PROGRAMME COMMITTEE

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SORGHUM AND MILLET IMPROVEMENT PROGRAMMES

ICRISAT

SORGHUM IMPROVEMENT PROGRAMME, 1975

H. Doggett and P.K. Lawrence

Background:

Success was achieved in the IRRI rice improvement programme and in the CIMMYT wheat improvement programme through the production of basic types which gave substantial yield improvements over wide geographic areas. Both rice and wheat are irrigated crops, so environmental hardships are ameliorated: both have a long background of research, thus, the North 10 dwarf wheat and day-length insensitive dwarf rice had already been developed before the International Institutes were started. The "break through" in both crops resulted from the exploitation of one or two major genes: and for both there was an element of luck in the disease pattern, in that if Septoria had been present in India to the extent that it is in Africa, the Mexican wheats would have failed here, while a different distribution of virus diseases would have greatly restricted the useful area of IR 8.

Environmental differences are extreme in the semi-arid tropics, and ICRISAT may not be able to develop varieties or hybrids which are adapted throughout the greater part of this region. A conspicuous feature of the ICRISAT crops is the paucity of past research effort, although this is less true for sorghum than for the others. It may not be easy to obtain a big advance through exploiting one or two major genes, although this could occur with pennisetum millet: and all four crops go out into a very hostile disease and pest environment which is created and maintained by the existing indigenous cultivars, wild types, and weeds.

We must therefore accept that progress in our crop improvement programmes may not be sudden and spectacular, although it should be steady.

Requirements for success:

Objectives need to be clearly defined, and concentrated upon: the best possible range of genetic variability must be obtained and utilized: and we need well organized co-operating centres so that selection and testing can be done under the full range of ecological conditions prevailing in the semi-arid tropics.

Principles:

The origin of desirable crop characters lies in the local farmers' cultivars, and to some extent in the crop's wild relatives. The germplasm collection is therefore the ultimate source material, but much time-consuming manipulation is required to move the desired characters from local cultivars into high yielding, good agronomic types. The best starting point is therefore material from other plant breeders who have already taken unimproved germplasm and have begun to shape it in desired directions.

The basic breeding process is selection, which for all but the simplest of characters requires some form of testing so that chosen plants may be ranked in order of excellence. Complex character expressions such as yield which interact markedly with environment must be tested widely over locations and seasons: fortunately, broad adaptation to the former shows reasonable correlation with the latter. Existing germplasm needs to be screened using appropriate selection procedures, to identify cultivars or plants with desirable characters. New germplasm must be collected, and evaluated.

The second basic breeding process involves the creation of populations in which the desired character combinations are very likely to occur, coupled with selection to identify desirable plants which segregate in these populations. Such populations may be created in a simple manner by hybridising two parents which differ in the desired characters. The segregating progeny from such hybrids are screened for the desired character combinations, and individual plants are selfed (inbred) and reselected for a number of generations until reasonable uniformity of plant type has been achieved. This inbreeding-with-selection procedure is an essential part of any program for largely self-pollinating crops where the end product is either a variety, or a parent for a hybrid. The plants chosen for inbreeding may come from any kind of cross, and can therefore be chosen from any part of the programme.

The biparental cross makes little use of the available germplasm: and if the parents differ by 10 desired genes, over 1 million plants are required in the next generation to obtain one plant combining all the desired characters. For parents differing by 21 genes, 4^{21} plants are required to obtain a single plant with the desired combination, or about one plant in 4.4×10^{12} Such a method is therefore likely to be most successful where gene differences between parents are few.

An alternative to growing vast numbers of plants in which to select is to use a composite population breeding system. In this, the segregating population is grown in manageable numbers, and plants which have some of the desired character combinations are chosen, perhaps 10 percent of the whole population. These are then inter-crossed (recombined) in all combinations, their progeny re-selected and inter-crossed in the same way. The mean

value for the progeny in each generation will be better than in the preceding generation. The whole population is improved step by step and the probability of getting all the deisred characters together in one plant is increasing all the time. This system is easily followed in a cross-pollinating crop, and male-sterility makes it possible to develop and improve populations of sorghum in the same way. The discovery of male-sterility also makes possible the creation of synthetic varieties like those developed in maize, but for sorghum the realisation of this possibility lies in the future.

Generally, more than two parents are used to create composite populations, but this need not be so. The opposite extreme to biparental crosses is composite populations based on large numbers of parents, which sample a greater part of the available germplasm. An intermediate situation where rather few parents are involved in a flexible and controlled manner has been proposed by N.F. Jensen (1970) and termed a Diallel Selective Mating System (Crop Sci. 10, p. 629). We shall be using this systen in at least one of our projects.

Numbers and probabilities are at the heart of crop improvement: we require large numbers of crosses, large numbers of plants, and enough land on which to grow them. Given the availability of ample resources, the number of plants which should be grown is restricted only by the number which can be screened and assessed. This screening process is fundamental, and involves testing large numbers of entries in replicated trials in several environments. Measurement is essential to discriminate between the good and the less good and several environments are essential to show up those types which have broader adaptation and are therefore more likely to give consistent yields from season to season.

