation during the 1992 rainy seasons. EAFMYT contained 36 entries and was distributed to six locations in Kenya, Uganda, and Ethiopia for yield evaluation. EFMHBDRN contained 81 entries and was distributed to seven locations in the same three countries for screening for blast resistance.

We have received and analyzed data of EAFMYT from three locations. The mean grain yields of the selected high-yielding entries are presented in Table 64. Location mean grain yields for EAFMYT ranged from 1.6 t ha^{-1} at Serere to 4.4 t ha^{-1} at Kiboko, while the coefficient of variation ranged from 14% at Kiboko to 44% at Serere. The highest yielding entry across locations was KNE 1034 (3.7 t ha^{-1}), followed by KNE 1015 and KNE 741 (3.6 t ha^{-1}). All three significantly outyielded the control varieties Engeny and KAT/FM 1.

We have received and analyzed data of EFMHBDRN from four locations and the mean head blast disease scores of the selected highly resistant entries at each location are presented in Table 65. The head blast disease incidence at Serere was low, as indicated by the fact that the highly susceptible KAT/FM 1 control was relatively free of blast disease. The head blast disease incidence at the other locations was adequate for evaluation.

Mean grain yields of the selected head blast resistant lines ranged from 2.0 to 2.7 t ha^{-1} with a mean of 2.3 t ha^{-1}; time to 50% flowering ranged from 70 to 79 days with a mean of 71 days. Mean grain yield and time to 50% flowering of the

Table 63. Mean grain yields (t ha^{-1}) of selected high yielding entries in EARSAM Preliminary Sorghum Yield Trial (EPSYT-3) evaluated[1] at Lanet (LA) 1900 masl, Njoro (NJ) 2225 masl, Kabete (KT) 1800 masl, and Mahwa (MH) 1800 masl, rainy season, 1992.

Entries	LA	NJ	KT	MH	Mean
Cyatanobe	8.4	7.7	5.4	2.4	6.0
IS 25545	11.5	4.9	4.2	2.1	5.7
BM 27	7.2	6.2	6.5	2.0	5.5
MB 29	6.9	6.0	6.6	2.2	5.4
IS 9203	7.7	7.2	5.4	1.4	5.4
S 96	7.3	6.5	5.6	2.3	5.4
BM 32	6.1	7.7	5.3	1.9	5.3
N 8	7.0	6.2	6.0	1.8	5.2
IS 9201	7.3	7.5	4.3	1.5	5.1
MB 38	8.3	5.3	6.0	0.9	5.1
MB 30	7.7	5.5	6.1	1.2	5.1
BM 16	7.2	5.7	4.6	2.8	5.1
Urukuraza	8.1	6.0	5.3	0.8	5.1
MB 39	7.1	5.2	5.6	2.2	5.0
MB 35	6.0	5.8	5.4	2.0	4.8
Ikinyaruka	5.9	7.8	4.4	1.0	4.8
Ndamoga	6.9	4.0	5.3	2.8	4.7
N 15	5.9	6.6	4.5	0.9	4.5
Abaleshya	4.9	6.1	4.3	2.3	4.4
N 18	6.4	3.4	4.8	1.9	4.1
Control E 1291	5.4	3.8	5.5	0.5	3.8
Location mean (36 entries)	6.9	5.7	5.1	1.7	4.8
SE	±0.67	±1.00	±0.39	±0.23	±0.32
CV (%)	17	31	13	24	

1. 6x6 triple lattice design, three replications, plot size = 3.75 m^2 at Lanet, Njoro, and Mahwa, and 7.5 m^2 at Kabete.

control varieties KNE 409 and KAT/FM 1 was 2.7 and 1.2 t ha^{-1} and 74 and 64 days, respectively.

There was a strong negative correlation between head blast score and time to 50% flowering at Kiboko (r = -0.776**), Alupe (r = -0.624**), and Kakamega (r = -0.618**) where disease levels were high enough for screening, indicating that late-maturing genotypes are more likely to be free of blast diseases than early-maturing genotypes. It is possible that the very late genotypes escape the disease, rather than being resistant, since they flower and set seeds late in the season when the weather conditions are not favorable for blast infection and development.

Network Activities

EARSAM Steering Committee Meeting

The EARSAM Network Steering Committee Meeting was held in Bujumbura, Burundi, from 26-30 May. Network activities were reviewed and evaluated and the following decisions were taken:

- It was reconfirmed that the 8th EARSAM Workshop on Sorghum and Pearl Millet Improvement should be held from 28 Oct-5 Nov 1992 at Wad Medani, Sudan. (This was later changed to 30 Oct-5 Nov, 1992).

Table 64. Mean grain yields (t ha^{-1}) of selected high-yielding entries in EARSAM Preliminary Finger Millet Yield Trial (EPFMYT) evaluated[1] at Kiboko and Alupe in Kenya and Serere in Uganda, rainy seasons 1992.

Entries	Kiboko	Alupe	Serere	Mean
KNE 1034	5.5	3.1	2.5	3.7
KNE 1015	5.2	3.3	2.3	3.6
KNE 741	5.3	3.8	1.6	3.6
KNE 758	5.2	2.6	2.5	3.4
KNE 1060	5.0	3.1	2.2	3.4
KNE 1063	4.6	3.0	2.3	3.3
KNE 1124	4.3	3.0	2.5	3.3
Controls				
P 224	4.5	2.1	2.2	2.9
Engeny	4.8	2.4	0.7	2.6
KAT/FM 1	2.9	0.9	0.4	1.4
Mean (36 (entries)	4.4	2.4	1.6	2.8
SE	±0.37	±0.42	±0.41	±0.23
CV (%)	14	30	44	

1. 6x6 triple lattice design, three replications, plot size = 2.0 m^2.

- The recommendations of the EARSAM Scientific Working Group on *Striga* were adopted. The Steering Committee requested scientists in Ethiopia and Sudan to collate and publish available research information in the region on the control of *Striga*.
- A Scientific Working Group on sorghum leaf diseases should be established and a short training course on computer data analysis for technicians should be organized.
- Sorghum and millet utilization should be promoted through the involvement of industries in the region.

Eighth EARSAM Regional Workshop

The Eighth EARSAM Regional Workshop for Sorghum and Millet Improvement was held from 30 Oct to 5 Nov at Wad Medani, Sudan. The workshop was attended by scientists from Burundi (2), Ethiopia (4), Kenya (5), Sudan (15), Tanzania (3), Uganda (2), Nigeria (1), Zimbabwe (2), ICRISAT (8), and USA (1). The objectives of the workshop were:

- To provide an opportunity to sorghum and millet scientists in the region to exchange research knowledge, expertise, and experience among themselves and with other scientists from the regional and international organizations.
- To foster a sense of fraternity and regional responsibility among NARS and NARS scientists in the region, thereby strengthening even further the existing linkages, and to accelerate the flow of research information and germplasm in the region.

A total of 36 scientific papers was presented and critically reviewed. Papers were presented that covered a wide range of disciplines including breeding, agronomy, crop protection, resource management and conservation, utilization, and socioeconomics. There was active scientific interaction and discussion.

Workshop participants were also given the opportunity to visit ARC research experiments at Wad Medani and farmers' sorghum fields in the El Gedaref region. High levels of *Striga* infestation are a major constraint to sorghum production in the area. Participants visited a farmer who used a *Striga* control technology developed by the Agricultural Research Corporation to effectively control *Striga* in his sorghum field.

A number of workshop recommendations were made and these included the following:

- Socioeconomic surveys should be conducted to identify farmers' needs and priorities.
- Comparative agroclimatological data analysis of different production zones within the EARSAM network should be carried out to facilitate exchange and adoption of research methodology and production aspects.
- Field days should be held to bring together researchers, extension specialists, administrators, and farmers to exchange ideas, knowledge, and experiences, and to provide feedback for further improvement in the recommended packages.
- Food technologists should evaluate sorghum and millet varieties for specific quality parameters for different food products.
- Scientific working groups for drought, ergot, anthracnose, and grain mold diseases of sorghum, and finger millet blast disease should be organized.

Table 65. Head blast scores[1] at individual locations and mean grain yield and time to 50% flowering of selected resistant entries in the EARSAM Finger Millet Head Blast Disease Resistance Nursery (EFMHBDRN) evaluated[2] at Kiboko (KB), Alupe (AL), and Kakamega (KM) in Kenya and Serere (SE) in Uganda long rainy season, 1992.

