THE CEREALS PROGRAMS OF ICRISAT

A plan of research

for

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ICRISAT

International Crops Research Institute for the Semi-Arid Tropics

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1f) Trials and nurseries

Crop genotypes produced by ICRISAT contribute to national breeding programs and agriculture in the semi-arid tropics on a global scale. To facilitate screening and testing, and to reduce the time required for transfer of cultivars from experimental field to farmers' field, a cooperative cereals research network is being established. Three levels of testing are involved in the identification of promising breeding lines and cultivars. First, international trials and nurseries (ITN) to screen and compare all ICRISAT elite material across a range of agro-ecosystems in the SAT of Africa, Asia and Mesoamerica. Second, regional cooperative trials and nurseries (CTN) to compare selected material from the ITN and elite lines from national programs within regions. Third regional adaptation trials (RAT) in which breeding lines and cultivars selected from CTN are tested by national programs for inclusion in their breeding programs or release to farmers. Such a research network involves national programs as equal partners with ICRISAT in testing, and allows them direct access to elite breeding lines and cultivars produced by all ICRISAT programs.

Projects

M-101(74)IC - International testing and cooperation. S.B. King and J.R. Witcombe. 1990.

M-501(86)IS - Multilocational selection and evaluation: nurseries and yield trials. K. Anand Kumar. 1990.

M-508(86)IS - Yield tests and exchange nurseries. S.N. Lohani. 1989.

S-101(85)IC - International testing and cooperation. S.Z. Mukuru 1990.

2. SEED PRODUCTION

2a) Breeder seed

Breeder seed are produced by individual research scientists and made available to private and public breeding programs on request. Sufficient seed is also produced by individual research units to plant various yield trials and adaptation nurseries.

2b) Quantity seeds

The mandate of ICRISAT does not provide for research on seed production, or for the production of seed in quantity to supply seed industries or farmers. The program, however, does provide seed of released open-pollinated cultivars and of hybrid parents to NARS and the seed industry when available.

Availability of seed in quantity is essential for the successful adoption of any cultivar by farmers. The seed industry in India is well established and rapidly multiply seed of new open-pollinated as well as hybrid cultivars for distribution to farmers. Seed industries or poorly developed, or essentially non-existant in several African countries. To assist these countries in establishing quantity seed production capabilities in their NARS, the cereals program organizes workshops through its regional programs to train scientists in hybrid seed production and seed certification.

3. CROPPING SYSTEMS

Research with wheat, rice and maize demonstrated that improvement of cropping systems contributes at least as much to increases in yield as does genetic improvement of cultivars. Indeed, improved cultivars demand changes in cropping systems to achieve their full yield potential. In regional programs, agronomists form part of the breeding programs.

Research by agronomists is contributing substantially to the successful adoption and cultivation of high yielding cultivars in India, Africa and Mesoamerica. It was demonstrated that _Striga_ can be successfully controlled in farmers fields through improved soil fertility, crop rotation, deep plowing and weeding. In West Africa it was shown that allowing crop stubble to remain on the field, can double yield of pearl millet the next year, and that limited applications of phosphate and nitrogen can again double yield in farmers fields. It was further demonstrated that intercropping a cereal with a legume produces a higher overall yield under stress than either crop in monoculture.

Important cooperative studies between physiologists and breeders are to breed late-maturing (135 day) sorghum cultivars for the northern Guinea zone of West Africa, cold tolerant sorghum cultivars for the highland cropping systems of Mesoamerica and Eastern Africa, and early-maturing (55-60 days) pearl millet cultivars to fit into the farming systems of the Sahel. Early maturing cultivars of sorghum are being grown in India on residual moisture during the dry (rabi) season. A project is being established in cooperation with the All India Sorghum Improvement Program (AICSIP) to improve the yield potential of rabi sorghum.

<u>Projects</u>

M-512(86)IS - Evaluation and intensification of millet production systems in the Sahelian zone. L.K. Fussell. 1990.

M-513(86)IS - Evaluation of intercropping systems based on pearl millet as main cereal. L.K. Fussell. 1989.

RM-145(87)IC - Characterization and grouping of the different sets of sorghum growing environments in Eastern Africa based on agroclimatic data. S.M. Virmani and Vartan Guiragossian. 1989.

S-123(86)IC - Study the existing and improved sorghum based cropping systems suitable for Mexican, Central American and Carribean situations. Compton L. Paul. 1991.

S-124(86)IC - Study of sorghum based cropping systems suitable for small farmers in Latin America. Compton L. Paul. 1991.

S-130(87)IC - Improvement of local creole photosensitive sorghums for intercropping systems used by small farmers in Mesoamerica. Rene Clara. 1992.

S-130(87)IC - Improvement of local creole photosensitive sorghums for intercropping systems used by small farmers in Mesoamerica. Rene Clara. 1992.

S-508(86)IS - Design and evaluation of improved sorghum based cropping systems and soil fertility management practices. S.V.R. Shetty. 1989.

4. PLANT PROTECTION

4a) Pathology

The number of pathogenic fungi that infect sorghum and pearl millet is large. They cause severe crop losses when environmental conditions favour their development, and susceptible cultivars are grown and fungicides are not applied. Use of fungicides for disease control in sorghum and pearl millet is not economical, except when used as seed treatments.

The more important, wide spread fungal sorghum diseases, in order of importance, are grain molds caused by species of several genera such as *Fusarium*, *Curvularia* and *Phoma*, root and stalk rots caused by species of genera such as *Macrophomina* and *Fusarium*, anthracnose (*Colletotrichum graminicola*), downy mildew (*Peronosclerospora sorghi*) and rust (*Puccinia purpurea*). Leafblight (*Exserohilum turcicum*) and ergot (*Sphacelia sorghi*) are sorghum diseases in southern and eastern Africa, and sooty stripe (*Ramulispora sorghi*) and gray leaf spot (*Cercospora sorghi*) are widespread in West Africa.

Downy mildew (*Sclerospora graminicola*) is by far the most serious fungal disease of pearl millet across its range of cultivation. Ergot (*Claviceps fusiformis*) sporadically reaches epidemic proportions in both India and Africa. Smut (*Tolyposporium penicillariae*) is common in West Africa and North India. Rust (*Puccinia penniseti*) is common in India and Southern Africa. False mildew (*Beniowskia sphaeroidea*) is of relatively minor importance and is limited to parts of eastern and southern Africa.

The biology and epidemiology of these pathogens are being investigated at IC to provide information on screening techniques that can be used effectively to identify resistant genotypes. Effective screening techniques have been developed for resistance to grainmolds, downy mildew, anthracnose, and root and stem rots in sorghum, and downy mildew, ergot and smut in pearl millet. Screening of germplasm or breeding lines for resistance to these fungal pathogens is becoming routine and technical staff rather than research scientists should be able to conduct this important research activity.

In order to increase yield and avoid terminal drought stress, sorghum breeders are developing photoperiod insensitive cultivars that mature before the end of the rains, and the inflorescences are therefore liable to infection by a series of fungal species. Studies on the biology of grain mold infection, and the genetics of resistance to this pathogen will be a major research thrusts in the sorghum pathology unit during the next several years.

Resistance to grainmold is genetically complex. Several factors contribute to resistance. These include high tannin and phenolic acid content, open panicle, and hard grains. Resistant, low tannin genotypes contain significantly more flavan-4-ol than susceptible genotypes. Several sorghum genotypes with acceptable resistance have been identified. Resistance to grain molds in genotypes with coloured-grain, and high tannin have successfully been transferred to white-grained genotypes with low tannin content. These breeding lines lack yield potential, and pathologists are working in close collaboration with breeders to increase the agronomic potential of selected genotypes without losing their grain mold resistance.

Root and stalk rots cause severe lodging to the sorghum crop under moisture stress. This makes the crop difficult to harvest and grains are also subject damage on the ground before the inflorescences are harvested. Infection <u>per se</u> also reduces grain yield. Root and stalk rots are caused by a multitude of fungi either alone or in combination, and breeding for escape from infection is almost impossible. It is, however, possible to select against lodging by improving stalk quality and introducing late senescence. Stiff stalk is associated with layers of lignified cells directly below the epidermis and around the vascular tissue. Nonsenescence is a trait that allows plants to stay green until grains mature. Selection for these traits under conditions of moisture stress is possible. Several genotypes with one or both of these traits have been identified. The genetics of these traits are being studied, and the breeders need to introduce these traits into parents of hybrids. All presently grown sorghum hybrids lodge extensively under conditions of late moisture stress. A successful breeding program will have to involve pathologists, physiologists and breeders.