Next year, we hope to have evaluation trials at a number of centres in India and Africa, with nursery sets of good material for observation. We have started to make the necessary arrangements and contacts, and expect to distribute three groups of material: (1) Some 500 elite lines to a few selected centres. (2) A few hundred lines drawn from our breeding populations to each major ecological zone. (3) Some 50 elite lines to everyone who would be interested to grow them.

The Programme

The programme has been broken down into a series of projects, each of which is the responsibility of a research scientist. The regular support staff for each scientist is one field assistant and two field helpers. These have not been named in the projects as yet, because we are still choosing and sorting people according to aptitude and interests. The work load was scored on a points system, and shared as equally as possible among the scientists.

The objectives are set out with each individual project.

S-brd-1. International testing and yield trials.

Objective. The identification of sorghum lines combining good yield across environments with good grain quality.

Discussion. The trials group is the spearhead of our crop improvement advance. Every other project will feed material to this group for evaluation. A single trials organization should be the most effective way to get a steadily improving standard of excellence in the conduct of the trials and the retrieval of information. Each scientist will remain responsible for his own material

in the trials, and will be fully involved in its assessment. We shall conduct evaluation trials of sorghum breeding material at all stages of development over a wide range of environments, and we shall study different methods for the measurement and interpretation of adaptation. The evaluation will include yield, height, length of maturity and grain quality at every site, and a much more complete assessment of plant characteristics at several sites. Large trials will be used for screening in the early stages of evaluation: and smaller trials with larger plots and more replications for elite material in the later stages of selection. The volume of material to be handled will be determined by experience. It seems likely that we shall handle some 5,000 to 10,000 entries at Patancheru: we would like to have 1,000 to 5,000 entries at two or three additional sites in India if these become available: about 1,000 entries at several sites in India and Africa: and 50-100 entries wherever anyone is prepared to grow them.

Scientist. P.K. Lawrence.

Co-operating Scientists. The testing procedures will require the co-operation of other ICRISAT Scientists, especially in the disciplines of entomology, plant pathology, biochemistry and plant physiology. We also hope to involve scientists of the national programmes very thoroughly in this evaluation work.

S-brd-2. Source populations and the introgression of exotic germplasm.

Objective.

(a) To utilize new germplasm possessing valuable characteristics through introgression and the creation of random mating populations.

(b) To make better use of material already in the programme through the creation of fresh source populations.

(c) To make available to other plant breeders in the semi-arid tropics a wide range of genetic variability in a form which can be rapidly incorporated into their programmes.

Methods.

(i) The introgression of new germplasm by making appropriate crosses and backcrosses.

(ii) Testing of progeny from exotic x adapted crosses and backcrosses at 2 or 3 locations.

(iii) Crossing chosen varieties and cultivars to suitable sterile sources: followed by the random intercrossing of sterile segregates for 3 to 4 generations to produce a random mating population.

(iv) Shaping such populations by mass selection of simply inherited characters to improve the general agronomic characters of the populations, prior to more intensive improvement work.

Comment. Exotic germplasm is often far removed from the agronomic types needed in modern intensive farming: developing and shaping populations in this way offers a good system for incorporating it quite rapidly into the programme. Other breeding material already in the programme may need combining and modifying through similar methodology.

Scientist. S. Gowda.

Co-operating Scientist. P.K. Lawrence.

S-brd-3. The improvement of advanced populations.

Objective. To improve advanced populations for yield, quality, adaptation and other special characteristics so that they become increasingly valuable sources of new cultivars for breeders in national and regional programmes.

Methods. The direct comparison of breeding methods belongs to research institutions in the developed world rather than to ICRISAT: here, we have chosen systems which seem appropriate, and we shall learn a good deal about their practical utility in the course of operating them.

(A) Intrapopulation Improvement

(1) S_1 testing.

Generation 1. Select male-sterile plants from recombination population.

Generation 2. Half-sib rows, 50 percent of the rows rejected, fertile (selfed) heads chosen from remaining rows.

Generation 3. S_1 testing in a variety trial. Sibbing in rows.

Generation 1. Recombination of selected entries: selection of male-steriles.

This system is being used in two "fast line" populations, NP (B) and NP (R), both made up by merging appropriate populations from Lincoln, Nebraska. A high selection pressure is being used, and one cycle of 3 generations can be completed each year.

(2) S_2 testing.

Generation 1. Select male-sterile plants from recombination population.

Generation 2. Half-sib rows evaluated in trials. 50 percent rejected: fertile (selfed) heads selected from the remainder.

Generation 3. S_1 testing in variety trials, under several environments.

Generation 4. S_2 selections from best S_1 rows grown under a wide range of environments. Sibbing in rows.