	Head blast score					Grain yield ($t\ ha^{-1}$)	Time to 50% flowering (d)
	KB	AL	KM	SE	Mean		
KNE 624	2.0	2.5	1.0	1.0	1.6	2.2	78
KNE 620	2.0	1.5	2.0	1.0	1.6	2.7	78
KNE 612	2.5	2.5	1.5	1.0	1.9	2.5	72
KNE 786	2.0	3.0	2.0	1.0	2.0	2.4	75
KNE 618	2.0	2.5	2.5	1.0	2.0	2.5	79
KNE 824	2.0	3.0	2.0	1.0	2.0	2.4	72
KNE 688	2.5	2.5	2.0	1.0	2.0	2.6	71
KNE 626	2.0	2.5	2.0	1.5	2.0	2.7	75
KNE 671	2.0	3.0	2.5	1.0	2.1	2.4	77
KNE 822	2.5	2.5	2.5	1.0	2.1	2.5	72
KNE 657	2.0	2.5	3.0	1.0	2.1	2.4	76
KNE 900	2.0	3.0	3.0	1.0	2.3	2.4	75
KNE 1149	3.0	3.0	2.5	1.5	2.5	2.7	72
KNE 882	3.0	2.5	3.0	1.5	2.5	2.5	70
Controls							
KNE 409	4.0	7.5	5.0	3.0	4.9	2.7	74
KAT/FM 1	8.5	7.5	7.5	4.5	7.0	1.2	64
Mean (81 entries)	3.3	4.5	3.7	1.8	3.3	2.3	71
SE	±0.57	±0.71	±0.76	±0.81	±0.36	±0.18	±1.49
CV (%)	25	23	29	64			

1. Blast score on a scale of 1-9, where 1 = highly resistant and 9 = highly susceptible.
2. 9x9 simple lattice design, two replications, plot size = 2.0 m^2.

- Universities should be encouraged to participate fully in NARS research programs in their countries and in the EARSAM network research activities.

A new EARSAM Network steering committee was elected.

KARI/ICRISAT Field Day

In collaboration with the Kenya Agricultural Research Institute (KARI), we held a Field Day at KARI's Kiboko Research Station on 17 Jun. Kiboko is located 156 km from Nairobi on the Nairobi/Mombasa road.

The Field Day was attended by 98 participants, including scientists, extension officers from the Ministry of Agriculture, farmers, representatives from nongovernment organization (NGOs), and donor agencies based in Nairobi. The participants were conducted by KARI and EARCAL scientists through irrigated and rainfed yield trials, and breeding nurseries of sorghum, finger millet, pearl millet, and pigeonpea. They were particularly impressed by early-duration pearl millet composites in the rainfed trials, which produced grain when most of the local sorghum and maize crops failed. The rainfed trials and nurseries received only 151 mm of rainfall during the entire

season. Participants also observed and tested a wide range of food products prepared from sorghum, millet, and pigeonpea.

During the discussions, participants recommended that more extension officers and farmers from the semi-arid areas of Kenya should be involved in field days, and that they should be made aware of the available technologies. They also suggested that short training courses should be organized, specificallv for women, on nutrition and the preparation of new food products from sorghum, millet, and pigeonpea.

Research Travel and Consultancies

Staff name	Date	Organization visited	Country visited	Purpose
King, S.B.	15-17 Jul 13-14 Aug	Kenya Agril. Res. Inst. Kakamega, Alupe, and Lanet; Rural Technology Devpt. Center, Nakuru	Kenya	To discuss sorghum and finger millet rresearch with KARI staff, evaluate trials and nurseries for diseases, and development of low-cost farm machinery
	25-27 Aug	Eastern Province	Kenya	For pigeonpea monitoring tour with KARI scientists
	3-4 Sep	KARI, Kakamega, and Egerton Univ.	Kenya	To evaluate finger millet nurseries, and to interact with Egerton's program
King, S.B.	15-20 Nov	Alemaya University of Agriculture, Institute for Agricultural Research, and International Livestock Center for Africa	Ethiopia	To discuss collaborative research
Mukuru, S.Z.	20-21 Aug	Laikipia Rural Devpt. Program, Ministry of Agric.; Beef Ref. Station, Lanet; and Egerton Univ.	Kenya	To observe and evaluate sorghum trials and nurseries and discuss sorghum research with Ministry and KARI staff
	27-29 Aug	KARI, Mtwapa	Kenya	To observe and evaluate KARI National Performance and KARI staff
	13-18 Sep	SAFGRAD, Addis Ababa	Ethiopia	For SAFGRAD impact assessment, and to collect scientific and economic data from government ministries and international organizations
Mukuru, S.Z. and King, S.B.	30 Nov-4 Dec	ICRISAT Center	India	To attend Cereals In-house Review
Mukuru, S.Z.	8-12 Jan	Secretariat for Research, Ministry of Agriculture	Uganda	For survey of finger millet diseases in farmers' fields

Staff name	Date	Organization visited	Country visited	Purpose
Mukuru, S.Z.	8-14 May	ISABU	Burundi	To attend EARSAM Steering Committee
	21-26 Jan	Makere University	Uganda	To evaluate EARSAM cooperative sorghum and finger millet trials
	13-19 Sep	IAR	Ethiopia	To assist SAFGRAD Network Impact Assessment Team to collect scientific and economic data for the study
	18-23 Nov	SAFGRAD	Burkina Faso	For discussion and review SAFGRAD Networks Impact Assessment report

Workshops and Conferences Attended

Staff name	Workshop/Conference	Date	Place	Organizer
King, S.B.	Workshop on the National Agricultural Masterplan for Tanzania	23-25 Mar	Dar-es-Salaam, Tanzania	SPAAR (W. Bank) and Ministry for Agriculture and Livestock Development, Tanzania
King, S.B.	Meeting of the International Federation of Agriculture Producers (IFAP)	7-8 Dec	Nairobi, Kenya	ILRAD
King, S.B.	Launching meeting of AfDB-funded pigeonpea project (eastern Africa)	17-18 Mar	Nairobi, Kenya	ICRISAT/EARCAL
King, S.B. and Mukuru, S.Z.	8th EARSAM Regional Workshop on Sorghum and Millet Improvement	30 Oct - 4 Dec	Wad Medani, Sudan	EARSAM
Mukuru, S.Z.	The First International Crops Science Congress	14-23 Jul	Ames, Iowa, USA	Iowa State University
Mukuru, S.Z. and King, S.B.	2nd KARI Scientific Conference	7-9 Oct	Nairobi, Kenya	KARI

Latin American Sorghum Improvement Program (LASIP)

Latin American Sorghum Improvement Program (LASIP)

Sorghum Research

Evaluation of Cold-tolerant Varieties

C.L. Paul and R. Clará V.

On-station trials. With the objective of studying the performance of advanced cold-tolerant, red-seeded genotypes in the Mexican highland environment, we sowed 54 varieties under irrigated and rainfed conditions at El Batan, Mexico. Plant growth and climatic variables were monitored to understand the effects of climate and soil moisture on phenological development and yield components of the genotypes.

Sowing under rainfed conditions in the highland environment was delayed 10 days (Table 66). While emergence at the higher soil moisture level under irrigation occurred 9 days after sowing (on 14 May), seedlings under the lower soil moisture level (rainfed condition) emerged 20 days after sowing (on 4 Jun). One irrigation at sowing thus enabled emergence to take place 30 days earlier in the frost-free growing season than under rainfed conditions.

Growth stage 2 (from floral initiation to 50% flowering) lasted 53 days in plots receiving irrigation at sowing and 41 days in rainfed plots.

Table 66. The effect of sowing cold-tolerant sorghum genotypes under two soil moisture regimes (irrigation at sowing and rainfed condition) on phenological development at El Batan, Mexico, 1992.

		Days from sowing to[1]:		
	Date of sowing	Emergence	Floral initiation	50% Flowering
Irrigated at sowing	5/5	9 (14/5)[2]	41 (15/6)	95 (8/8)
Rainfed	15/5	20 (4/6)	56 (10/7)	97 (20/8)

1. Data are means of six genotypes.
2. Actual dates are shown in parentheses.

Table 67. Performance of advanced cold tolerant varieties under irrigated and rainfed conditions at El Batan, Mexico, 1992[1].

	Irrigated		Rainfed	
Variety	Yield (t ha^{-1})	Plant height (m)	Yield (t ha^{-1})	Plant height (m)
ICSV-LM 90067	2.1	1.3	3.2	1.2
ICSV-LM 90124	3.0	1.2	3.1	1.0
ICSV-LM 90165	3.9	1.1	2.5	1.1
ICSV-LM 90070	5.6	1.2	3.1	1.2
ICSV-LM 90026	4.5	0.9	1.9	0.9
VA 110 (control)	2.7	0.9	1.7	1.0
Mean	3.6	1.1	2.6	1.1
CV(%)	16	6	11	6
SE	±0.26	±0.03	±0.13	±0.03

1. Two irrigations; plots 10 rows x 50 m; nine repetitions of 4 m x 2 row samples.

Data on yield and plant height are presented in Table 67. Two varieties, LM 90165 and LM 90070, outyielded the local control in both the rainfed and irrigated trials.

On-farm trial. Advanced cold-tolerant varieties were sown in large plots on a farmer's field in the Mexican highlands. Heavy weed infestations drastically reduced yields to approximately 2 t ha^{-1}, but these were still equal to the yield of the local control.

Evaluation of Lowland Genotypes

C.L. Paul

On-farm trials. In Phase III of the collaborative research project with the Bank of Mexico (winter season 1991/92), we multiplied seed of four varieties selected during Phase II. These were grown on fields ranging from 0.75 ha to 1.5 ha in size in five isolated farms.