Anthracnose is a worldwide sorghum disease of importance in some regions. The present project on the biology and epidemiology of this disease will continue through 1989 with emphasis on genetic variation of the pathogen, and genetics of resistance to infection.

Little is known about the biology or epidemiology of sorghum ergot, or whether resistance to this pathogen is present in cultivated genotypes. Since ergot and longsmut are important diseases in eastern Africa, cooperative projects with the Eastern Africa sorghum and millet network (EARSAM) were initiated in 1987 to familiarize national program scientist with screening techniques. The present strategic research project on ergot biology at IC will continue until a pathologist becomes available in eastern Africa. Sooty stripe and gray leaf spot are being studied in cooperation with pathologists in West Africa, and leaf blight is being investigated in ICRISAT/SADCC.

The principal fungal disease of pearl millet is downy mildew. The biology of Sclerospora graminicola remains poorly understood. The fungus shows considerable pathogenic variation, with isolates from the eastern part of West Africa being the most aggressive. In India, resistance has broken down in several pearl millet hybrids. Breeding for resistance to downy mildew is necessarily a continuous process, due to high ability of the pathogen to adjust its virulence. A new type of resistance to downy mildew was recently identified in several pearl millet genotypes, whereby plants successfully recover from infection. This trait is expressed in two ways. The main shoot recovers to produce disease free leaves and panicles, or secondary shoots develop from the base of a diseased main shoot. After recovery, disease symptom rarely develop.

Screening for resistance to downy mildew using the infection row system has become routine, although the importance of infection from infector rows (sporangial) and from soil (oospores) is not fully understood. A greenhouse technique developed for mass screening looks promising, but facilities are needed to fully utilize this procedure in our breeding projects.

The natural incidence of rust on pearl millet is usually highest during the winter months. Rust infection generally increases with plant age, with a dramatic increase in severity after flowering. These observations emphasize the importance of screening different genotypes for resistance at similar stages of host maturity. Resistance is controlled by dominant alleles of a single or a few genes, and several sources of resistance have been identified.

Grain smut is a relatively minor disease in pearl millet and occurs only when plants mature during periods of rain. Screening for resistance is effective, and studies suggest that smut resistance identified at IC will be effective also in West Africa.

Reports of false mildew on pearl millet have been limited to southern and eastern Africa. Several genotypes with resistance to this disease were identified in our disease screening nurseries in Africa. The importance of this disease is not well known, and need to be assessed.

Major epidemics of infection by ergot in pearl millet have been reported only in India, but this disease is widespread also in Africa. Research at IC indicated that resistance is dependent on fertilization taking place before infection of the stigma by ascospores of the pathogen. Resistant genotypes have a very short period between stigma receptiveness and pollen maturity in the same spikelets (short protogyny). Resistant genotypes are mostly from India, and are generally late maturing. Attempts to breed ergor resistant male sterile and pollen parents for hybrid seed production have so far failed. Breeding for resistance is possible. The success of such hybrids, however, is questioned. Sufficient pollen at the critical time of stigma maturity may not be available. It is recommended that this breeding project be continued but that activities be reduced. Screening, and breeding of ergot resistant open-pollinated cultivars will continue on a limited scale at IC as well as in Africa.

International disease nurseries for pearl millet and sorghum to determine stability of resistance and pathogen variability have been in operation for a number of years, and several sources of stable resistance to various pathogens have been identified.

Identification and characterization of sorghum and pearl millet viruses will receive special attention at IC. Virus diseases are of particular economic importance in southern and eastern Africa. Research on viruses occuring in India can be done at IC. In eastern and southern Africa where viruses are particularly important, research will have to be conducted through collaboration with national scientists in these countries. It may also be possible to study these viruses through collaboration with scientists in European or American institutes. A research project on sorghum viruses is being developed between IC, EARSAM and Kenyan scientists.

Projects

M-124(85)IC - Downy mildew: Biology, epidemiology and resistance identification. S.B. King and S.D. Singh. 1990.

M-127(85)IC - Rust: Biology, epidemiology and resistance identification. S.B. King and S.D. Singh. 1990.

M-134(86)IC - Collaborative millet pathology research between ICRISAT Center and ICRISAT Sahelian Center. S.B. King. 1989.

M-137(87)IC - Panicle diseases: Biology and resistance identification. R.P. Thakur and S.B. King. 1990.

M-514(86)IS - Downy mildew: screening techniques and resistance identification. J. Werder. 1989.

M-515(86)IS - Smut and ergot screening techniques and resistance identification. J. Werder. 1989.

M-516(86)IS - Striga hermonthica: Biology, screening and resistance identification. J. Werder. 1989.

M-803(86)SD - Identification of major millet diseases and screening for disease resistance in SADCC region. W.A.J. de Milliano. 1989.

S-110(85)IC - Biology and genetic control of sorghum grain molds. R. Bandyopadhyay, S.Z. Mukuru and R. Jambunathan. 1990.

S-111(85)IC - Biology and genetic control of sorghum anthracnose. Suresh Pande. 1989.

S-112(85)IC - Biology and genetic control of sorghum downy mildew. L.K. Mughogho. 1989.

S-113(85)IC - Biology and epidemiology of sorghum root and stalk rot complex. Suresh Pande. 1989.

S-114(85)IC - Biology of sorghum ergot. R. Bandyopadhyay. 1989.

S-132(87)IC - Investigation of biology and control of sorghum long smut, and control ergot in Eastern Africa. L.K. Mughogho, Vartan Guiragossian and R. Bandyopadhyay. 1990.

S-505(86)IS - Screening for grain mold resistance. M.D. Thomas. 1990.

S-507(86)IS - The biology and identification resistance to sooty stripe. M.D. Thomas. 1989.

S-804(86)SD - Identification of major sorghum diseases and screening for resistance in the SADCC region. W.A.J. de Milliano. 1989.

S-805(86)SD - Pathology and epidemiology of sorghum leaf blight. W.A.J. de Milliano. 1989.

4b) Entomology

Insect pests are major constraints to sorghum and millet production in Africa and Asia. Major insect pests on sorghum are stem borers belonging to the genera Chilo, Busseola and Sesamia particularly C. partellus, midge (Contarinia sorghicola), head-bug (Calacoris angustatus) and shootfly (Atherigona soccata). Army worms cause crop losses in Africa and the Americas. Insect pests are not a serious problem on pearl millet in the Indian subcontinent. In Africa the stem borer Coniesta (Acigona) ignefusalis, and the earhead caterpillar Raghuva albipunctella cause serious damage to the pearl millet crop, and several insect species attack panicles during flowering and early grain filling.

Most if not all of these insect pests can possibly be controlled with timely application of insecticides. Chemical control of insects, however, is not practical in subsistence agriculture of the semi-arid tropics. Time of planting and crop maturity can be adjusted somewhat to avoid some pest damage. Breeding for resistance to these insects is the acceptable alternative to chemical control.

Screening for insect resistance under natural conditions of infection is difficult since the degree of insect pressure is difficult to control. Considerable progress has been made during the last decade in understanding the biology of sorghum stemborer, shootfly and midge, and these insects are now reared in the laboratory for use in field screening of germplasm and breeding lines at IC.

Screening techniques developed at IC have been successfully transferred to the breeding programs in Africa. Genotypes of sorghum with various degrees of resistance to stem borers and midge have been identified. It was demonstrated that midge resistance is heritable and can be incorporated into advanced breeding lines. Hybrids retain this resistance. Resistance to stem borer is genetically complex, and selected lines are being random-mated to increase resistance. Resistance to shootfly appears to be absent in the wild-weed-cultivated complex of S. bicolor. The only resistance to shootfly so far identified is in S. versicolor, S. purpureosericeum and S. dimidiatum, distant relatives of cultivated sorghum. These species do not naturally cross with S. bicolor, but hybrids can be obtained through early transfer of hybrid embryos to culture media. Although head-bugs can as yet not been successfully reared in the laboratory, insects can be trapped, and used in cage-screening. This technique allowed for the identification of genotypes with acceptable resistance to Calcoris angustatus.

Priority research in sorghum entomology at IC and ICRISAT/SADCC is to incorporate shootfly, stemborer, and midge resistance into female parents of sorghum hybrids, and to develop effective screening techniques for resistance to head-bugs. The West African sorghum program at present concentrates on developing open-pollinated cultivars resistant to these insect pests, with lower priority given to the development of resistant hybrids. The Nigeria team, however, will emphasize hybrid production when it is in place.