Generation 1. Best 5 to 10 percent of the entries to recombination population. Male-steriles selected for next cycle.

The majority of advanced populations will be improved by this system. It is close to traditional breeding procedures, involving testing and selection in the F_1, F_2 and F_3 generations from a cross. The best are returned to be the parents of the next set of crosses for the following cycle. Only two generations are grown each year, and the S_2 testing is done in the kharif or long rains, leaving plenty of time for results to be evaluated before recombination in the summer season.

(B) Interpopulation improvement:

(3) Reciprocal recurrent selection, using an inbred tester.

Two populations are used, a B population which can produce cytoplasmic sterile lines, and an R population which produces pollinator parents for hybrids. The B line is improved by an intrapopulation method, either S_1

or S_2 testing. Lines are withdrawn at intervals and converted to A lines for use as testers in the improvement of the R population, which is improved as follows:

Generation 1. Fertile heads in the R population are used to pollinate the tester, and are also selfed.

Generation 2. Test crosses are evaluated in variety trials: selfed pollinators are grown out and sibbed in the rows.

Generation 3. The best pollinator parents are recombined to form the population with which to start the next cycle.

This system will be used on two populations, RS(B) and RS(R). These were developed at Serere and have been improved under recurrent selection for several generations. Both populations should be improved by this procedure, and hybrids developed from lines withdrawn from the two populations should be good.

Comment. The development of broadly adapted populations will be a major part of this project, but attention will also be given to populations for particular ecological regions or special consumer requirements. We hope to co-operate with the group at Lincoln, Nebraska in obtaining more fundamental information on population improvement in sorghum.

Scientist. Bhola Nath Verma.

Co-operating Scientist. P.K. Lawrence.

S-brd-4. Development and testing of hybrids.

Objective. To produce high yielding hybrids, adapted over a wide range of environments.

Methods. The best entries from the elite trials, over a wide range of environments, will be tested on a cytoplasmic sterile. Restorers will be used to make hybrids on standard steriles, and these will be evaluated in trials. Maintainers will be converted to steriles by back-crossing, and evaluated as female parents.

Comment. Seed production facilities are still very limited in the developing world, and the widespread use of hybrids lies some way in the future. However, hybrids have proved so valuable under adverse conditions that a small programme for developing and testing the best varieties as potential parents is justified.

Scientist. Not yet appointed.

Co-operating Scientist. H. Doggett.

S-brd-5. Grain-grass sorghums.

Objective. To develop grain-grass sorghums of short maturity which tiller freely and can be ratooned.

Methods. R.E. Karper developed grain-grass sorghums in Texas which have a plant form resembling that of wheat rather than sorghum. These are being crossed to cultivars with good grain quality, shoot-fly resistance, midge resistance, *Striga* resistance, and good yield. Jensen's Diallel Selective Mating System will be used to develop the desired types.

Comment. A short-term sorghum with a wheat-like plant type might be extremely useful in areas of irregular rainfall if it could be ratooned, giving two grain

crops under favourable conditions. Under hard conditions, the first growth might be grazed or cut for fodder, yet still produce a grain crop on subsequent more favourable rain. Such types must evidently be resistant to shoot-fly and to midge, if they are not to be a menace to the conventional local sorghums.

Scientist. K.V. Ramaiah.

Co-operating Scientist. H. Doggett.

S-brd-6. Tetraploid grain-sorghums.

Objective. To exploit the potential for improved yield and quality which may be available from utilizing tetraploid sorghum germplasm.

Methods. Intercrossing and selection among tetraploid grain sorghums developed in East Africa and at Lincoln, Nebraska: crosses with wild tetraploid types: and crosses with newly created autotetraploid sorghums obtained by the use of colchicine. Random mating populations will be developed, using male-sterility, and selection pressure applied for yield, grain quality, and grain size.

Comment. The wild tetraploid sorghums are vigorous and highly successful, and they cross freely with autotetraploid grain types. The wild tetraploids represent a new source of germplasm, and there is additional potential for the partial fixation of hybrid vigour. Tetraploid grain-grass types would be extremely useful in dry and difficult areas, and the potential offered by the success of wild sorghum tetraploids should be exploited.

Scientist. K.V. Ramaiah.

Co-operating Scientist. H. Doggett.

S-brd-7. East African varieties and hybrids.

Objective. To develop sorghum cultivars well adopted to the semi-arid conditions of East and Central AFrica, and also suited to conditions in S. American and S.E. Asia.

Methods. Continued screening and yield testing of segregating material from the East AFrican programme: and conversion to photoperiod insensitivity by backcrossing from short, photoperiod insensitive populations.

Comment. Material developed in the East African programme contains good combinations of leaf disease resistance, Striga resistance, shoot-fly resistance, and broad adaptation. It has received good reports from S. America, Nigeria, Ethiopia and Thailand. Improvement in grain quality is required, and most of the material is too sensistive to photoperiod. Further development and testing of this material is justified.