Previous Page Blank

Table 68. Grain yield of four elite varieties grown under irrigated conditions in farmers' fields in Morelos, Mexico, during the winter season, 1991/92.

Variety	Location	Yield (t ha^{-1})
ICSV-LM 86513	Yautepec	6.2
ICSV-LM 89516	Yautepec	7.5
ICSV-LM 89522	Yautepec	7.4
ICSV-LM 86502	Xalostoc	6.2
Mean		6.8
SE		±0.48

Five samples each of 3 rows x 10 m were harvested on each farm for grain yield data (Table 68). Grain yield exceeded 6.0 t ha^{-1} for all four varieties.

About 20 tons of quality seed were produced for distribution to farmers within the Morelos area.

Phase IV of the project involved the sowing of the seed increased in Phase III by farmers of the area. Some 400 ha were actually sown to three of the varieties under rainfed conditions by farmers in June 1992. We sampled five farmers' fields (Table 69) to check on the success of the technology transfer. The improved varieties outyielded the local commercial hybrid control by 93 to 170% and produced an average yield of 8.4 t ha^{-1} of grain. On the basis of these data, and those of Phases I and II during 1990 and 1991, the four varieties were earmarked for release in 1993 under the "Caudillo del Sur" farmer cooperative that plans to sow some 1800 ha under rainfed conditions during 1993.

Collaborative Research with National Programs

R. Clará V.

Variety trials. Results of 1991 Comision Latinoamericana de Investigadores en Sorgo (CLAIS) trials in Central America showed that the best yielding varieties from the advanced yield trial (ERVAC-91) across eight locations were ICSV-LM 90502 (5.3 t ha^{-1}), ICSV-LM 86513 (5.3 t ha^{-1}), ICSV-LM 89522 (5.2 t ha^{-1}), ICSV-LM 89527 (5.1 t ha^{-1}), and ICSV-LM 90501 (5.1 t ha^{-1}). The control was ISIAP Dorado (4.3 t ha^{-1}).

The same trial in two locations of South America showed that four varieties, ICSV-LM 90501, ICSV-LM 89527, ICSV-LM 90502, and ICSV-LM 89516, were equal to or better than local control ISIAP Dorado in yield and agronomic characteristics (Table 70), and for tolerance to foliar diseases, fall armyworm, and aphids.

Varietal nursery. Results of the varietal nursery (VOVAC-91) across 10 locations in Latin America (including 5 locations in Mesoamerica) are presented in Table 71. These results indicated that we have improved our germplasm and now have varieties that are better than the control, ISIAP Dorado. Ten new varieties bred in LASIP had 20% to 32% higher yield than ISIAP Dorado (control), and these were tolerant to the main diseases in the region.

Hybrid nursery and yield trials. The CLAIS Central American network also distributed one advanced yield trial (ERHIC-91), one observation nursery (VOHIC-91), and one yield trial of parental lines (ELPHIC-91). The best hybrids of the ERHIC-91 trial were 1696A x ICSR-LM 88507 (5.8 t ha^{-1}), ATx623 x ICSV-LM 86541 (5.3 t ha^{-1}), and 1696A

Table 69. Performance of sorghum varieties in farmers' field in Morelos, Mexico, 1992.

Genotype	Yield (t ha^{-1})	Height (m)	Exsertion (cm)	Head length (cm)	Panicle weight (g)	1000-grain weight (g)
ICSV-LM 86502	9.2	1.7	7.6	23.2	59	23.1
ICSV-LM 89522	8.3	1.5	12.4	24.9	67	25.7
ICSV-LM 89516	6.6	1.5	14.0	25.9	50	24.1
Hybrid (control)	3.4	1.6	18.2	21.3	28	22.4
Mean	6.9	1.6	13.1	23.8	54	23.8
CV(%)	14	5	25	9	19	4
SE	±0.44	±0.04	±1.5	±1.0	±4.4	±0.5

x ICSV-LM 86542 (5.2 t ha^{-1}). all of which outyielded the commercial control DK-64 (4.7 t ha^{-1}). The best hybrids of the observation nursery (VOHIC-91) were 1696A x ICSR-LM 88503 (7.2 t ha^{-1}), ICSA 4 x ICSR-LM 88516 (6.2 t ha^{-1}), ICSA 21 x ICSV-LM 89513 (6.2 t ha^{-1}), ATx625 x ICSR-LM 88505 (6.2 t ha^{-1}), and ICSA 4 x ICSR-LM 86557 (6.0 t ha^{-1}). All five outyielded the commercial control DK-64 (4.2 t ha^{-1}).

Table 70. Best varieties of advanced yield trial in Ecuador (Boliche) and Peru (Chiclayo), rainy season, 1991.

Variety	Grain yield (t ha^{-1})	Plant height (m)	Time to 50% flowering (d)
ICSV-LM 90501	8.3	1.6	74
ICSV-LM 89527	6.2	1.7	71
ICSV-LM 90502	5.6	1.6	70
ICSV-LM 89516	5.5	1.6	75
ISIAP Dorado (control)	5.8	1.5	68
Mean	5.6	1.6	71
SE	±0.33	±0.45	±0.6
CV(%)	26	3	4

Table 71. Mean performance of the best entries in the varietal nursery (VOVAC-91) across 10 locations in Latin America during 1991/92.

Variety	Grain yield (t ha^{-1})	Plant height (m)	Time to 50% flowering (d)
ICSV-LM 89537	6.3	1.7	73
ICSV-LM 90503	6.2	1.8	72
ICSV-LM 89527	6.2	1.5	70
ICSV-LM 90501	6.1	1.5	74
ICSV-LM 86513	6.1	1.5	73
ICSV-LM 89525	6.1	1.5	71
ICSV-LM 90522	6.0	1.6	75
ICSV-LM 89522	5.8	1.5	69
ICSV-LM 90504	5.8	1.6	74
ICSV-LM 89555	5.7	1.5	70
ISIAP Dorado (control)	4.8	1.3	71
Mean	4.7	1.4	70
SE	±0.58	±0.04	±1.4
CV(%)	25	7	4

Table 72. Mean performance of the best entries of hybrid nursery (VOHIC-91) across nine locations in Latin America during 1991/92.

Pedigree	Yield (t ha^{-1})	Plant height (m)	Time to 50% flowering (d)
A1-155 x ICSV-LM 89511	8.3	1.7	66
ICSA-4 x 87BB-396	7.4	1.8	63
ATX 631 x PM-5920	7.3	1.9	65
1696A x ICSR-LM 88503	6.9	1.5	66
ICSA-17 x R-6956	6.8	1.6	65
ICSA-21 x ICSV-LM 89513	6.7	1.7	62
ICSA-4 x ICSR-LM 88516	6.6	1.4	66
954066A x ICSR-LM 88515	6.4	1.7	65
DK-64 (commercial control)	5.6	1.4	61
Mean	5.7	1.4	64
SE	±0.67	±0.04	±0.8
CV(%)	23	5	3

Results of the VOHIC-91 hybrid nursery across nine locations of CLAIS Latin American countries showed that eight hybrids exceeded or equaled the local control DK-64 in yield (Table 72). The best heterosis was obtained by crossing ICRISAT LASIP germplasm with that from Texas A&M University.

Technology Exchange

Network Activities

The Ninth Annual Meeting of CLAIS Subprogram Central America was held on 26-27 Mar in Managua, Nicaragua. LASIP staff were involved in its organization and in the assessment of the Network's activities in planning and review of research results.

The Steering Committee, which consists the of NARS sorghum coordinators, has been given greater responsibilities in the coordination of the network.

NARS scientists attending the meeting received financial support from the Central American Basic Grains Program, financed by the European Economic Community as well as from private seed companies.

The First Annual Meeting of CLAIS Subprogram

South America was held on 6-10 Oct in Campinas, Brazil. While ICRISAT financed the participation of the NARS scientists, the Brazilian national program, EMBRAPA, and a Brazilian private company, AGROCERES, were very helpful in the in-country organization and local financing.

This was the first meeting of NARS sorghum program scientists from South American countries. The participants were grateful to the ICRISAT LASIP for making the meeting possible. Important decisions on intercountry collaboration were made during the 5-day meeting and field tours.

Training/Field Days

In collaboration with the Mexican National Research Institute, INIFAP, we organized a 1-day training session in Morelos, Mexico, on sorghum production practices. Twenty farmers and 10 field technicians of the Cooperative "Union de Ejidos Caudillo del Sur" participated. This Cooperative validated three of the advanced materials from the LASIP/Bank of Mexico collaborative research project.

One Colombian and one Venezuelan scientist were trained at the Research Fellow and In-service level, respectively, at ICRISAT Center, India.

During the year, two field days were held in Morelos, Mexico, in collaboration with the Bank of Mexico and the cooperative "Union de Ejidos Caudillo del Sur". The first, held in May, was attended by 60 farmers and technicians, and the second, in November, was attended by 25 participants.