Pearl millet cultivars resistant to Coniesta (Acigona) stemborer and Raghuva earhead caterpillar are essential for successful cultivation of this cereal in West Africa. Laboratory rearing techniques for these insects are being developed at ISC to facilitate screening for resistance. Screening of germplasm for acceptable resistance, and incorporation of such resistance into advanced breeding lines must form an important component of pearl millet breeding in West Africa. At this time the only escape from Raghuva is to plant late maturing cultivars. It would appear as if pearl millet roots stimulate emergence from the pupal diapause. If emergence is too early no pearl millet will be in the correct stage of maturity for attack, and if emergence is too late the fully extended inflorescences are not suitable for insect development. Understanding the mechanisms of termination of the diapause developmental stage may provide information on which breeding for resistance can be based.

Stemborer, cotton stainer and beetles are other insect pests of importance on pearl millet in West Africa. Stemborer infestation is primarily from pupae surviving in dried stems. High soil temperature kills the pupae, and infection appears to come primarily from stalks used as fences or screens around villages. Infestation will probably increase if the recommend practise of incorporating stubble into the soil is adopted by farmers. Cotton stainer attacks pearl millet grain only when more favored host plants are not available. Beetles eat the anthers and stigmas. Genetic resistance to these three insects is unlikely to be found in pearl millet. They are minor insect pests, but can cause severe damage in localized areas. Farming practices to control these insect pests need to be developed.

Projects

M-518(87)IS - Studies on infestation technique and biology of Conlesta and Raghuva. M.J. Lukefahr. 1989.

S-115(85)IC - Studies on the biology, ecology and control of sorghum midge and head-bugs. H.C. Sharma. 1989.

S-116(85)IC - Studies on the population dynamics and economic thresholds for sorghum shootfly and stem borer. S.L. Taneja. 1989.

S-117(85)IC - Identification and utilization of resistance to sorghum midge and head-bug. H.C. Sharma and B.L. Agrawal. 1990.

S-118(85)IC - Identification and utilization of resistance to sorghum stem borer and shootfly. S.L. Taneja and B.L. Agrawal. 1990.

S-122(86)IC - Evaluation of sorghum cultivars for adaptability, yield potential and pest resistance in highlands of Mexico. Compton L. Paul. 1991.

Tr-S-009(87)IC - Bioecology and economic importance of the earhead bug, Calocoris angustatus on sorghum. K.F. Nwanze, and Post-doc Hirotaka Kokubo.

4c) Parasitic weeds

Striga is the only genus of parasitic weeds that cause serious damage to cereals. The genus is widely distributed in the Old World and different species attack monocotyledonous and dicotyledonous crops. The most important species that parasitize cereals are the widely distributed S. asiatica in Africa and Asia, and S. hermonthica in western and eastern Africa. Striga asiatica has two distinct races, one with white flowers primarily distributed in Asia, and the other with red flowers widely distributed in eastern and southern Africa.

There are two obvious methods of controlling Striga as a parasitic weed in cereal field. The easiest method is through improved cultural practices. These include crop rotation, hand or mechanical weeding, including the use of herbicides, and improved soil fertility. An increase in available soil nitrogen substantially reduces germination of Striga seeds. Weeding reduces the seed supply present in the soil. A more difficult but effective method is to breed Striga resistant genotypes. There are atleast two resistance mechanisms. The most common appears to be low stimulation by the tolerant host of Striga seed germination. Less common appears to be the inability of Striga seedlings to parasitize plants. A major problem is breeding for resistance is variation in virulence of Striga genotypes of the same species in association with different crop genotypes. At this time all sorghum and pearl millet hybrids are susceptible to attack by Striga. Sorghum genotypes have been identified with wide tolerance to the major races of S. asiatica or S. hermonthica, and other sorghum genotypes are available with various degrees of resistance to both of these *Striga* species. No cultivated race or genotype of pearl millet has so far been identified with acceptable tolerance to *Striga*. The close wild and weed relatives of pearl millet so far tested are also all susceptible to *Striga*.

Clearly, a package of cultural practices to include crop rotation, weeding and improved soil fertility is the most effective, immediate method of *Striga* control. Research on the most economical combination of these practices is urgently needed, and the effectiveness of these cultural practices in controlling *Striga* needs to be demonstrated to NARS extension personnel as well as directly to farmers. These activities must receive high priority in pearl millet research at ICRISAT Sahelian Center, and in the sorghum program for West Africa.

Breeding for resistance, must not be neglected. A practical constraint to rapid progress has been ineffective screening techniques. Scientists of the Indian National Program and those from ICRISAT independently screened the same sixteen thousand germplasm lines of sorghum, and identified several hundred different collections as resistant to the white flowered race of *S. asiatica*. Less than 1.0% of the genotypes selected as resistant were identified by both group of scientists. Laboratory and field techniques are being developed to effectively screen breeding and germplasm lines for resistance to *Striga*. Several germplasm lines of sorghum are resistant to *Striga*. A cultivar with acceptable yield and resistance to *Striga* has been released for cultivation in *Striga* infested areas of India, and the cultivar Framida is being successfully tested in West Africa where *S. hermonthica* is a serious weed. All released hybrids, however, are susceptible to *Striga*.

Priority research at ICRISAT center and ICRISAT/SADCC must be to incorporate resistance to *Striga* into parents of sorghum hybrids. It is essential that these breeding project include lines that were found to be resistant to *S. forbesii* and *S. hermonthica* as well as *S. asiatica*. In West Africa, breeding of open-pollinated cultivars should receive equal emphasis with breeding of *Striga* resistant hybrids.

The *Striga* project at ICRISAT center being supported by IDRC needs a change in focus. At this time the major emphasis is on developing techniques to screen for high or low production of *Striga* seed germination stimulant by sorghum. Such techniques were recently developed in France at the University of Piere and Marie Curie, where the biology of all species of *Striga* are being investigated.

Emphasis in this IC/IDRC project needs to shift to studies on mechanical and chemical mechanisms of escape by different sorghum genotypes. This will allow breeders to select genotypes with different mechanisms of resistance and breed populations with wide tolerance to *Striga* from which male and female parents as well as open-pollinated cultivars can be developed. It is also essential to determine why nitrogen in the soil prevents *Striga* seeds from germinating.

Breeding for resistance to *Striga* in pearl millet is more complex than in sorghum. Resistance may not be present in cultivated pearl millet and its close wild relatives. It is proposed that cultivars from highly infested regions be screened, rather than random samples from the available germplasm pool. It is further proposed that special collection missions be organized by the Genetic Resources Unit to highly infected areas, to seek resistance in farmers fields. The project at ISC to screen wild *Pennisetum* species for *Striga* resistance needs to continue although preliminary studies suggest that wild taxa are as susceptible to infection by *Striga* as are cultivars. Screening within the wild-weed-cultivated complex of *P. glaucum* (*P. americanum*) must take priority over screening of species that are distantly related to the cultivated complex. Gene transfer between the cultivated complex and its distant relatives will be difficult, but the possibility of such transfer needs to be explored should *Striga* resistance be found in these species. The biotechnology unit must develop techniques to transfer *Striga* resistance from *Sorghum* to *Pennisetum*.

Projects

S-102(85)IC - Resistance to *Striga asiatica*. P.K. Vaidya. 1990.

M-516(86)IS - *Striga hermonthica* : Biology, screening and resistance identification. J. Werder. 1989.

S-803(86)SD - Screening/evaluating of sorghums and millets resistant to *Striga*. A.T. Obilana. 1989.

5. PLANT NUTRITION

Low soil phosphorus levels are important factors in the SAT limiting yield in farmers fields. These deficiencies can be overcome by supplying fertilizers to the soil. Fertilizers are often not available to the subsistence farmer. Studies have shown that certain bacteria associated with sorghum and pearl millet roots fix nitrogen in the rhizosphere. The level of fixation, however, is low and unpredictable, with the amount of nitrogen fixed rarely exceeding a few kg of N per hectare. Agronomic exploitation of such associative nitrogen fixation does not seem possible without drastic genotypic changes in these cereal crops and/or the bacteria associated with their roots. For these reasons studies started in 1976 to study the biology and effectiveness of associative N_2-fixation in sorghum and pearl millet were terminated in 1987.

Research in the microbiology unit is shifting to studies on the effects that microorganisms have on uptake of nutrients by plants from the soil. The present project on vesicular-arbuscular mycorrhiza (VAM) is being expanded to study the effect of these organisms or uptake of otherwise unavailable phosphorus. Lack of available phosphorus is a major limiting factor in cereal yields across Africa.

Agronomic studies in the cereals program at IC on plant nutrition need to be combined with those in the Resource Management Program at IC.

Projects

M-131(85)IC - Vesicular arbuscular mycorrhiza (VAM) development in pearl millet and sorghum in the SAT and the response to inoculation. K.K. Lee. 1988-1989.