Scientist. K.V. Ramaiah.

Co-operating Scientist. H. Doggett.

S-brd-8. West African dwarf sorghums.

Objective. To develop good quality dwarf sorghums which yield well in the Guinea Savannah zone of West Africa, and under short-day conditions such as the rabi season in India: and to introduce photoperiod insensitivity to much of this material.

Comment. West African sorghums in the Guinea Savannah zone are tall and photoperiod sensitive. Dwarf types have a greater yield potential, and D.J. Andrews made much progress in developing better yielding dwarfs and dwarf random-mating populations. Some of these sorghums perform well in

the Indian rabi season. The further development of this material and the incorporation of shoot-fly and midge resistance will be valuable.

Scientist. Not yet appointed.

Co-operating Scientist. D.J. Andrews.

S-brd-9. Striga resistant sorghums.

Objective. To obtain sorghum cultivars which combine good yield and grain quality with resistance to Striga.

Methods. A part of the world collection was screened for resistance to Striga hermonthica, and a composite population developed, by Stan Kind in the USAID Project 26 programme. This population will be selected under "sick plot" conditions in different geographical areas where different species or strains of Striga occur. New Striga resistant cultivars will be identified: and screening for a low level of stimulant production will be done.

Comments. Striga can cause devastating crop loss on sorghum, and large areas of land in the semi-arid tropics have been rendered useless for growing sorghum because of heavy infestation with Striga seed. There are three important Striga species, and several strains within species. Screening for resistance must therefore be done in several countries. More remains to be discovered about the types of resistance and Striga strains available, and we hope for close collaboration with the Weed Research Organisation in Oxford in due course.

Scientist. Not yet appointed.

Co-operating Scientist. H. Doggett.

S-brd-10. High altitude sorghums.

Objective. To develop a wider range of short-terms, photoperiod insensitive high altitude sorghums with good grain quality.

Methods. Intercrossing good high and low altitude varieties and testing at high altitude sites in Mexico, Ethiopia, and the Nilgiri hills. Exchanging and testing material being developed in the Ethiopian and CIMMYT programmes, and working with high altitude populations developed in projects S-brd-2 and S-brd-3.

Comment. Ethiopia has a particularly valuable group of high altitude sorghums which have not yet been used at all extensively in breeding programmes: and there is a lot of hybrid vigour shown in crosses between low altitude and high altitude types which should be valuable to both zones. Extensive areas of high altitude sorghum are grown in Eastern Africa, and there is a big potential for these types in Central and South America.

Scientist. D.S.R. Murthy

Co-operating Scientist. H. Doggett.

S-brd-ent-1. Breeding for resistance to pests.

Objectives. To develop and combine resistances to shoot-fly, midge, stem borer, and storage pests, which will be incorporated into high yielding material with good grain quality.

Methods. Varieties and segregating populations will be screened in the field and in the laboratory for resistance to these pests. Resistances will then be combined together both by traditional means and through composite populations. All hopeful material will be screened at several sites in India and Africa. All entries in variety trials will be screened for pests at Patancheru so that we have an assessment of their pest rating when assessing performance.

Comments. Pests are the most serious cause of crop loss in sorghum. Shoot-fly, midge, and stem borer can seriously affect yields, while weevils and grain moths can destroy the harvest in storage. Resistance has been observed against all these pests, with the possible exception of grain moth, and the task is now to develop and exploit these resistance to the best effect.

Scientists. S. Gowda (Plant breeding), Seshu Reddy (Entomology).

Co-operating Scientists. J.C. Davies, P.K. Lawrence, H. Doggett.

S-brd-path-1. Early sorghums with clean, quality grains.

Objectives. To develop short-term sorghums with quality grains which are either (a) resistant to grain moulds or (b) protected from grain moulds by large glumes.

Methods. (a) Short-term sorghums with quality grains will be tested for resistance to grain moulds: and the best sources of grain mould resistance will be sought by screening the collection. These will be intercrossed. Similarly, sorghum with large glumes of the membranaceum type will be crossed with good early varieties, having high grain quality, to develop an envelope completely enclosing the grain so protecting it from mould spores. It is probable that Jensen's Diallel Selective Mating System will be used here also.

Comment. Many traditional sorghum cultivars developed for use in the main rainy season of the semi-arid tropics have a photoperiod sensitive "trigger" mechanism so that flowering occurs at the end of the rains, and the grain ripens in dry weather on residual moisture. Short-term varieties would often give more reliable yields and would also make better use of the available rainfall, but cannot be grown because of the damage done to grain quality by

moulds. Good grain mould resistance exists in some cultivars, e.g. Zera Zera from the Sudan, while other types have enveloping glumes which protect the grain from moulds yet thresh freely at harvest.

Scientists. D.S.R. Murthy (plant breeding)

K.N. Rao (plant pathology)

Co-operating Scientist. Y.L. Nene

S-brd-phys-1. Efficient sorghum plant types.