Seed Distribution

During 1992, LASIP distributed 2170 seed samples totaling 350 kg to 19 countries (Table 73).

Cultivar Release

During 1992, five cultivars bearing ICRISAT LASIP germplasm were released to farmers in four countries of Latin America. These cultivars included Eskameka (Costa Rica), ES727 (El Salvador), Alanje Blanquito (Panama), ICA-Yanuba (Colombia), and the hybrid HE 241 (Colombia). Three of these are a direct result of multilocational trials through the CLAIS network and LASIP/NARS collaboration in on-farm trials. Eight more cultivars are pending release in 1992/93. Presently, these cultivars occupy 8500 ha in four countries. Seed increase at the beginning of 1993 is expected to contribute to substantial increases in production and area sown to ICRISAT LASIP sorghum germplasm.

Table 73. Sorghum seed samples distributed by LASIP during 1992.

Country	No. of samples	Quantity (kg)
Argentina	118	6.7
Bolivia	118	2.3
Brazil	42	0.4
Colombia	275	8.1
Cuba	91	4.0
Dominican Republic	2	1.0
Ecuador	104	1.3
El Salvador	432	4.3
Guatemala	310	11.1
Honduras	1	2.0
India (ICRISAT)	5	1.5
Iran	10	0.1
Mexico	283	297.2
Paraguay	76	1.9
Perú	18	0.7
South Africa	8	0.1
USA (Texas A&M)	161	2.8
Venezuela	116	3.3
Total	2170	349.7

Publications

Publications

Journal Articles

Binelli, G., Gianfranceschi, L., Pe, M.E., Taramino, G., Busso, C., Stenhouse, J., and **Ottaviano, E.** 1992. Similarity of maize and sorghum genomes as revealed. Theoretical and Applied Genetics 84:10-16.

Jambunathan, R., Kheredekar, M.S., and **Stenhouse, J.W.** 1992. Sorghum grain hardness and its relationship to mold susceptibility and mold resistance. Journal of Agricultural and Food Chemistry 40:1403-1408. (JA 1307)

Mahalakshmi, V., Bidinger, F.R., Rao, K.P., and **Raju, D.S.** 1992. Performace and stability of pearl millet topcross hybrids and their variety pollinators. Crop Science 32:928-932. (JA 1245)

Nwanze, K.F., and **Harris, K.M.** 1992. Insect pests of pearl millet in West Africa. Review of Agricultural Entomology 80:1133-1155. (JA 1337)

Nwanze, K.F., Pring, R.J., Sree, P.S., Butler, D.R., Reddy, Y.V.R., and **Soman, P.** 1992. Resistance in sorghum to the shoot fly, *Atherigona soccata*: epicuticular wax and wetness of the central whorl leaf of young seedlings. Annals of Applied Biology 120:373-382. (JA 1866)

Nwanze, K.F., Sree, P.S., Butler, D.R., Reddy, D.D.R., Reddy, Y.V.R., and **Soman, P.** 1992. The dynamics of leaf surface wetness of sorghum seedlings in relation to resistance to the shoot fly, *Atherigona soccata*. Entomologia Experimentalis et Applicata 64:151-160. (JA 1184)

Reddy, B.V.S., Mughogho, L.K., Narayana, Y.D., Nicodemus, K.D., and **Stenhouse, J.W.** 1992. Inheritance pattern of downy mildew resistance in advanced generations of sorghum. Annals of Applied Biology 121:249-255. (JA 1295)

Sharma, H.C.. Doumbia, Y.O., and **Diorisso, N.Y.** 1992. A headcage technique to screen sorghums for resistance to mirid head bug, *Eurystylus immaculatus* Odh. in West Africa. Insect Science and Its Application 13:417-427. (JA 1034)

Sharma, H.C., and **Lopez, V.F.** 1992. Genotypic resistance in sorghum to head bug, *Calocoris angustatus*. Euphytica 58:193-200. (JA 1195)

Sharma, H.C., and **Lopez, V.F.** 1992. Screening for plant resistance to sorghum head bug, *Calocoris angustatus* Leth. Insect Science and Its Application 13:315-325. (JA 966)

Sharma, H.C., and **Norris, D.M.** 1991. Comparative feeding preference and food intake and utilization by the cabbage looper (Lepidoptera: Noctuidae) on three legume species. Environmental Entomology 20:1589-1594. (JA 1175)

Sharma, H.C., and **Vidyasagar, P.** 1992. Orientation of males of sorghum midge, *Contarina sorghicola* to sex pheromones from virgin females in the field. Engomologia Experimentalis et Applicata 64:23-29. (JA 1236)

Singh, S.D., Singh, P., Andrews D.J., Talukdar, B.S., and **King, S.B.** 1992. Reselection of a pearl millet cultivar utilizing residual variability for downy mildew reaction. Plant Breeding 109:54-59. (JA 1164)

Soman, P., Jayachandran, R., and **Peacock, J.M.** 1992. Effect of soil crusting on seedling growth in constrasting sorghum lines. Experimental Agriculture 28:49-55. (JA 1091)

Soman, P., and **Seetharama, N.** 1992. Genotypic and environmental variation in nodal root growth of post-rainy season (*Rabi*) sorghum. Experimental Agriculture 28:331-341. (JA 1279)

Thakur, R.P., Chahal, S.S., and **Singh, S.D.** 1992. Status of research on control of fungal diseases of pearl millet. Pages 61-82 *in* Progress of plant pathological research (Sokhi, S.S., Chahal, S.S., and Singh, P.P., eds.). Ludhiana 141 004, Punjab, India: Indian Society of Plant Pathologists. (JA 927)

Thakur, R.P., and **King, S.B.** 1992. Ergot of pearl millet. Pages 302-315 *in* Plant diseases of international importance: diseases of cereals and

Previous Page Blank

pulses. Vol. 1 (Singh, U.S., Mukhopadhyay, A.N., Kumar, J., and Chaube, H.S., eds.). Englewood Cliffs, New Jersey, USA: Prentice Hall. (JA 695)

Thakur, R.P., Shetty, K.G., and **King, S.B.** 1992. Selection for host-specific virulence in asexual populations of *Sclerospora graminicola*. Plant Pathology 41:626-632. (JA 1169)

Witcombe, J.R., and **Soman, P.** 1992. Selection for seedling emergence using a glasshouse test in pearl millet. Plant Breeding 108:78-80. (JA 1030)

Conference Papers

Alagarswamy, G., Stenhouse, J.W., and **Pattanayak, C.M.** (eds.) 1992. Sorghum Research and Development Network for Asia: Report of the Consultative Meeting to Consider the Establishment of Sorghum Research and Development Network for Asia, 16-19 Sep 1991, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 31 pp.

Bandyopadhyay, R. 1992. Sorghum ergot. Pages 235-244 *in* Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 740)

Bidinger, F.R. 1992. Utilization of plant genetic resources in crop breeding programmes. Pages 70-81 *in* Proceedings of the First National Workshop on Plant Genetic Resources (Maggs, G.L., and Strohbach, B., eds.). Windhoek, Namibia: Namibia Scientific Society. Dinteria No. 23. (CP 762)

Forbes, G.A., Bandyopadhyay, R., and **Garcia, G.** 1992. A review of sorghum grain mold. Pages 265-272 *in* Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen. R.A., and Bengston, G.D., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 738)

de Wet, J.M.J., Bidinger, F.R., and **Peacock, J.M.** 1992. Pearl millet (*Pennisetum glaucum*) - a cereal of the Sahel. Pages 259-267 *in* Desertified grasslands: their biology and management (Chapmanm, G.P., ed.). London, UK: Academic Press. (CP 640)

King, S.B. 1992. World review of pearl millet diseases: knowledge and future research needs. Pages 95-108 *in* Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 743)

Laxman Singh, Mukuru, S.Z., Silim, S.N., and **King, S.B.** (eds.) 1992. Proceedings of the Consultative Group Meeting on Production and Agro-processing of sorghum and pigeonpea in Kenya, 18-19 Sep 1992. P.O. Box 39063, Nairobi, Kenya: Eastern Africa Regional Cereals and Legumes Program (EARCAL), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the Kenya Agricultural Research Institute (KARI).

Leuschner, K., and **Pande. S.** 1992. Plant protection for sustainable agriculture in sorghum and pearl millet cropping systems in Africa. Pages 203-213 *in* Proceedings of the 1991 International Sorghum and Millet CRSP Conference, Jul 8-12 1991, Corpus Christ, Texas. USA (Schilling, T., and Stoner, D., eds.). INTSORMIL Publication no. 91-1. Lincoln, Nebraska, USA:INTSORMIL.