M-139(87)IC - Evaluation of genotypic variability in cereals for efficient absorption of phosphorus and other related nutrients under a limited level of available soil phosphorus. K.K. Lee. 1990.

6. PLANT ADAPTATION

6a. Drought stress

Probably the major limitations to crop production in the SAT are limited rainfall for crop growth and the associated high temperature because of high levels of radiation and reduced evaporation of water from soils and crop canopies. Farmers sow into warm, dry soils at the beginning of the season. A break in the rains after sowing can subject seedlings to severe dessication and lethal soil temperatures (upto 55 C). Long periods without rain during the season result in the loss of leaf area, disruption of the reproductive process, and cessation of crop growth. Inadequate moisture during grain filling results in shortened grain filling periods, poorly filled grains and often severe crop losses.

While there are numerous opportunities to maximize moisture availability to SAT crops through agronomic practices, tolerance of moisture and temperature stress is an essential component of varietal adaptation to SAT environments. This has become evident in studies of traditional landraces, which are often more tolerant to severe stress conditions, and consequently some times more productive than modern cultivars. It may not be possible to improve on the tolerance of these landraces, but the incorporation of such tolerances into modern varieties is essential to assure that their performance on farmers' fields is in no way inferior to that of the traditional landraces. The selection for, or the incorporation of such tolerance to environmental stress is thus an essential part of ICRISAT's cereal breeding programs.

Research at IC during the last decade was designed to understand the effects of drought on sorghum and millet, and to develop methods for effective screening of genotypes for efficient crop establishment, and tolerance to heat and moisture stress. Such sreening techniques are now in use, and research emphasis is on understanding the physiology and heritability of seedling emergence and survival under stress, recovery from midseason stress, and grain production under terminal stress.

Seedling emergence rates in the sandy soils of the Sahel are generally adequate, but seedling survival may be low under conditions of extreme soil temperatures. In India, poor emergence may be as large a factor in poor stands as is seedling survival. Initial studies suggest that there is considerable genetic variation for both factors. The characteristics that enhance both emergence and survival need to be studied to make the present empirical screening of breeding materials more effective and perhaps more efficient.

Studies on pearl millet indicate that the crop has good recovering ability from midseason stress, due primarily to its asynchronous tillering habit. Yield losses due to terminal stress are much more serious. Genotypic differences in tolerance exist, apart from differences in drought escape, and are associated with better grain setting and filling under stress conditions. Investigations are underway into reasons for such differences. At the same time, two composites are under selection for grain setting and filling ability under terminal stress by utilizing an off season "drought nursery". Efforts to select for tolerance of terminal stress in early hybrids, specially for short growing season environments need to increase.

In sorghum, sets of genotypes resistant and susceptible to midseason water and temperature stress conditions have been identified during hot summer season at Patancheru, and during normal rainy season at Anantapur, a chronically drought-prone location in India. Physiological investigations with such sets of lines showed marked differences with respect to leaf-water potential, relative water contents, root/shoot ratio, osmotic adjustment, proline accumulation, and capacity to recover once the midseason stress is terminated either by irrigation or rain. With our recently built rain-out shelter it will be possible to carry out similar studies at Patancheru during the normal growing season itself. Further studies will be aimed at clarifying factors governing leaf rolling, nature and role of substances that may be important in maintaining cellular integrity under stress, and in elucidating the interaction between temperature and water stress on leaf-water retention and growth.

Sorghum is an important crop in India during the post rainy season, when plants have to mature on stored soil moisture. Understanding the ability of some genotypes to tolerate terminal stress better than others are essential in improving yield potential of rabi sorghums.

Crop growth environments during rabi are being characterized and physiological characteristics associated with stable and high yields such as appropriate phenology, leaf-area development, non-senescence, and efficient root systems are being studied. Investigations on carbon and water economy in relation to crop productivity, senescence, and predisposition to root and stalk rots will receive highest priority for future research.

Projects

M-122(85)IC - Identification and assessment of drought resistance. V. Mahalakshmi. 1989.

M-135(86)IC - Improvement of pearl millet for better crop establishment. P. Soman and L.K. Fussell. 1989.

M-519(87)IS - Evaluation of pearl millet for tolerance to terminal drought in West Africa. L.K. Fussell and F.R. Bidinger. 1990.

S-107(85)IC - Factors affecting seedling emergence and survival from environmental stress. P. Soman. 1990.

S-108(85)IC - Factors affecting plant survival from mid-season stress. J.M. Peacock. 1989.

S-109(85)IC - Factors affecting plant productivity under terminal stress. N. Seetharama. 1989.

6b. Photoperiod response

The matching of variety maturation to the duration of the growing season is the basis of genotype adaptation in the SAT. Varieties that flower too early may face serious problems of panicle insect damage, grain molding, and bird damage. Varieties that flower too late may not have sufficient moisture available to fill grains and may have problems with stalk rots and lodging.

For NARS whose breeding programs are located in the area in which the varieties produced are to be grown, the selection for a desirable photoperiod response occurs naturally as a consequence of selection for an appropriate maturity for that location. For ICRISAT, which is producing genetic material for use in a wide range of latitudes, and therefore in a wide range of daylengths, selection in one daylength for a photoperiod response appropriate to other daylengths is not straight forward. Also, as ICRISAT utilizes a wide range of germplasm from a variety of origins, genetic material produced by its breeding programs contain genotypes with a wide range of photoperiod response.

The problem takes different specific forms in different regional programs. Products of crosses using West African parental materials from 12-14 N (13.7 hr daylength on July 1) will flower sufficiently early in Hyderabad (17 N and 14.0 hr on July 1) but may be late to flower at Hisar (29 N and 14.9 hr on July 1). So ICRISAT Center pearl millet material need to be screened for low photoperiod sensitivity to allow them to flower early enough in the short season millet growing of North West India.

Material bred at the SADCC/ICRISAT Center in Bulawayo are intended for a restricted range of latitudes, where day and season length does not change a great deal, so photoperiod response is not of great concern, with one exception. This is Tanzania, where pearl millet and sorghum are grown in an area of 5-10 S latitude in a relatively long growing season (100-120 days). Material selected in Bulawayo (20 S latitude and 14.1 hr daylength on January 1) flower too early for Tanzania (13.3 hr daylength on January 1). As all pearl millet will flower early in these short daylengths, the requirement here is for a long vegetative period. Such material, if it is also photoperiod sensitive, will flower very late when grown in the longer daylengths at the SADCC/ICRISAT Center. Selection of such material is difficult at Bulawayo, as it is basically selection for unadapted material.

The problem is most acute in West Africa, where season length changes markedly over a small range of latitude, and cultivars are highly daylength sensitive. Season length has been estimated to change at the rate of 22 days for each degree of latitude, which is equal to a difference of 85 days between 10 N and 14 N in a transect from central Nigeria to southern Niger. In this situation, a strong degree of local adaptation by a very specific photoperiod response is needed to assure a proper duration for each degree of latitude.

Selection therefore with respect to photoperiod response in pearl millet in the three regional ICRISAT breeding centers will be for a low degree of response at IC, for a range of specific responses at ISC, and for a long vegetative period for Tanzania in SADCC. This differential selection is presently being done at IC with the use of an extended daylength nursery which simulates the daylength in northern India, at ISC by breeding different material in and for different latitudes, and at the SADCC/ICRISAT Center by having separate programs for Tanzania and the rest of the region.

Research to learn more about the physiological and genetic nature of photoperiod response, and crop duration in general, is needed to devise effective means of selecting genotypes in regional centers that will have the proper adaptation to ranges of latitudes and season lengths in regions which the centers service.

<u>Projects</u>

M-119(85)IC - Control of flowering by photoperiod. F.R. Bidinger. 1990.

M-505(86)IS - Study of photoperiod sensitivity of full season millets. S.N. Lohani. 1990.

6c. Yield physiology

Pearl millet, in contrast to sorghum, has been very little studied, and not enough is known about the determinents of grain yield in the crop. The cereals program maintains a modest effort in the form of a joint physiology-breeding project to develop and test hypotheses on yield determinents in the crop. The project has examined the usefulness of increasing productive tiller number in West African phenotypes, the response to selection for increased panicle surface area and increased grain size, the problems of grain filling in dwarf cultivars, and the effects of the lengths of different growth stages on yield.

Similar research is underway for rabi sorghums that are grown under very different daylength and temperature conditions than rainy season sorghums, and for which yield determining processes may be different. The sorghum studies are designed to eventually modify the present sorghum growth model (SORGF) for rabi conditions and rabi-adapted varieties.

Projects

M-110(85)IC - Evaluation of specific characters and hypothesis relating to yield and yield stability. F.R. Bidinger and K.N. Rai. 1990.