Objectives. To develop sorghum types which produce a high yield per growing day and which can tolerate or avoid periods of severe drought stress.

Methods. Studies will be made by the plant physiology group on the variability and characteristics of the main growth stages of the sorghum plant. Suitable parents will then be selected to attempt appropriate recombinations which will then be assessed in terms of yield per growing day. The best methods of screening sorghum lines for drought endurance will also be worked out co-operatively.

Comment. Studies at Lincoln, Nebraska have shown that there are differences between sorghum types in the three main growth stages, and it looks as though these differences could be exploited to develop more efficient plants. Drought endurance studies are also in progress there, and we shall co-operate closely with Dr. Eastin's group at Lincoln.

Scientists. (Plant breeder not yet appointed).

N. Seetharama (plant physiology).

Co-operating Scientists. A.H. Kassam, H. Doggett.

S-brd-q+n-1. Sorghum grain quality improvement.

Objective. (a) To achieve sorghum grains with excellent flour preparation, food type, and flavour characteristics.

(b) To obtain grains with enhanced nutritional quality.

Methods. The best possible combinations of free threshing, plump, corneous, pigment-free grains with thin pericarp (lustre) will be obtained. Milling and cooking characteristics, and flavour, and properties of the prepared foods will be studied and identifiable characteristics used in the breeding programme.

Sorghums with high lysine (3 percent of protein) will be bred, and the influence of a low prolamine content on the digestibility and cooking characteristics of the grain will be studied, using rapid laboratory screening tests to select for these characteristics in segregating populations.

Comment. The two main products of sorghum grain are starch and protein. Flavour, appearance, cooking qualities, and keeping qualities of the grain are of over-riding importance to the consumer, and the best, most consistent yields must be obtained in combination with these qualities.

Sorghum can produce around 8 percent of protein even under conditions of very high yields, but this protein is among the lowest of the cultivated grains for lysine content. It is therefore worth enhancing the nutritional value of this protein by increasing the lysine content to the levels current in rice or wheat. The protein matrix in the endosperm consists largely of prolamine, which is low in nutritional value, and which appears to reduce

digestibility. The characteristics of low prolamine types should therefore be studied. We hope to cooperate with Dr.J.D. Axtell at Purdue and Dr. L. Rooney at Texas A & M in the quality work.

Scientist. (Plant breeder not yet appointed)

S.P. Yadav (Biochemistry)

Co-operating Scientists. R. Jambunathan and H. Doggett.

HD:psn

PEARL MILLET PROGRAMME

D.J. Andrews, J.V.Majmudar, and H. Doggett

Introduction. The FAO production yearbook records that in 1972, 65 million hectares of millets were planted, and 43 million tons of grain produced. Seven species of millet are included together, and pennisetum (pearl) millet is the most important among these. Centrally Planned nations produced 24.5 million tons of millet on 32 million ha, which will have been almost entirely proso and other small millets. India planted 16.5 m. ha., and produced 7.6 m. tons: Africa planted 13.8 m. ha and produced 8.5 m. tons. The Indian figures for 1973-74 were as follows:-

Pennisetum millet		Eleusine millet		Other small millets	
area	production	area	production	area	production
13.6	7.1	2.4	2.1	4.5	1.9

The proportion of pearl millet to other millets in Africa is probably not very different from that in India, and we may guess that some 70 percent of the millet acreage in the developing world is planted to pennisetum millet, or about 20 to 25 million hectares. Present grain yields are around 500 to 700 kg/ha.

Pearl millet is grown by small, subsistence farmers on the lighter soils of the semi-arid tropics, and much of the area is in drought-prone regions, although some is grown as an early maturing cereal in the Guinea-Savannah zone of West Africa when rainfall in the growing season is usually ample. Risk is an important consideration in the erratic rainfall areas, and inputs are low, so new varieties must be able to yield consistently under difficult conditions, yet be capable of responding well to improved inputs and better management.

Downy mildew and ergot diseases are important factors in reducing pearl millet yields, especially in conventional hybrids. Broader based hybrids and synthetics containing a wider range of resistances have an important part to play in combatting the disease problem.

Pearl millet is mainly cross-pollinated (over 70 percent of out-crossing) and recurrent selection systems in composite populations used so successfully in the maize crop are appropriate to use in this crop also. The general objective of the breeding programme is to develop genotypes or populations giving more grain of adequate nutritional quality and which are as widely adapted and stable as possible.

1. Genotypes need to be constructed which utilize more efficiently the available and potential environmental resources. High harvest index and appropriate maturity length are important, and stability of yield is essential.
2. The best possible combinations of tolerances for yield reducing factors are needed. Such factors are pests, diseases, and stresses due to the physical environment.
3. Acceptable combinations of grain type and nutritional quality must be combined with the improved yield.