Liu, C., Witcombe, J., Pittaway, T.S., Nash, M., Hash, C.T., and **Gale, M.** 1992. Restriction fragment length polymorphism in pearl millet, *Pennisetum glaucum* Pages 233-241 *in* Complexes d'espèces, flux de gènes et ressources génétiques des plantes. Actes du colloque international, Paris 8-10 janvier 1992 organisé en hommage à Jean Pernès Professeur à l'Université de Paris-XI. Cachan, France: Lavoisier. (CP 756)

Mukuru, S.Z. 1992. Using the world germplasm collection in breeding for disease resistance at ICRISAT. Pages 325-328 *in* Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds.). Patancheru, A.P. 502 324, India:

International Crops Research Institute for the Semi-Arid Tropics. (CP 736)

Mukuru, S.Z. 1992. Breeding for grain mold resistance. Pages 273-285 in Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 739)

Mukuru, S.Z. 1992. Traditional technologies in small grain processing. Pages 47-56 *in* Utilization of sorghum and miliet (Gomez, M.I., House, L.R., Rooney, L.W., and Dendy, D.A.V., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 681)

Pande, S., and **Karunakar, R.I.** 1992. Stalk rots. Pages 219-234 *in* Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 742)

Pande, S., and **Singh, S.D.** 1992. Successful transfer of ICRISAT downy mildew resistance screening technology: an example of transfer of technology. Pages 331-334 *in* Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 737)

Waniska, R.D., Forbes, G.A., Bandyopadhyay, R., Frederiksen, R.A., and **Rooney, L.W.** 1992. Cereals chemistry and grain mold resistance. Pages 265-272 *in* Sorghum and millets diseases: a second world review (de Milliano, W.A.J., Frederiksen, R.A., and Bengston, G.D., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (CP 735)

Information Bulletins/Research Bulletins

Harris, K.M., and **Nwanze, K.F.** 1992. *Busseola fusca* (Fuller), the African maize stalk borer: a handbook of information. (In En. Summaries in En, Fr, Es.) Information Bulletin no. 33. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics, and Wellingford, UK: CAB International. 92 pp. (IBE 033)

Sharma, H.C., Taneja, S.L., Leuschner, K., and **Nwanze, K.F.** 1992. Techniques to screen sorghums for resistance to insect pests. Information Bulletin no. 32. Patancheru, A.P., India: International Crops Research Institute for the Semi-Arid Tropics. 48 pp. (IBE 032)

Thakur, R.P., King, S.B., Rai, K.N., and **Rao, V.P.** 1992. Identification and utilization of smut resistance in pearl millet. Research Bulletin no. 16. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 36 pp. (RBE 016)

Research Projects

Previous Page Blank

Research Projects

Sorghum Breeding

CS-170(90)IC/IC
Genetic diversification in sorghum. B.V.S. Reddy, J.W. Stenhouse, N. Seetharama, K.E. Prasada Rao, and P. Soman.

CS-171(90)IC/IC
Breeding early maturing sorghum lines. H.F.W. Rattunde, R. Bandyopadhyay, V. Subramanian, P. Soman, and S.L. Taneja.

CS-172(90)IC/IC
Breeding medium maturing sorghum lines. J.W. Stenhouse, F. Wehmann, H.C. Sharma, S.L. Taneja, R. Bandyopadhyay, N. Seetharama, and P. Soman.

CS-173(90)IC/IC
Breeding grain mold resistant sorghums. J.W. Stenhouse, B.V.S. Reddy, R. Bandyopadhyay, and R. Jambunathan.

CS-174(90)IC/IC
Collaborative yield trials, maintenance breeding, and distribution of elite sorghum cultivars and breeding lines. J.W. Stenhouse, B.V.S. Reddy, R. Bandyopadhyay, H.C. Sharma, and S.L. Taneja.

CS-190(90)IC/IC
Breeding milo and nonmilo cytoplasmic male-sterile sorghum lines. B.V.S. Reddy, R. Bandyopadhyay, S.L. Taneja, K.E. Prasada Rao, H.C. Sharma, S. Sivaramakrishnan, P. Soman, and S.D. Singh.

CS-191(90)IC/IC
Sorghum hybrid production and testing. B.V.S. Reddy, R. Bandyopadhyay, H.C. Sharma, S.L. Taneja, S.D. Singh, and K.E. Prasada Rao.

CS-210(90)IC/IC
International sorghum trials. C.M. Pattanayak, G. Alagarswamy, J.W. Stenhouse, B.V.S. Reddy, K.V. Ramaiah, D.S. Murty, S.Z. Mukuru, and A.B. Obilana.

CS-211(90)IC/IC
International sorghum nurseries. G. Alagarswamy, C.M. Pattanayak, K.F. Nwanze, L.K. Mughogho, J.W. Stenhouse, D.S. Murty, K.V. Ramaiah, K. Leuschner, S.Z. Mukuru, M D. Thomas, and N. Seetharama.

CS-212(90)IC/IC
Characterization of sorghum test locations environments. G. Alagarswamy, C.M. Pattanayak, S.M. Virmani, S.Z. Mukuru, C. Luce, R. Tabo, M.V.K. Sivakumar, A.B. Obilana, and C.L. Paul.

Millet Breeding

CM-170(90)IC/IC
Population improvement and breeding of pearl millet varieties by recurrent selection. C.T. Hash, E. Weltzien R., S.D. Singh, V. Mahalakshmi, F.R. Bidinger, P. Soman, V. Subramanian, E. Monyo, and S. Mukuru.

CM-171(90)IC/IC
Genetic diversification of pearl millet. E. Weltzien R., C.T. Hash, F.R. Bidinger, V. Mahalakshmi, S.D. Singh, S. Appa Rao, and M.L. Whitaker.

CM-190(90)IC/IC
Genetic and cytoplasmic diversification of pearl millet male-sterile lines. K.N. Rai, C.T. Hash, F.R. Bidinger, S.D. Singh, S. Appa Rao, S. Sivaramakrishnan, K. Anand Kumar, and E. Monyo.

CM-191(90)IC/IC
Breeding of pearl millet pollinators. B.S. Talukdar, S.D. Singh, C.T. Hash, E. Weltzien R., F.R. Bidinger, K. Anand Kumar, and E. Monyo.

CM-192(90)IC/IC
Breeding of pearl millet hybrids. B.S. Talukdar, K.N. Rai, C.T. Hash, H.C. Sharma, V. Subramanian, and E. Monyo.

CM-210(90)IC/IC
Production and distribution of pearl millet breeding material and genetic stocks. C.T. Hash, K.N. Rai, B.S. Talukdar, E. Weltzien R., F.R. Bidinger, S.D. Singh, M.V. Potdar, and C.S. Busso.

 Previous Page Blank

Cereal Pathology

CSM-126(91)IC/IC
Mechanisms and genetics of resistance to pearl millet downy mildew, and sorghum anthracnose, leaf blight, and ergot. R.P. Thakur, S.D. Singh, R. Bandyopadhyay, C.T. Hash, and B.V.S. Reddy.

CSM-128(91)IC/IC
Variability in pearl millet downy mildew and sorghum anthracnose pathogens. R.P. Thakur, R. Bandyopadhyay, S.D. Singh, S. Sivaramakrishnan, M.D. Thomas, and D.E. Hess.

CSM-129(91)IC/IC
Management of sorghum and pearl millet diseases. S.D. Singh, R.P. Thakur, R. Bandyopadhyay, M.M. Anders, M.D. Thomas, D.E. Hess, and S.B. King.

CSM-130(91)IC/IC
Epidemiology of pearl millet and sorghum downy mildews, and sorghum anthracnose and ergot. R. Bandyopadhyay, R.P. Thakur, and D.R. Butler.

Cereal Physiology

CSM-111(90)IC/IC
Traits, hypotheses and selection procedures in the breeding of pearl millet and sorghum. F.R. Bidinger, C.T. Hash, K.N. Rai, B.S. Talukdar, E. Weltzien R., and B.V.S. Reddy.

CM-113(91)IC/IC
Water balance analyses to predict drought periods in pearl millet growing regions. V. Mahalakshmi, E. Weltzien R., F.R. Bidinger, and E. Monyo.

CSM-114(91)IC/IC
Morphological and developmental variation associated with grain yield in sorghum and pearl millet. P. Soman, B.V.S. Reddy, F.R. Bidinger, H.F.W. Rattunde, C.T. Hash, and K.F. Nwanze.

CSM-115(91)IC/IC
Mechanisms associated with tolerance to environmental stress in sorghum and millet. P. Soman, F.R. Bidinger, and N. Seetharama.

CS-116(91)IC/IC
Basis of phenological adaptation of sorghum in different agroecological zones. V. Mahalakshmi, R.J. Summerfield, K.E. Prasada Rao, and S.N. Silim.

CM-117(91)IC/IC
Mechanisms of tolerance to heat stress in pearl millet seedlings. P. Soman, A. Thomas, and E. Weltzien R.

Cereal Entomology

CS-151(90)IC/IC
Bioecology, host-plant resistance, and management of sorghum panicle feeding insects. H.C. Sharma, B.V.S. Reddy, J.W. Stenhouse, K.E. Prasada Rao, V. Subramanian, O. Ajayi, and A. Ratnadass.