7. NUTRITION AND CONSUMPTION

Sorghum and pearl millet are cereals of necessity not of choice. Wheat, rice or maize are grown, wherever possible, in preference to sorghum and pearl millet. The only advantage of the last mentioned two cereals over the others are that they will grow, and produce a harvest under conditions of heat and moisture stress where the other cereals will fail.

Research is centered around (1) maintaining grain quality in high yielding open-pollinated and hybrid cultivars, (2) improving grain quality where possible for traditional uses of these cereals, and (3) finding alternate uses for the grains of these cereals.

Projects

M-132(85)IC - Evaluation of food quality characters and physico-chemical properties of pearl millet. V. Subramanian and Pheru Singh. 1992.

S-106(85)IC - Evaluation of food and nutritional qualities of sorghum. D.S. Murthy. 1989.

8. RESEARCH ON CONCEPTS AND PROCEDURES

It is essential that data from trials and nurseries are comparable from one year to the next.

Projects

M-121(85)IC - Repeatability and applicability of drought nursery results (joint project with AICMIP). V. Mahalakshmi. 1990.

9. EXPLORATORY RESEARCH

9a) Development of techniques

Techniques to efficiently screen for resistance to various biotic and abiotic stresses are continuously being improved as the biology and genetics of tolerance to these stress factors become better understood. Effective screening techniques for tolerance to the insect pest Raghuva are urgently needed.

An effective technique is needed to genetically transform sorghum and pearl millet with selected exogenous genetic material. A technique was developed for transformation of maize that uses germinating pollen (male gametophytes) as vehicles to transport transforming DNA to the embryo sac. Modifications to this technique for success with sorghum and pearl millet are being developed. It is also essential for the biotechnology unit to develop methods for successful regeneration of functional plants from protoplasts of sorghum and pearl millet. The development of haploids would be beneficial in studying the genetics of resistance to various stress factors.

Projects

Tr-S-XXX(87)IC - Identification and characterization of sorghum and pearl millet viruses. S.B. King, L.K. Mughogho, D.V.R. Reddy and Postdoc.

Tr-S-XXX(87)IC - Transfer of shootfly resistance from parasorghum to grain sorghum through genetic transformation. J.M.J. de Wet and Postdoc.

Tr-M-XXX(87)IC - The use of dihaploids to study the genetics of downy mildew resistance in pearl millet. J.M.J. de Wet and Postdoc.

9b) Basic investigations

Basic research is being conducted, wherever necessary, in cooperation with institutes having facilities and expertise not available at IC. These include studies on the molecular biology of heat and drought stress, biology of infection by selected fungal pathogens, characterization of viruses that may serve as universal gene transfer vectors, and development of a restriction fragment library of the sorghum and pearl millet genomes.

Projects

M-138(87)IC - Identification of biochemical yield limiting traits in cereals. S.P. Wani. 1989.

CO-M-2(87)IC - Study of pathogenic variation in downy mildew of pearl millet. S.B. King and Postdoc. 1990.

Tr-S-XXX(87)IC - Restriction fragment mapping of the sorghum and pearl millet genomes. J.M.J. de Wet and Postdoc.

F. COOPERATION WITH NARS

1. TECHNICAL ASSISTANCE

Technical assistance to NARS is provided through short term assignments of IS scientists to ICRISAT regional programs where these scientists train NARS scientists in screening and breeding techniques. Further assistance is provided through cooperative research projects and training.

2. COORDINATION OF NETWORKS

Cereal research teams have been established in southern, eastern and West Africa, and in Mesoamerica to coordinate regional research and cooperation with and between NARS of cooperating countries.

Projects

M-511(86)IS - Regional and international cooperation. S.O. Okiror. 1990.

M-804(87)SD - Cooperative regional millet evaluation program. S.C. Gupta. 1992.

3. HUMAN RESOURCE MANAGEMENT

3a) Short term training

In service trainees and apprentices in the Training Program may select to do a research project, and receive training in any one of the cereals research units.

3b) Visiting scientists

Scholars are recruited as needed to spend from a few days to several months in the program to familiarize project scientists with new research procedures, or to help establish new research initiatives.

3c) Post-doctoral fellows

Post-doctoral fellows are recruited to help initiate new research project, or to assist in established research projects at IC. The cereals program plans to make extensive use of post-doctoral fellows in the biotechnology unit.

3d) Research scholars

Research scholars do their thesis research under the direction of senior scientists in the Cereals Program. They are recruited through the training program.

6. CONFERENCES AND WORKSHOPS

a) Field days

International sorghum and millet field days alternate annually. Scientists from countries in Africa, Asia and the Americas are invited to these field days. Field days consist of visits to research fields where experiments are discussed, followed by more formal general discussions. This provides NARS scientists with opportunities to request seed of selected breeding lines, open-pollinated cultivars and hybrid parents, and to suggest directions of research that may benefit their programs. Field days also provide opportunities for NARS scientists from various countries to become familiar with activities in other countries.

b) Workshops

One international workshop is organized each year. Proposed workshops for the next six years are:

1988 : International Workshop on Sorghum and Millet Diseases (SADCC)
1989 : Problems of Crop Establishment in Cereals (ISC)
1990 : Sorghum in the Nineties (IC)
1991 : Millet Diseases Workshop (IC)
1992 : Sorghum and Millet Improvement using Population Breeding Methods (IC)
1993 : Breeding Pearl Millet for Arid Zones (ISC)

Regional workshops dealing with selected regional problems are organized primarily as a training tool.

c) Consultants

Consultants are recruited to advise on selected research problems and projects. They visit IC individually or form part of workshops.

A. RESEARCH PRIORITIES

Research priorities, center or network where research is receiving priority attention, and expected time when initial research can be completed are listed. Research is divided among first priority, second priority and research support activities. Within these three categories, research is divided by type of activity rather than priority. The abbreviations translate as IC=ICRISAT Center, ISC=ICRISAT Sahelian Center, SADCC=ICRISAT Southern Africa Team, WASP=ICRISAT West Africa Sorghum Project, EARSAM=ICRISAT Eastern Africa Sorghum and Millet Network, MAS=ICRISAT Mesoamerican Sorghum Network, and CCRN=Cooperative Cereals Research Network.

I. FIRST PRIORITY

1. **Breeding sorghum and pearl millet open-pollinated varieties and hybrid parents with multiple resistance to yield limiting factors (IC, ISC, SADCC, WASP, EARSAM, MAS)**

2. **Grain mold resistance in sorghum (IC, WASP)**
   Study biology of causal fungi (long-term)
   Population breeding approach to improve resistance (1989)
   Transfer of resistance into male sterile and pollen parents (1991)

3. **Root and stalk rots resistance in sorghum (IC, WASP, SADCC)**
   Study biology of causal fungi (long-term)
   Select for stalk quality and non-senescence (1988)
   Transfer traits into hybrid parents (1991)

4. **Downy mildew resistance in pearl millet (IC, ISC)**
   Study biology of *Sclerospora graminicola* (long-term)
   Study host-pathogen interaction (long-term)
   Improve resistance in breeding lines, open-pollinated cultivars and hybrid parents (continuous)

5. **Stem borer resistance in sorghum (IC, SADCC)**
   Study mechanisms of resistance (long-term)
   Population breeding approach to improve resistane (1989)
   Transfer resistance into breeding lines (1992)

6. **In pearl millet (ISC)**
   Develop mechanisms to rear *Raghuva* in the laboratory (1988)
   Screen germplasm for resistance (1990)
   Study mechanisms of resistance (1990)
   Introduce resistance into breeding lines (1993)

7. **Shootfly resistance in sorghum (IC)**
   Use biotechnological techniques to transfer resistance from Parasorghum to breeding lines (1989)
   Improve agronomic fitness of resistant lines (1991)
   Transfer resistance into hybrid parents (1993)

8. **__Striga__ control through improved farming practices (ISC)**
   Determine effects of weeding and soil fertility on control (1989)
   Develop effective cultural control methods (1989)

9. **in sorghum (IC, WASP, SADCC)**
   Screen lines identified as resistant to __S. asiatica__ (India) for resistance to __S. asiatica__ (Africa), __S. hermontica__ and other __Striga__ species (1989)
   Screen local germplasm for resistance to African __Striga__ species (1990)
   Incorporate resistence into African sorghum breeding lines.(1993)

10. **__Striga__ resistance in pearl millet (ISC, IC)**
   Screen local germplasm for resistance (1990)
   Screen wild relatives for resistance (1990)
   Use biotechnological techniques to transfer resistance from wild species or sorghum into pearl millet (1993)
   Transfer resistance into breeding lines (long-term)