Phases in the breeding programme

1. Accumulation of genetic resources
   - (a) Collection and cataloguing of land-races and wild millets, including the current world collection.
   - (b) Material from other breeders, and developed varieties.

2. Generation of good combinations

(a) Identification of source material

(b) Specific and controlled crosses

(c) Recombination within composites

3. Selection

(a) Qualitative and quantitative evaluation, in the field and laboratory.

(b) Identification of hybrid parent and/or variety material

(c) Early generation multilocational testing (to include high and low production levels and exposure to yield reducing factors)

4. Output

(a) Inbred lines for hybrids, synthetics, or possessing special attributes

(b) Varieties (synthetics, or composite bulks).

(c) Information on results and technology.

Breeding methods

The breeding behaviour and morphology of pearl millet has many useful features which facilitate manipulation by the breeder. It is essentially a cross-pollinating crop but the effects of inbreeding are not severe. The range of genetic variability within the cultivated species is immense and further variation exists in related species (though successful crosses have been few). High yields with relatively early maturity (less than 90 days) make possible three generations in a year.

Protogyny with the hermaprodite and staminate florets on the same inflorescence, allows selfing and the use of both artifical and natural cross pollination without the need for emasculation or genetic male sterility.

The numbers of progeny which can be derived from a single plant or cross are very large due to the high seed number per head (1000+) and tillers from a single plant can be used simultaneously for different purposes.

Since male and female flowers are on the same spike the production of commercial hybrids requires cytoplasmic steriles. Three separate cytogenetic male sterility systems have been described.

Two main breeding methods are available; (a) the traditional inter-crossing followed by inbreeding: (b) recurrent selection in composites (populations). From composites, conventional and broad based hybrids and synthetics can be produced rapidly. High yielding composites or synthetics cannot be made quickly by traditional methods, since several generations of intercrossing and testing are required before release.

The traditional approach involves controlled crossing between two or a few parents that seem favourable and selecting for some homozygosity among the progeny. Variations may include backcrossing, crossing F_1s or subsequent generations but essentially the approach utilizes controlled crossing and any progeny is derived from few parents. Thus the possibilities of recombination are restricted by the low number of crosses, and the accumulation of favourable genes is limited to those contained in the small number of parents.

For simply inherited characters, the traditional approach has given excellent results. Most of todays varieties and hybrids have been developed in this way.

The use of recurrent selection in composite populations can utilize a much broader range of the available germplasm. Two kinds of recurrent selection systems are required for the composite populations: the less immediately

important together with the back-up populations need to be improved without much expenditure of skilled man-power and resources: while the advanced populations need methods which will make rapid progress without too fast a decline in genetic variability.

Gridded mass selection, choosing a large number of individual plants (200-500) representing a selection pressure of some 10-25 percent, with an occasional cycle of S_1 testing, seems to be a satisfactory method for the back-up populations.

Since pearl millet is a cross-pollinating crop, some form of inter-population selection system is likely to be more useful than an interpopulation method to improve the advanced populations. Interpopulation systems select in the population pair used for different loci which give heterosis in the population cross hybrid, and one half of this heterosis will be retained in later generations of this cross when used as synthetics or composites. However, S_1 testing has proved valuable in maize, is simple to use, and a cycle of three generations can be completed in a year. It is unlikely that S_2 testing will be worth while, as the slender evidence available suggests that this gives higher yielding selfed populations rather than higher yielding random-mating populations. (Homer et al., Crop Sci. 9, pp.539-543. (969).

In addition to S_1 testing, a full-sib system will be used for intrapopulation improvement. This will operate as follows:-

Generation 1. Recombine selfed-seed of 50-100 selected lines in paired rows, making plant to plant crosses between families to obtain recombination. This generation can simultaneously

be screened for downy-mildew resistance, the crosses being made only between resistant plants. At least 500 inter-family crosses would be made, and sufficient seed for adequate testing ensured by using several heads from each plant.

Generation 2. Test the crosses in variety trials under several environments in India and Africa, evaluating yield, agronomic characters, and monitoring quality. Also test in disease and pest nurseries, and self resistant plants. Choose the single best selfed plants in 50 to 100 of the families, chosen on the basis of the yield and performance testing in the trials.

Generation 1. Recombine by intercrossing the families derived from these 50-100 selfed plants, etc.

This full-sib system has three attractions:-

(1) Two generations a year gives time to obtain and evaluate results without undue haste.

(2) There is a recombination generation each year.

(3) Selection against diseases (and pests if necessary) is done in both the testing and the recombination generations. This should help to sort out the present unsatisfactory disease situation in this crop.

Among the interpopulation systems available, reciprocal recurrent selection using an inbred tester (RI) looks as though it is among the best systems for maize. (S.A. Eberhart, 1974, unpublished). It would seem to be well adapted to pearl millet. RI requires 3 seasons, which could, if necessary, be done in

one year, but could easily be spread over 2 years, again helping to maintain a good distribution of work with plenty of "lead time" in the programme.