CS-152(90)IC/IC
Bioecology and management of sorghum shoot pests. S.L. Taneja, K.F. Nwanze, B.V.S. Reddy, J.W. Stenhouse, P. Soman, K.E. Prasada Rao, O. Ajayi, and K. Leuschner.

CS-153(91)IC/IC
Insect-host plant relationships: environmental and plant physiological factors in sorghum resistance to shoot fly. K.F. Nwanze, P. Soman, V. Subramanian, S.L. Taneja, D.R. Butler, K.B. Laryea, and S. Shivaramakrishnan.

CS-154(91)IC/IC
Development of integrated pest management strategies for sorghum insects. K.F. Nwanze, H.C. Sharma, S.L. Taneja, T.G. Shanower, M.M. Anders, D.R. Butler, J.W. Stenhouse, and M.L. Whitaker.

Cell Biology

CSM-270(90)IC/IC
Construction and use of RFLP-based genetic linkage maps in pearl millet and sorghum. C.S. Busso, C.T. Hash, J.W. Stenhouse, and S. Sivaramakrishnan.

CM-271(90)IC/IC
Use of molecular markers in the classification of male-sterile cytoplasm and characterization

of genetic variation in *Pennisetum glaucum* (pearl millet). S. Sivaramakrishnan, K.N. Rai, and V. Sujata.

EARCAL

CSM-002(90)IC/EL
Breeding sorghum cultivars adapted to eastern Africa. S.Z. Mukuru, V.Y. Guiragossian, R. Bandyopadhyay, and B.V.S. Reddy.

CM-003(90)IC/EL
Breeding millet varieties/composites adapted to eastern Africa. S.Z. Mukuru, V.Y. Guiragossian, L.K. Mughogho, S.B. King, S. Appa Rao, W. Kamau, and M.W. Ogenga-Latigo.

CSM-004(90)IC/EL
Cooperative regional yield trials and nurseries. S.Z. Mukuru, V.Y. Guiragossian, C.M. Pattanayak, and B.V.S. Reddy.

Staff List

Previous Page Blank

Staff List

ICRISAT Center

Program Office

Director	L.K. Mughogho (until May) D.E. Byth (from May)
Sr Admn Officer	N.V.N. Chari
Sr Secretary	S.B. Stanley R.L.N. Sastry (until Mar) G. Satyakumari (until Apr)
Secretary	I. Krishna Murty
Office Asst	G.Ch.S. Raju (until Jun) Padmini Haridas Shantha M. Williams N.K. Ganapathi K. Prabhakar V.R. Reddy C.R. Mohan Rao T. Vijaya Kumar
Jr Office Asst	B. Hanumanth Rao K. Trinadha Raju (until May)
Sr Driver/ General Asst	T.F. Anthony Taher Ali Khan G. Rama Rao (from Jul) S.A. Hussain Mohd. Ejajuddin Khan K. Ashok Kumar N.N.S. Rao (until Jul) R. Abraham M.A.H. Khan (until May) K.A. Qureshi (until Feb) Mohd. Azam Ali (from Apr)

Sorghum Breeding

Pr Scientist	J.W. Stenhouse
Sr Scientist	Belum V.S. Reddy
Scientist	G. Alagarswamy H.F.W. Rattunde
Postdoc Fellow	F. Wehmann (until Mar)
Sr Research Associate	K.D. Nicodemus
Research Associate	C.V. Abraham G. Sree Ramulu B. Raghavender A.J. Reddy D.M. Reddy P. Malla Reddy R. Madhiyazhagan B. Ramaiah
Sr Field Asst	R. Hanumanth Rao D. Laxma Reddy B. Balakrishna Singh K. Devendram K.S.P. Varma S.A. Rasheed G. Venkateswarlu P.L. Ranga Reddy R. Rajender K.B. Reddy Mohd. Mahboob Ali D. Vara Prasad K. Ashok Kumar S.S.C. Bose P.V. Krishnam Raju P.V.D.M. Rao B. Venkataiah
Field Helper	K. Ponnusamy D. Chandrasekara Rao G. Subuddi B. Anjaiah
Field Attend	B. Sangaiah Sudhakara Chary Ch. Ravinder Rao M. Narsimulu Y. Narasimha Rao

Millet Breeding

Pr Scientist	C.T. Hash, Jr.
Sr Scientist	K.N. Rai

Previous Page Blank

Scientist	B.S. Talukdar E. Weltzien R.
Sr Research Associate	B.P. Reddy A.S. Rao (on leave from Jul) A.G. Bhasker Raj M.N.V. Ratnaji Rao (until Sep)
Research Associate	A.M. Rao P.P. Prakash Babu N.R. Sharma R.K. Yadav (until May)
Sr Field Asst	T.T. Ramakrishna M. Mark M. Sudershan Mohd. Akbar Mohd. Basheer Ahmed Mohd. Ahmeduddin Dashrath Singh B. Laxman J. Ravinder Nair P. Om Prakash V. Eshwar Rao K. Shivraj C. Muralidhar A. Ganapathi
Field Helper	Jaihind B.S.C. Sekhara Rao M. Ananth Krishan Rao
Field Attend	G. Ram Reddy Ch. Babu Rao (from Apr)

Cereals Pathology

Pr Scientist	L.K. Mughogho (until May)
Sr Scientist	S.D. Singh R.P. Thakur
Scientist	R. Bandyopadhyay (on study leave until Jul) S. Pande (until Mar)
Postdoc Fellow	J.A. Sifuentes (until Jul)
Res Scholar	V. Celia Chalam
Sr Research Associate	V. Panduranga Rao
Research Associate	R.I. Karunakar Y.D. Narayana (on study leave) M.V. Satyanarayana R. Harikrishnan S.S. Navi P. Sathaiah G. Venkateswarlu (until Apr)
Sr Field Asst	P. Jagan Mohan Rao B. Suresh Babu P. Anantha Rao S.B. Rammohan Rao Mohd. Azeez D. Rangaswamy Reddy
Field Helper	A.V. Jayarajan B. Bhaskara Raju K. Gandaiah R. Narsing Rao V.S.N. Banerjee

Cereals Physiology

Pr Scientist	F.R. Bidinger (on study leave until Sep)
Scientist	V. Mahalakshmi (on secondment from Jul) P. Sornan (until Sep)
Postdoc Fellow	A. Thomas (until Jan)
Res Scholar	Elasha A. Elasha
Research Associate	D.S. Raju R. Jayachandran K. Purushotham Rao
Sr Field Asst	B.L. Rao Y.R. Mohan K. Pratap Reddy D.V.C. Mohan Rao B. Raja Reddy
Field Helper	P. Ram Babu D. Dharani M. Kistaiah L. George M. Anjaiah B. Shivaiah
Field Attend	N. Pentaiah

Cereal Entomology

Pr Scientist	K.F. Nwanze
Scientist	S.L. Taneja H.C. Sharma
Postdoc Fellow	S.J. Duffield (from May)
Res Scholar	T.E. Bashir (until Feb) M.A. Farah (until Sep) K.G. Kausalya (from Apr) K. Vijaya Laxmi L. Sigsgaard (from Oct)
Sr Research Associate	Y.V.R. Reddy V.K. Henry
Research Associate	P. Vidyasagar (until May) M.V.R. Naidu G. Venkateswarlu (from May)
Sr Field Asst	A. Narasimha K.J. Chary K. Hareendranath V. Venkateswara Rao Mohd. Zaheeruddin Durgam Krishna
Field Helper	S.V.N. Chandra S. Raja Rao J. Raja Rao Janardhan

Molecular Biology

Assoc Principal Scientist	C.S. Busso (until Sep)
Sr Scientist	N. Seetharama
Postdoc Fellow	V. Sujata (until Feb)
Sr Research Associate	Santosh Gurtu (from Jun)
Research Associate	S. Chandrapalaiah (until Jan) A. Usha Rani (until Jul)
Sr Field Asst	T. Hanumantha Rao V. Chandrasekharan Asari Mohd. Yousuf
Field Helper	A. Chandra Reddy C. Laxminarayana

Cooperative Cereals Research Network

Pr Scientist	C.M. Pattanayak (until Jan)

Cereal Genetics

Pr Scientist	K.V. Ramaiah (until Mar)
Field Attend	Ch. Babu Rao (Until Mar)

Kenya

Eastern Africa Regional Cereals and Legumes Program (EARCAL)*

Pr Scientist (Pathology) and Team Leader	S.B. King
Pr Scientist (Breeding)	S.Z. Mukuru Laxman Singh
Sr Scientist (Agronomy)	S.N. Silim
Admin Officer	S. Otieno (till Dec)
Tech Officer	O.M. Karuru J.G. Kibuka E.O. Manyasa H.K. Nguigi (from Apr) B.N. Kabira (from Aug)
Secretary	L.M. Bwire M.M. Nyaoso A.N. Njorgoge (from Jun)
Off Assistant	M.M. Nyangweso
Driver/Gen Asst	G.N. Kabira J. Mwangi P.M. Mwangi

* The EARCAL staff in both cereals and legumes

Mexico

Latin American Sorghum Improvement Program (LASIP)