11. **Seedling establishment and survival under stress in pearl millet (ISC, IC)**
   Study mechanisms of emergence and survival (1989)
   Introduce tolerance to heat and drought stress from selected local landraces into breeding lines (1993)

12. **Develop techniques for plant regeneration from cells, protoplasts and immature embryos, and for genetic transformation of sorghum and pearl millet (IC)**
   Plant regeneration from cells and protoplasts (1990)
   Embryo rescue (1988)
   Genetic transformation (1989)

13. **Improve the food quality of sorghum (IC, SADCC)**
   Screen breeding lines for grain quality (continuous)

14. **Ability to fill grain during late season stress in pearl millet (IC, ISC)**
   Study the ability to set seed under stress (1990)
   Determine the mechanisms involved (1990)
   Transfer or select for these mechanisms into breeding lines (1993)

II. __SECOND PRIORITY__

1. **Rust resistance in pearl millet and sorghum (IC)**
   Study the biology of __Puccinia penniseti__ (1989)
   Identify and utilise resistance in breeding (continuous)

2. **Ergot resistance in pearl millet and sorghum (IC, WASP, SADCC,**
   Study the biology of __Claviceps fusiformis__ and __Sphacelia sorghi__ (1989)

Investigate the feasibility of introducing resistance into hybrids and open-pollinated cultivars (1991)

3. **Downy mildew and anthracnose resistance in sorghum (IC, SADCC)**
   Study the biology and epidemiology of *Peronosclerospora sorghi* and *Colletotrichum graminicola* (1990).
   Developing breeding lines with tolerance (1990).

4. **Grain smut resistance in pearl millet (ISC, IC)**
   Study the biology of the pathogen and mechanisms of resistance (1990)
   Identify and utilise resistance in breeding (continuous)

5. **Leafblight resistance in sorghum (SADCC)**
   Screen germplasm for resistance (1990)
   Transfer resistance into breeding lines (1995)

6. **Sooty stripe and grey leaf spot resistance in sorghum (WASP)**
   Screen germplasm for resistance (1990)
   Transfer resistance into breeding lines (1995)

7. **Virus resistance in sorghum and pearl millet (IC, EARSAM, SADCC)**
   Identify and characterize viruses of importance (1989)
   Identify means of viral transfer (1990)
   Identify and utilize resistance in breeding (1993)

8. **Midge resistance in sorghum (IC, WASP)**
   Improve yield potential of resistant breeding lines (1989)
   Transfer resistance into hybrid parents (1992)

9. **Head bug resistance in sorghum (IC)**
   Use a population breeding approach to increase tolerance to *Calocoris angustatus* (1990)
   Study mechanisms of resistance (1990)
   Transfer resistance into breeding lines (1995)

10. **Stemborer resistance in pearl millet (ISC)**
    Study the source of infection (1988)
    Develop techniques for laboratory rearing (1988)
    Identify and transfer resistance genes into breeding lines (long term)

11. **Recovery from drought and heat stress in sorghum (IC, WASP)**
    Study the genetics of recovery mechanisms (1989)
    Introduce recovery mechanisms into breeding lines (1992)

12. **Determinants of yield in pearl millet (IC)**
    Study the correlations between different yield components and developmental cycle (1990)
    Use this information to improve selection methods for yield potential (1993)

13. **Uptake by cereals of limited mineral nutrients (IC, ISC)**
    Study the rhizosphere in relation to mineral nutrients and microorganisms including mycorrhiza (1990)

Enhance the beneficial effects of mycorrhiza through manipulation of the mycorrhizal genome (1993)

Investigate the possibility of breeding pearl millet for more efficient uptake of mineral nutrients (1993)

III. RESEARCH SUPPORT ACTIVITIES

1. Collect, maintain and characterise germplasm of pearl millet and sorghum (IC, ISC)

2. Convert germplasm collections with selected fitness traits into acceptable breeding lines (IC, ISC, MAS, SADCC)

3. Improve screening techniques for resistance of sorghum and pearl millet to various biotic and physical stresses (IC, ISC, SADCC, WASP)

4. Screen germplasm lines when needed, and breeding lines routinely for tolerance to stress (IC, ISC, SADCC, WASP, EARSAM, MAS)

5. Population improvement by recurrent selection to derive open-pollinated varieties and hybrid parents (IC, ISC, SADCC, WASP, EARSAM, MAS)

6. Screen advanced breeding lines and cultivars of sorghum and pearl millet from all ICRISAT cereals programs across the SAT in selected locations (CCRN).

7. Maintain collections of male sterile lines and restorer lines of sorghum and pearl millet with acceptable ranges of phenotypic variation (IC, ISC, SADCC).

8. Meet requests for seed from NARS and the private sector (IC, ISC, WASP, EARSAM, MAS).

B. INTRODUCTION

The responsibilities of the different cereals research programs, teams and networks of ICRISAT extend across Asia, Africa and Mesoamerica. Regional responsibility is divided among the cereals program at IC (Asia), the millet program at ISC (West Africa), the West Africa sorghum team in Nigeria and Mali, the sorghum and millet network in Zimbabwe (SADCC), the sorghum and millet network in Kenya (EARSAM), and the sorghum team in Mexico (Mesoamerica).

The first fifteen years of cereals research at ICRISAT Center (1972-87) concentrated on developing and refining techniques to screen for various biological and physical stress factors, assembling germplasm, identifying genotypes with desirable agronomic traits from among germplasm collections, and diversifying the genetic base of selected breeding populations. These activities were very successful. Screening techniques were developed or refined at IC, and screening for resistance to many major pathogens, pests and other environmental stresses have become routine. ICRISAT breeding material are being used by national programs in a number of Asian, African and American countries, and several cultivars developed at IC found rapid and wide spread acceptance with farmers in the SAT.

During the next six years (1988-93) research emphasis at IC will shift from adaptive to strategic research. Screening of accessions from GRU for useful agronomic traits will receive less attention than screening of breeding lines for superior agronomic fitness. Emphasis will be on understanding the mechanisms of resistance to diseases and pests, and of tolerance to heat and drought stresses, and the use of this information to improve screening and breeding methods. Breeders at IC will concentrate on breeding open-pollinated varieties and male sterile and pollen parents of superior quality that incorporate tolerance to biological and physical stresses, for use by national programs and by ICRISAT regional research programs, teams and networks. New open-pollinated and hybrid cultivars will continually be produced by IC breeders.

International screening and testing of breeding material and cultivars will be consolidated into a Cooperative Cereals Research Network (CCRN). Advanced breeding material and cultivars from IC and ISC, and from regional ICRISAT programs and networks will be combined and tested across a range of agro-climatic zones, and the best genotypes will enter into cooperative trials and nurseries with national agricultural research systems (NARS) of participating countries. This will reduce unnecessary duplication of trials and nurseries, and give NARS scientists direct access to the best breeding material available in ICRISAT research programs. The network will encourage adoption of selected cultivars by farmers.

C. FACILITIES AT ICRISAT CENTER

Space available at ICRISAT Center for basic, strategic and adaptive research is extensive (Table 1). The new biotechnology unit will share laboratory space with biochemistry. Biochemistry at this time has 8340 sq. ft. of laboratory and office space. It is anticipated that funds will be made available by the Asian Development Bank to remodel about 2810 sq. ft. of this laboratory space, and to purchase the necessary equipment to use this facility as a cereal biotechnology laboratory. The adjacent 340 sq. ft. now occupied by sorghum breeding will be incorporated into this laboratory as a tissue culture facility. Other modifications required within the next two years will involve improvement of long-term storage facilities for breeder seed, and development of laboratory facilities to screen seedlings for resistance to disease, particularly pearl millet downy mildew.

New capital development needs for the next two years are to construct a 65 sq. m greenhouse divided into bays for seed production of pearl millet breeding material in isolation. This will allow breeders to rapidly advance breeding lines by growing three generations each year under total isolation. New and replacement capital equipment needs will in part be met through provisions in the third phase of a UNDP special grant. ICRISAT center is fifteen years old, and several pieces of important equipment need to be replaced because they have become obsolete.

We have screening and testing facilities in India at the sub-stations Hisar, Dharwad, Ananthapur and Bhavanisagar, and facilities for field trials at Aurangabad, Gwalior, Mysore, Akola, Bijapur, Panthnagar and Nandyal. Soil salinity is a serious problem at Hisar. A facility for pearl millet field trials is urgently needed in Rajasthan. Cultivars produced at IC are commonly too late in maturity for successful cultivation in this major millet growing region of India.