Two populations are used, and an inbred tester line is withdrawn, multiplied, and used as the parent for test crosses with the other population. Both the populations follow the outlined procedure, in parallel.

Generation 1. 25-50 selected S_1 lines are grown in paired rows, and exposed to disease attack. Several thousand crosses are made between families, and the best 2,000 or so are taken at harvest.

Generation 2. The 2,000 crosses are planted with the inbred tester from the other population. Some 50 percent of the 2,000 crosses are hybridised with the inbred tester, crossing several heads to ensure plenty of seed. Again, disease infection can be used to determine which of the 2,000 crosses to reject, and which individual plants to use in the crosses to the tester inbred line. At harvest, keep the best 500 crosses for evaluation.

Generation 3. Evaluate the 500 test crosses in yield trials for all important characters, over different environments in India and Africa. Grow one replication in a nursery for selfing.

Generation 1. Recombine the chosen 25-50 entries in paired rows, using the selfed seed from the nursery, etc.

This system also allows for plenty of exposure to diseases and pests, and therefore selection for resistance.

A combination of full sib testing and reciprocal recurrent selection, known as reciprocal full sib selection, is likely to be the most promising interpopulation system, certainly when the B and R composite populations are developed.

On this system, full sibs are made between populations, both parents are selfed, and the chosen parents recombined within populations. Evidently two heads are required on each parent plant, one for sibbing, and one for selfing.

Generation 1. Choose 50 lines from each population and make full sib crosses between populations. self each parent plant.

Generation 2. Evaluate 500 or more of the full sib crosses.

Generation 3. Recombine selfed parents of the best 5-10 percent of the crosses, within populations. Select good plants to repeat cycle, generation 1.

Discussion of some constraints

The following areas of interest influence success of the program:-

A. Morphology

B. Physiology

C. Diseases

D. Cytoplasmic male sterility

E. Grain weathering and dormancy

F. Grain quality

G. Intercropping

H. Adaptation and stability of yield

I. Out reach program

A. Morphology:

The concept of a rigid ideotype is unpalatable to most physiologists and breeders since such plants appear to have rather specific environmental requirements. Nevertheless, there are certain fundamental features in plant structure which are associated with yielding ability. Plant height and duration, number and type of tillers, leaf pattern, root development and head type are among the more obvious.

Plant height and total biological yield/ha appear to be strongly correlated at low to medium productivity levels. Tall land-race types are highly efficient in production of dry matter giving 3 to 5 tons per acre in unfertilized conditions, but unfortunately the harvest index of such types is only 10-15% so average yields are 300-600 kg/ha. Improving the harvest index while maintaining or increasing the biological yield level is a fundamental objective.

The use of dwarfing genes appears necessary here, primarily to avoid lodging. Dwarf genotypes have been necessary to produce top yields in many crops, but grain made at this level of production is relatively expensive in terms of costly inputs (mechanical or animal energy and artificial fertilizers). Dwarf types, inspite of allowing higher plant densities, usually produce less total biological yield, presumably because the dwarfing genes have many pleiotropic effects on plant growth processes. As a total readjustment of the genetic make-up may be necessary, before efficiency comparable to that of tall plants can be obtained, a lot of breeding work remains to be done on dwarfs. Fortunately in the SAT most of the farming is labour intensive and thus plant type does not have to be related to mechanical harvesting. Dwarfness does not have to be used to such an extent as might limit light penetration, and uniformity in height does not seem to be particularly necessary. Extreme dwarfness may not be desirable.

The duration of the crop's life cycle is important. It should be tailored to fit the growing season (usually the with-moisture period as cold is not often a consideration except in the high altitude areas) particularly to avoid likely periods of drought stress, yet to mature in favourable conditions. However, there is an optimum maximum duration, (where sole cropping is concerned) where vegetative growth is developed to the most efficient stage to support grain production. Too long a vegetative phase means energy and minerals wasted in non-productive or even "saprophytic" dying leaves and older parts; while too short a vegetative phase means underdeveloped capacity to make or fill the potential grain sink. While recognising that maturity is an important feature of crop adaption, we should tend to breed earlier rather than later maturing genotypes.

In millet there are three main types of tillering: Synchronous and non-synchronous basal tillering, and sub-terminal tillering which is never synchronous. Non-uniformity in flowering allows a determinate type of plant some flexibility to utilise extended favourable environmental conditions. In millet this advantage is out-weighed by the potential build up of head diseases (eg ergot) and head pests (eg midge). The first type of tillering is therefore the most desirable and it should be of a type where the primary tillers produced even in good conditions suppress the development of subsequent ones. The best number of tillers per plant is debatable, but should be moderate and we may hazard 4 to 8. Tillers become independent units at a relatively early stage. Thus it is misleading to say the harvest plant density is n thousand plants/hectare without indicating that 5 n thousand heads were produced. In present genetic backgrounds number of heads/plant, via grain number per plant, is well correlated with yield. However, it probably acts in another way also, in that since tillers soon become independant units, a high number of yielding tillers per plant in a normal seeded population, implies the desirable feature of low interplant competition. The potential for tillering also allows recovery from yield reducing factors which might knock out some or all of the older tillers. In general millet has this type of recovery well developed.