Pr Scientist and Team Leader	C.L. Paul
Assoc Breeder	R. Clará V.
Secretary	B. Delgadillo (Jan-Mar and Oct-Dec) I. Sandoval (Mar-Jun) G. Luna (Jul-Sep)
Tech Assistant	D. Ojeda Y.
Jr Field Asst	C. Roman A. H. Vasquez P. (until May)

Appendices

Cumulative List of ICRISAT-bred Sorghum and Pearl Millet Cultivars

ICRISAT name	Other name	Release name	Remarks
Sorghum			
ICSV 1	SPV 351	CSV 11	Released cultivar in India (1984)
		SPV 351	Released cultivar in Malawi (1989)
ICSV 2	SPV 386	ZSV 1	Released cultivar in Zambia (1983)
ICSV 112	SPV 475	SV 1	Released cultivar in Zimbabwe (1985)
		UANL-I-187	Released cultivar in Neuvo Leon, Mexico (1987)
		CSV 13	Released cultivar in India (1988)
		Pacifico 301	Released cultivar in Mexico (1990)
		Pinolero I	Released cultivar in Nicaragua (1990)
ICSV 197	PM 11344		Highly resistant to sorghum midge (*Contarinia sorghicola*)
ICSV 145	SAR 1		Resistant to *Striga asiatica* in India Recommended for cultivation in *Striga*-endemic areas of India, except Karnataka (1988)
E 1966	IS 30468	NTJ-2	Pure line selection from germplasm line Released in Andhra Pradesh, India for postrainy season cultivation (1990)
ICSH 153	CSH 11 (SPH 221)	CSH 11	Released hybrid in India (1986) (Male sterile, 296A, from AICSIP)
AGROCONSA I		AGROCONSA I	Released hybrid in El Salvador (1987) Male sterile, ATx625, from Texas A&M University. Pollinator, M 90362, from ICRISAT
ICSV 1007 HV	SRN 39	Mugawim Buda-1	Released in Sudan in May 1991 for *Striga hermonthica* endemic rainfed, mechanized farming areas. It exhibited broad-spectrum resistance throughout the *Striga*-infested areas of the world.
IS 9830		Mugawim Buda-2	Released in Sudan in May 1991 for *Striga hermonthica* endemic rainfed peasant farming conditions
M 90906		Yezin 1	Released cultivar in Myanmar
M 36248		Yezin 2	Released cultivar in Myanmar
M 36335		Yezin 3	Released cultivar in Myanmar
M 36172		Yezin 4	Released cultivar in Myanmar
M 62641		Costeño 201	Released cultivar in Mexico (1989)
M 90812		Tropical 401	Released cultivar in Mexico (1991)
M 91057	ICTA C-25	Istmeño	Released cultivar in Mexico (1991)
PP 290		Perlita	Released cultivar in Mexico (1991)
SPL 132A			Used as a female parent, its hybrid, Liao Hybrid No. 4 was released in 1988 in China.
Breeding line		ISIAP Dorado	Released cultivar in El Salvador (1983)
		Blanco 86	Released cultivar in Mexico (1987)

Previous Page Blank

Materials released cont'd....

ICRISAT name	Other name	Release name	Remarks
M 62650		Sureño	Released cultivar in Honduras (1985)
SEPON 77		Nica-sor (T-43)	Released cultivar in Nicaragua (1985)
M 90362		UANL-I-287	Released cultivar in Neuvo Leon, Mexico (1987)
M 90975	ICTA C-21	ICTA Mitlan 85	Released cultivar in Gautamela (1985)
A 6072		Yuan 1-54	Released cultivar in China (1982)
A 3681		Yuan 1-98	Released cultivar in China (1982)
A 3872		Yuan 1-28	Released cultivar in China (1932)
A 3895		Yuan 1-505	Released cultivar in China (1982)
		ICA Yanuba	Released cultivar in Colombia (1992)[1]
		Sorghica PH-302	Released hybrid in Colombia. Male sterile and pollinator, ICA Yanuba, from ICRISAT (1992)[1]
Pearl Millet			
ICMV 1	WC-C75	WC-C75	Released cultivar in India (1982) Released cultivar in Zambia (1987)
ICMV 4	MP 15	ICMS 7703	Released cultivar in India (1985)
ICMH 451	MH-179 ICH 451	MH-179 (ICMH 451)	Released cultivar in India (1986)
ICMH 501	MH-180 ICH 501	MH-180 (ICMH 501)	Released cultivar in India (1986)
ICMH 423	MH-143 ICH 423	ICMH 423	Released cultivar in India (1986)
MP 124 (ICTP 8203)	ICTP 8203 MP 124	MP 124 (ICTP 8203)	Released cultivar in Maharashtra and Andhra Pradesh, India (1988)
		Okashana 1	Released cultivar in Namibia (1989)
		PCB 138	Released cultivar in Punjab, India (1989)
ICMV 82132		Kaufela	Released cultivar in Zambia (1989)
ICMV 155	ICMV 84400 MP 155	ICMV 155	Released cultivar in India (1991)

1. Original ICRISAT name to be confirmed

Research Travel and Consultancies

Staff name	Date	Organization visited	Country visited	Purpose
Alagarswamy, G.	13 Sep-18 Oct	ICRISAT Regional Programs and NARS	Nigeria, Niger, Mali, Burkina Faso, Ethiopia	To jointly evaluate the characterization of sorghum test location environment trials and gather soils and weather data of selected locations
Bandyopadhyay, R.	16-29 Aug	Natural Resource Institute, International Mycological Institute, University of Reading, Long Ashton Research Station	UK	To discuss collaborative research on epidemiology of cereals diseases and simulation modeling of pearl millet downy mildew
Bidinger, F.R.	20-25 Sep	RAU, HAU, and CAZRI, Fatehpur and Jodhpur, Rajasthan and Hisar, Haryana	India	To visit ICRISAT and ICAR-ICRISAT collaborative res. project experiments
	7-22 Nov	Division of Agric. Res., Mahanene Res. Station	Namibia	To help organize 1992-93 variety trial and agronomic research programs
Byth, D.E., Hash, C.T., and Weltzien R., E.	20 Aug-3 Sep	Dept. of Watershed and Soil Conservation, Rajasthan; CAZRI, Jodhpur; Social Work and Res. Centre, Tilonia; ARS Durgapura of Rajasthan Agric. Univ.	India	Accompanied Program Com. of ICRISAT Governing Board
Byth, D.E.	6-28 Sep	ISC, Niamey, WASIP-Mali, SADC, and Nairobi	Niger, Mali, Nigeria, Kenya, and Zimbabwe	For familiarization with the ICRISAT programs in West and southern Africa
	19 Oct 7 Nov	EARCAL, Nairobi and Wad Madani, Sudan	Kenya, Sudan	To review management procedures in EARCAL, and to participate in the Eighth EARSAM Regional Workshop
Hash, C.T.	5-6 Apr	Haryana Agrl. Univ., Hisar, Haryana	India	To consult on arrangements for collaborative research

Research Travel contd.....

Staff name	Date	Organization visited	Country visited	Purpose
Hash, C.T.	11-20 Apr	New Nandi Seeds, Baroda, Gujarat	India	To inspect seed production fields
	1 Jul	CIAT, Santa Cruz	Bolivia	To discuss opportunities for bilateral research cooperation on ICRISAT mandate crops
	19-25 Jul	Centre for Arid Zone Studies, Univ. Coll. of N. Wales, Bangor; Cambridge Lab., Norwich	UK	To meet with collaborators and review progress on cell biology research projects
Hash, C.T., and Weltzien R., E.	4-7 Sep	RAU, ARS Fatehpur, and HAU, Hisar	India	For initial evaluation of collaborative experiments
Hash, C.T.	23-27 Sep	JNKVV, College of Agric, Gwalior; C.S. Azad Univ., Kanpur; and Madhuri-kund, IARI, Delhi	India	To evaluate collaborative trials and meet with collaborators
	28 Sep-6 Oct	Univ. Paris-Sud, Orsay ISC, Niamey WASIP-Mali and IER	France Niger Mali	For familiarization with pearl millet research at these Centers
	8-9 Oct	HAU, Hisar	India	To evaluate collaborative trials and meet with collaborators
Mughogho, L.K.	8-31 Apr	LASIP and NARS	Mexico, Costa Rica, Colombia, and Brazil	To review ICRISAT's future activities in Latin America
Nwanze, K.F.	1-2 Jun	CAB International, Inst. of Entomology	UK	Regarding collaboration of insect pest information bulletins
	8-28 Sep	ISC, Niamey; WASIP-Mali; WASIP-Nigeria; and CNRA	Niger, Mali, Nigeria, and Senegal	To participate in Entomologists' Group Tour/Meeting on Sorghum and Pearl Millet Insect Pests in West Africa
Rai, K.N.	19 Sep-3 Oct	USDA-ARS, Tifton; Univ. of Nebraska, Lincoln; Kansas State Univ., Fort Hays	USA	To evaluate the performance and utilization of ICRISAT-bred materials in millet programs and to discuss areas of collaborative research

Research Travel contd.....