Research facilities are under construction at Motopos in Zimbabwe (ICRISAT/SADCC) and at Sadore in Niger (ISC). Funds have been made available to develop research facilities in Nigeria and Mali for the West African Sorghum program. Funds are being sought for experiment station development and construction for the Eastern Africa sorghum and millet network.

Table 1. Laboratory, office, storage and green house space at ICRISAT Center, 1987.

Bldg. No.	Major use	Area in Sq. m	Area in Sq. ft.
300	Laboratory	1,463	15,743
	Office	206	2,215
	Store	38	404
301	Laboratory	1,324	14,242
	Office	383	4,120
302	Laboratory	1,283	13,805
	Office	424	4,557
303 GF	Laboratory	204	2,199
	Office	931	10,017
303 FF	Laboratory	390	4,195
	Office	745	8,021
304	Crop Work Area	1,048	11,280
305 GF	Laboratory	191	2,053
	Office	628	6,761
	Short term storage	186	1,999
	Herbarium	52	555
	Medium term storage	206	2,221
	long-term storage	155	1,666
305 FF	Laboratory	318	3,422
	Office	1,036	11,148
	Storage	64	684

Bldg. No.		Area in Sq. m	Area in Sq. ft.
308	Crop Work Area	4,018	43,233
	Seed Driers	84	904
	Seed Stores	76	813
309	Laboratory	1,407	15,138
	Office	298	3,210
	Store	81	868
310	Greenhouse (300 x 5)	1,500	16,140
311	Screenhouse (300 x 2)	600	6,456
	New Glasshouse No.8	222	2,391
	Store rooms	60	641
	New Glasshouse No.9	238	2,557
315	Laboratory PQ	81	876
	Office	136	1,465
	Store	25	268
Total	Laboratory	6,661	74,700
	Office	4,788	51,534
	Stores	266	2,867
	Seed storage	758	8,161
	Crop work area	4,018	43,250
	Greenhouse	2,560	27,555

GF-Ground Floor, FF-First Floor, PQ-Plant Quarantine

D. STAFF

The number of approved permanent positions in the cereals program at IC (Table 2) will remain essentially stable through 1993. During 1987 a new position as coordinator of the CCRN was approved, and this vacancy will be filled in early 1988. A position that became vacant in the program when the sorghum and millet programs were merged into the cereals program in 1986 is being used to recruit a cereal biotechnologist. Reorganization within the program will allow for adequate office and research support staff for biotechnology and the CCRN. One national scientist will transfer from microbiology to biotechnology in 1988, and research assistants with interest in biotechnology are being sent for training in selected techniques at European and American laboratories before they join this research unit.

The program plans to make extensive use of postdoctoral research fellows, and of short term visiting scholars to introduce new techniques and initiate new research at IC. Cooperation with regional ICRISAT programs is being increased. Staff from IC will develop cooperative projects with staff in regional and national programs where expertise is needed. To keep IC scientists familiar with new developments in their respective fields, funds will be needed to allow them study leave for up to four months in selected laboratories. New projects will be funded through special grants.

The network in Eastern Africa and the team in Mesoamerica are administratively directed from the program office at IC. The Mesoamerica team includes an agronomist who is also team leader, a breeder and an associate breeder, and support staff. The breeder transferred to the Eastern Africa network as coordinator in 1986 and we hope to have a new breeder in place by early 1988. The Eastern Africa network is being supported by a SAFGRAD grant. It includes the coordinator/breeder and an agronomist/breeder that is being recruited and should be in place in early 1988.

Table 2. Cereal staff at ICRISAT center approved for 1988.

Research unit	PS	NS	RA	FA	AS	DGA	FAT
Breeding							
Sorghum	1	4	6	16	2	2	2
Millet	1	4	10	15	2	2	5
Pathology							
Sorghum	1	2	4	5	1	1	2
Millet	1	2	5	4	1	1	3
Physiology							
Sorghum	1	2	4	4	1	1	4
Millet	1	2	2	6	1	1	4
Entomology	1	2	4	5	1	1	4
Microbiology	1	2	5	7	1	1	1
Biotechnology	1	0	0	0	0	0	0
CCRN	1	0	0	0	0	0	0
Genetic Resources	0	2	0	0	0	0	0
Program office	1	0	2	0	5	1	0
Total	11	22	42	63	15	11	27

PS-Principal Scientist, NS-National Scientist, RA-Research Associate FA-Field Attendant, AS-Administration and Office staff, DGA-Driver/General assistant, FAT-Field attendant.

The program in Southern Africa (ICRISAT/SADCC) includes the executive director/project manager, a sorghum breeder, a millet breeder, a cereal pathologist, a cereal agronomist, a cereal entomologist, and their support staff. In West Africa the program is divided into millets at ISC and a sorghum program (WASP) presently based in Burkina Faso. The sorghum program is to be moved as a split team to Nigeria and Mali in 1988. The cereals team at ISC includes two breeders, two agronomists, an entomologist and a pathologist. In addition they are assisted by two geneticists funded by ORSTOM (Institut Francais de Recherche Scientifique pour le Developpement en Cooperation, France and a genetic resources botanist associated with IBPGR (International Board of Plant Genetic Resources). There are also an agroclimatologist and the usual support staff to assist cereal scientists at ISC. The team in Burkina Faso include three sorghum breeders, a millet breeder and a cereal pathologist. A USAID project supports a millet breeder and cereal agronomist in Mali. It is anticipated that the WASP program will be enlarged in 1988 by an addition of four scientists (agronomist, breeder, physiologist, and weed scientist) through cooperation with CIRAD (Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement, France).

Table 3. Cereal scientists at ISC and in ICRISAT regional programs (1987)

Research area	ISC	WASP	SADCC	EARSAM	MAS	MALI
Agronomy	2	0	1	1	1	1
Breeding	2	4	2	1	2	1
Entomology	1	0	1	0	0	0
Pathology	1	1	1	0	0	0

ISC=ICRISAT Sahelian Center; WASP=West African Sorghum Program; SADCC=SADCC/ICRISAT based in Zimbabwe; EARSAM=Eastern Africa Sorghum and Millet Program; MAS=Mesoamerican Sorghum Program; MALI=Mali Sorghum and Millet Program.

E. RESEARCH

1. GERMPLASM

1a) Conservation and diversity

Seed of new collections are multiplied under plant quarantine inspection and entered into long term seed storage banks. Collections are planted for general seed increase or rejuvination of seed as needed. A series of useful or curious mutations have been identified in both sorghum and pearl millet. The genetics of these are being studied. Among useful mutations are new sources of cytoplasmic male sterility, and new dwarfing genes in pearl millet. These agronomically useful traits need to be incorporated into breeding lines.

1b) Collection

The germplasm bank at ICRISAT contains 28,072 accessions of sorghum and 18,148 of pearl millet. Collection is continuing in priority regions of the world. Collection of genotypes that appear tolerant to specific stress factors in their natural habitats, is to receive special attention. Particularly important is tolerence of pearl millet onto *Striga*, *Raghuva*, and *Coniesta* (*Acigona*) in areas of natural infection.

Projects

GR-102(85)IC - Assembly of sorghum germplasm from other germplasm centers and collection within India. K.E. Prasada Rao. 1989.

GR-104(85)IC - Assembly, maintenance and evaluation of minor millets germplasm. K.E. Prasada Rao. 1989.

GR-105(85)IC - International cereal germplasm exploration and collection. Melak H. Mengesha, K.E. Prasada Rao and S. Appa Rao. 1989.

GR-107(85)IC - Collection of pearl millet germplasm in India. S. Appa Rao. 1989.

1c) Characterization and documentation

Collections are classified by species, subspecies and race as they are received, and passport data as proposed by IBPGR are recorded. Data are stored on computer files.

Characterization and documentation of new collections are continuing activities. Scientists of the genetic resources unit must identify collections with resistance to various stresses or with exceptional yield potential. Random screening of all available germplasm is no longer necessary.

Projects

GR-101(85)IC - Maintenance, evaluation, and documentation of sorghum germplasm. K.E. Prasada Rao. 1989.

GR-106(85)IC - Pearl millet germplasm evaluation and maintenance. S. Appa Rao. 1992.

GR-108(85)IC - Evaluation of selected pearl millet germplasm under different environmental conditions in India and Africa. M.H. Mengesha and S. Appa Rao. 1992.

M-133(86)IC - Joint experiments on selection and evaluation of genetic material in India and West Africa. S.B. Chavan, J.R. Witcombe and K. Anand Kumar. 1990.

M-509(86)IS - Germplasm evaluation. S.O. Okiror. 1990.

M-517(86)IS - Genetic structure of Pennisetum species. L. Marchais and S. Tostain. 1989.