Staff name	Date	Organization visited	Country visited	Purpose
Rai, K.N.	3-6 Oct	Haryana Agrl. Univ., Hisar, and Indian Agrl. Research Inst., Delhi	India	To evaluate pearl millet nurseries at HAU and IARI.
Rattunde, H.F.W.	25 Jun-6 Jul	Haryana Agrl. Univ., Hisar	India	To sow collaborative trials.
	4-8 Sep	Haryana Agrl. Univ., Hisar	India	To observe flowering, plant growth, and pest incidence in collaborative trials
	1-13 Oct	Hisar, Kota, and Udaipur	India	To observe cooperative trials with collaborators, and select and harvest breeding lines
Reddy, Belum V.S.	17-23 May	Tamil Nadu Agrl. Univ., Bhavanisagar	India	To observe sorghum test crosses
	22-25 Sep	ICRISAT Substation, Bhavanisagar	India	To organize field day for Tamil Nadu scientists at Bhavanisagar
Sharma, H.C.	2-5 Sep	Tamil Nadu Agrl. Univ., Agrl. Res. Station., Kovilpatti	India	To initiate ICRISAT/TNAU collaborative trials on sorghum midge and distribute seed for on-farm trials
	11 Dec 92-7 Jan 93	EARCAL/ICRISAT, Nairobi	Kenya	To work on host plant resistance to sorghum midge
Singh, S.D.	3-6 Aug	GBPUAT, Pantnagar	India	To discuss leaf disease nursery problems and record first observations
	1-4 Sep	Univ. of Mysore	India	To record downy mildew data in the downy mildew nursery
	16-19 Sep	GBPUAT, Pantnagar	India	To record final data in leaf disease nursery
Soman, P.	15-22 May	Rajasthan Agrl. Univ., Fatehpur	India	Regarding collaborative research on seedling establishment

Research Travel contd.....

Staff name	Date	Organization visited	Country visited	Purpose
Stenhouse, J.W.	24 Jul	IGER, Aberystwyth	UK	To discuss collaborative work
	10 Aug	LASIP	Mexico	For familiarization with LASIP
	12-13 Aug	Texas A&M Univ., College Station	USA	For familiarization with sorghum program
	12-13 Sep	Pantnagar	India	To view disease screening nurseries and discuss collaboration
Talukdar, B.S.	18-29 Aug	ISC, Niamey	Niger	For joint evaluation of topcross pollinators
Taneja, S.L.	21-24 Sep	Haryana Agrl. Univ., Hisar, Haryana	India	To evaluate stem borer trials
Thakur, R.P.	8-10 Apr	National Chemical Lab., Pune	India	To discuss collaboration on pearl millet downy mildew molecular research
	21-27 Sep	Rajasthan Agric. Univ., Udaipur	India	To visit International Sorghum Anthracnose Virulence Nursery and to collect anthracnose samples from fields
		Gujarat Agric., Gujarat, Surat	India	
	7-21 Oct	WASIP	Nigeria Niger Mali	To evaluate sorghum disease nurseries and discussions with collaborating scientists
Weltzien R., E.	20-21 Feb	Dept of Watershed Devpt. and Soil Consv., Govt. of Rajasthan	India	To discuss draft research proposal
	30 Mar-7 Apr	Dept. of Watershed Devpt. and Soil Conservation Jaipur; CAZRI, Jodhpur; Social Work and Res. Centre, Tilonia; URMUL Rural Health and Devpt. Trust, Bikaner, Rajasthan	India	To initiate framework for collaborative project involving farmers, selection of study villages, and planning research project

Research Travel contd.....

Staff name	Date	Organization visited	Country visited	Purpose
Weltzien R., E.	6-8 May	Iowa State Univ., Ames	USA	To discuss thesis project with P.J. Lynch
	20 Jun-6 Aug	CAZRI, Jodhpur; RAU, Jaipur, Fatehpur, and ARS Mandore; HAU, Hisar; Social Work and Res. Centre, Tilonia; URMUL Trust, Bikaner, Rajasthan	India	To plant collaborative experiments, initial evaluation of on-farm trials, and to plan visit of the Program Committee ICRISAT Governing Board
	30 Aug-3 Sep	As above	India	To guide tour of the Governing Board, and initial evaluation of collaborative experiments in Rajasthan and Hisar
	20 Sep-17 Oct	Same institutions as above and Society of Uplift of Rural Economy, Barmer, NBPGR Regional Stn., Jodhpur	India	For final evaluation of collaborative experiments, on-farm trials in Jodhpur, Bikaner, and Ajmer distsricts, selections of advanced breeding material, and participation in a collection mission of pearl millet landraces in Barmer district
	7-12 Nov	Agrl. Res. and Extension Authority of Yemen; Res. Station Al Kadan, near Hodeidah	Yemen	For familiarization with pearl millet production conditions in Yemen, and to develop a collaborative program for the improvement of the local cultivars of pearl millet

Workshops and Conferences Attended

Staff name	Workshop/Conference	Date	Place	Organizer
Bidinger, F.R., Byth, D.E., Weltzien R., E., Reddy, Belum V.S., and Stenhouse, J.W.	8th EARSAM Sorghum and Millets Improvement Workshop	30-5 Nov	Wad Medani, Sudan	EARSAM and the Agric. Res. Corp., Wad Medani, Sudan
Byth, D.E.	Biotechnology in Sorghum Improvement	1-3 Aug	Canberra, Australia	CSIRO, Univ of Queen-land
Byth, D.E.	SMIP Planning Workshop	6-28 Sep	Niamey, Niger	ISC/ICRISAT
Hash, C.T., Mughogho, L.K., Rai, K.N., Weltzien R., E., Singh, S.D., Soman, P., and Talukdar, B.S.	AICPMIP Annual Workshop	8-10 Apr	Fatehpur, India	AICPMIP and Raj. Agr. Univ., Fatehpur-Shekawati
Nwanze, K.F., Sharma, H.C., Singh, S.D., Taneja, S.L., and Thakur, R.P.	National Seminar on Changing Scenario on Pests and Pest Management in India	31 Jan-1 Feb	Hyderabad, India	CPPTI
Mahalakshmi, V.	In-house Review of Physiology Program	26 May	Hyderabad, India	Andhra Pradesh Agrl. Univ.
Mughogho, L.K., Rattunde, H.F.W., Reddy, Belum V.S., Sharma, H.C., Singh, S.D., and Stenhouse, J.W.	AICSIP Workshop	2-4 Apr	Surat, India	AICSIP
Rai, K.N., and Stenhouse, J.W.	The Third Annual Research Coordination Meeting of the Improvement and Devpt. of Sorghum and Millet Project of UNDP and the NARS's in Egypt, Somalia, Sudan, Syria, and Yemen	13-21 Apr	Sana'a, Yemen	UNDP

Staff name	Workshop/Conference	Date	Place	Organizer
Seetharama, N.	International Symposium: Applications and Prospects of Biotechnology for Arid Lands	5-7 Nov	Lubbock, Texas, USA	IC^2 Institute, San Gabri, Austin, Texas A&M University
	Plant Genome I - The International Conference on the Plant Genome	9-12 Nov	San Diego, CA, USA	USDA/ARS
Singh, S.D.	In-house Review of Pathology Program	22 May	Hyderabad, India	Andhra Pradesh Agrl. University
	National Workshop on IPM. Harmonization of Package of Practices	29-30 Jun	Hyderabad, India	Directorate of Plant of Plant Protection, Quarantine and Storage, Govt. of India
Stenhouse, J.W.	Traveling Workshop on Sorghum and Millets	2-11 Oct	Cairo, Egypt	UNDP
Talukdar, B.S.	National Symposium on Plant Breeding	31 Oct-6 Nov	Pantnagar, India	Dept. of Plant Breeding, G.B. Pant Univ. of Agr. and Tech.
Taneja, S.L.	Entomology Session of Andhra State Planning Meeting	20-21 May	Hyderabad, India	Andhra Pradesh Agrl. Univ
Thakur, R.P., and Weltzien R., E.	Symposium on Durability of Disease Resistance	24-28 Feb	Wageningen The Netherlands	WAU, Wageningen
	National Workshop on IPM. Harmonization of Package of Practices	29-30 Jun	Hyderabad India	Directorate of Plant of Plant Protection, Quarantine and Storage, Govt. of India
Weltzien R., E., and Rattunde, H.F.W.	Colloqium on Biotechnology and Plant Breeding Research	11-12 Mar	Stuttgart-Hohenheim, Germany	Dept. of Pl. Breed., Population Genetics, and Seed Sci., Univ. of Hohenheim
	Inaugural Meeting of the German Society of Pl. Breed. under the theme "500 Years of New-World Crops in Europe"	12-14 Mar	Stuttgart-Hohenheim, Germany	Dept. of Pl. Breed., Population Genetics, and Seed Sci., Univ. of Hohenheim