1d) Enhancement

Conversion of collections with agronomic potential to genotypes that are of immediate use in breeding projects must become a major part of the research activities in the genetic resources unit. Several projects are under way to transfer useful traits of sorghum and millet germplasm into breeding lines. Attempts are also under way to transfer shootfly resistance from wild species of Parasorghum to grain sorghums through culture of hybrid embryos on artificial media soon after fertilization.

Projects

GR-103(85)IC - Introgression of useful genes from wild species and distantly related landraces of sorghum. K.E. Prasada Rao and K. Leuschner. 1989.

S-105(85)IC - Conversion of valuable tropical sorghums into desirable and readily usable types. P.K. Vaidya. 1990.

1e) Breeding and genotype improvement

Breeding is the largest research unit in the cereals program, with about fifty percent of the budget assigned to it. Breeding is a collaborative research effort involving not only breeders, but scientists from all other units in the cereals program, the genetic resources unit and the biochemistry unit. These research units support breeding by providing basic information and screening techniques on which selection for resistance to pests, diseases, heat and drought and yield potential is based.

Enlarging the genetic base of breeding population has been, and still remains a major activity in the sorghum and millet breeding units. Breeding material in various stages of refinement are being screened for resistance to stress across the SAT, and selected lines are made available to ICRISAT regional programs, NARS scientists of cooperating countries, and to public and private seed companies. Emphasis is placed on breeding high yielding hybrids and open-pollinated cultivars that are resistant to diseases and pests in specific regions and agro-ecosystems. As an example, most public sector pearl millet hybrids now grown in India are based on ICRISAT male sterile parents that are resistant to downy mildew. Several of these inbreds also show promise in southern Africa. Similarly, IC sorghum breeding lines with resistance to Striga are widely used in breeding projects in West Africa. Indeed, IC breeding lines of sorghum form part of breeding programs in countries across Asia, Africa and Mesoamerica where ICRISAT has regional programs. ICRISAT Center breeding lines of pearl millet are poorly adapted to the Sahel environment. Breeders at ISC are therefore improving breeding populations that include West African local landraces.

The breeding units at IC produce open-pollinated cultivars and hybrids ready to be handed over to public and private seed industries. Although this is not a primary objective of the Cereals Program at IC, production of cultivars is an automatic and useful byproduct of population improvement, breeding line selection, and development of male sterile and pollen parents for hybrid seed production. The program regularly submits one or more of its open-pollinated as well as hybrid cultivars to AICPMIP or AICSIP (All India Coordinated Pearl Millet and Sorghum Improvement Projects) trials, as well as to international trials organized by the program at IC in cooperation with regional cooperators. Cultivars of sorghum produced at IC are grown across India, and those produced by ICRISAT Center and its regional programs are grown in West Africa, the Sudan, Southern Africa and Mesoamerica.

All new hybrids and open-pollinated cultivars of pearl millet being released in India are resistant to downy mildew. A newly identified recovery resistance trait is being tested for possible introduction into breeding lines. Total resistance to this or any other disease eventually breakes down, due to changes in virulence of the pathogen. It is hypothesized that since infection does occur, but plants develop immunity to the disease, pressure on the pathogen to increse its virulence may be reduced, and the useful life span of cultivars with recovery resistance may be prolonged.

The potential yield of new pearl millet hybrids under ideal conditions is over six tons per hectare. The major breeding efforts in pearl millet over the next five years at ISC are to find resistance to Striga and the ear-head bug Raghuva, and to improve seedling establishment and survival under heat and drought stress. At IC emphasis is on improving yield potential of hybrids under a combination of environmental stresses.

Breeding lines of sorghum with acceptable resistance to the different species and varieties of Striga, to midge, grain molds and root and stalk rots are available. These traits, however, still need to be incorporated into cultivars with acceptable yield. Special emphasis is being placed at IC on transferring grain mold resistance to cultivars with acceptable grain quality. High yielding cultivars are early flowering and commonly mature before the end of the rainy season, causing infection of inflorescences by various fungi and causing several losses in grain quality. Breeding for resistance to Striga and root and stalk rots are also high priority projects. Mechanisms of resistance to stemborer and shootfly are not yet fully understood, and are being investigated in the entomology unit. These insect pests are widespread and cause severe crop damage in Asia and Africa.

Virus diseases can be severe in both sorghum and millet, especially in southern Africa. The program is recruiting a post-doctoral fellow to work on virus identification at IC, and is developing research cooperation with NARS scientists in Kenya with expertise on plant virus research. In the meantime screening of sorghum germplasm for virus resistance has been intensified in southern and eastern Africa.

The yield potential of IC sorghum cultivars under conditions of medium severe heat and drought stress is over six tons per hectare. New hybrids regularly produce over five tons per hectare at Patancheru without irrigation. Yield stability, however, is as important as maximum potential yield. Most of the sorghum and pearl millet produced in India and Africa is grown by small farmers with limited resources. Successful cultivars must be able to provide a stable yield under conditions of various degrees of heat and drought stress, attacks by insects and pests, and less than optimum soil fertility. The effects of stress on components of yield in both sorghum and pearl millet are being studied in the physiology units. When these associations are better understood, the breeders will be in a position to select for yield stability under stress.

Sorghum and pearl millet hybrids are essential if these cereals are to complete with maize in southern Africa, eastern Africa, Nigeria and Mesoamerica. In India hybrids are preferred and an established seed industry is available to produce hybrid seed. In West Africa, only Nigeria has the infrastructure to produce hybrid seeds. Open pollinated cultivars need therefore to form an essential part of the millet breeding program at ISC and the sorghum breeding program in West Africa. It is proposed that the Nigeria sorghum team concentrates on hybrids and the Mali team on breeding open-pollinated cultivars.

<u>Projects</u>

M-102(85)IC - Population improvement and the breeding of varieties by recurrent selection. Pheru Singh. 1990.

M-105(85)IC - Breeding of pollinators. B.S. Talukdar 1992.

M-106(85)IC - Breeding of male-sterile lines. K.N. Rai. 1992.

M-107(85)IC - Breeding of hybrids. K.N. Rai, B.S. Talukdar and J.R. Witcombe 1989.

M-136(87)IC - Genetic diversification. S.B. Chavan, S.D. Singh and R.P. Thakur. 1992.

Tr-M-XXX(87)IC - Population improvement and breeding of varieties by recurrent selection. Eva Weltzein and J.R. Witcombe 1992.

M-503(86)IS - Population improvement. K. Anand Kumar. 1990.

M-504(86)IS - Development of seed parents and hybrids. K. Anand Kumar. 1990.

M-506(86)IS - Genetic base: identification parents, diversification and use in variety development. S.N. Lohani. 1989.

M-507(86)IS - Population improvement: full season varieties (120-150 days). S.N. Lohani. 1989.

M-510(86)IS - Breeding synthetics. S.O. Okiror. 1990.

M-801(86)SD - Improvement of pearl millet for grain yield and the desirable agronomic traits. S.C. Gupta. 1991.

M-802(86)SD - Improvement of finger millet for grain yield and food quality. S.C. Gupta. 1991.

S-103(85)IC - Sorghum improvement for multiple desirable traits by recurrent selection. B.V. Subba Reddy. 1990.

S-104(85)IC - Development of improved female parents (A&B lines) with milo and other cytoplasms and their evaluation in hybrid production. D.S. Murthy. 1990.

S-125(86)IC - Sorghum breeding for intermediate and lowland areas of Eastern Africa. V. Guiragossian. 1992.

S-126(86)IC - Sorghum breeding for cold resistance for highlands of Eastern Africa. Vartan Guiragossian. 1991.

S-128(87)IC - Improvement of cold tolerant sorghum genotypes for the highlands of Mexico. Rene Clara. 1992.

S-129(87)IC - Improvement of sorghum genotypes for intermediate and lowland areas of Mesoamerica. Rene Clara. 1992.

S-501(86)IS - Stable and high yielding early duration varieties for low rainfall regions of West Africa. K.V. Ramaiah. 1990.

S-502(86)IS - Stable and high yielding medium duration varieties for intermediate rainfall regions of West Africa. K.V. Ramaiah. 1990.

S-503(86)IS - Stable and high yielding medium late maturing varieties for high rainfall regions of West Africa. D.S. Murthy. 1990.

S-504(86)IS - Development of stable and high yielding early maturing hybrids for West Africa. D.S. Murthy. 1990.

S-801(86)SD - Improving sorghums for high and stable yields with wide adaptation. A.T. Obilana, W.A.J. de Milliano and K. Leuschner. 1991.

S-802(86)SD - Adaptation and evaluation of a series of introduced random mating populations toward developing diverse and variable populations for the region. A.T. Obilana. 1990.