Leaf pattern and duration requires mention if only because of the very diverse opinions that are held on angle, size and amount of desired leaf. Millet can produce a L.A.I. of up to 13, but it has been shown that the photosynthates needed to fill the grain can be made in 20 days by a LAI of less than 0.5. Millet appears to have too many leaves, yet yield is still correlated with leaf area upto LAI 5. Work on leaf angle on other crops has shown

that this is not a first limiting factor and a reflexed leaf is potentially as efficient as an erect leaf. A longer working life for individual leaves and well spaced upper nodes would seem desirable.

The millet root system has been very inadequately studied. The bulk of the roots appear to be shallow, in the top 10 cm, though a few roots have been traced to 3.6 m. This seems a little at variance with millets alleged efficiency of mineral extraction and soil moisture use. Root studies are more difficult than for aerial parts because of lack of accessability, yet this very fact should mean that there are now good returns to be obtained from root research.- An efficient root system must be correlated with grain yield as strongly as is structure of the above ground parts.

Head numbers, length, diameter, and compactness (grain/cm^2) of head and 1000 grain weight are all reported to be positively correlated with yield. Unfortunately, few tillers tend to be dominant over many and short heads and thin heads are also independantly dominant. Compactness is associated with cylindrical head shape. Inspite of the probable negative correlation between several of these characters good progress has been made in combining some of them. High head numbers from Indian and USA germplasm and length and compactness from African sources have been combined, and there should be good prospects for continued improvement in such combinations.

B. Physiology.

A major programme of research will be mounted by the Cereal Physiologist on the more important processes to develop simple screening methods which can be used in genotype selection. The areas of interest appear to be seedling vigour (considered to be most important for successful crop establishment in sub-optimal

conditions); leaf growth pattern; the partition of dry matter between vegetative and reproductive parts; head initiation and development; sink size (yield components), photosensitive and thermal responses.

Mineral nutrition of millet genotypes is another area which needs investigation and here comprehensive root studies will be essential. The possibility of rhizosphere N fixation needs substantiation. There is much circumstantial evidence to indicate that land-race millet genotypes to acquire otherwise unaccountable nitrogen. If so the extent of variability for this trait needs to be determined and selection techniques developed.

Restricted moisture availability is a commonly expected limitation to production in millet; several indices have been postulated for water relationship and drought studies - proline content, osmotic (solute) potential, N-reductase activity and heat tolerance, but there is still a need to develop or refine existing methods to the point where large quantities of germplasm can be quickly screened for water-use efficiency and drought tolerance.

C. Diseases:

Diseases more than pests constitute the main threat to millet production and a large part of the research effort will be directed towards screening germ plasm and breeding for resistance. Three diseases are important at present: Downy mildew (Green ear) *Sclerospora graminicola*, Ergot *Claviceps microcephala*, and Rust *Puccinia penniseti*. There are numerous other diseases, sometimes locally important and these may have to be considered in that context. The three diseases mentioned are widespread in all millet growing areas and while resistance exists for mildew and rust, this is less certain for ergot. Races of these diseases have not been specifically identified, but it will be surprising if they do not exist.

Downy mildew is probably responsible for most yield loss, but ergot, because of its high mammalian toxicity from a relatively low level of infection can cause a grain harvest to be totally uneatable. Rust often seems severe, but unless a substantial attack occurs before seed-set, yield losses are probably negligible. Selecting variety types which avoid the peak periods of incidence may substantially reduce losses from ergot and rust.

The methods used in breeding for resistance should be those which identify, select and accumulate the more effective long lasting types of resistance. Examples of major gene (vertical or race-specific) resistance in other crops indicate that with some exceptions, this is frequently an unreliable type since in a simple gene-for-gene situation the pathogen can quickly evolve a virulent new race. Seedling resistance and total immunity are often characteristics of major gene resistance. General (horizontal or non-specific) resistance is of a more durable type being based on the additive effects of numerous (often 'minor') genes and is effective against a wide spectrum of races. At best, some disease symptoms are exhibited and selection for non-specific resistance should be on mature plant expression as seedlings are usually susceptible. The problem is how to distinguish between specific and non-specific resistance while selecting. This can be done by exposing the material to the known races at one location (presupposing race identification and the existence of host differentials), or multi-location testing using the same sets of genotypes or progeny. Periodic recombination of the more resistant lines is essential to increase the level of resistance.

Preliminary findings on the inheritance of resistance to the downy mildew of sorghum and maize, S. sorghi suggest that one to several major genes are

involved, but with modifiers, though the most significant discovery has been that additive effects are apparent which can be used to increase resistance by selection. This information is not yet available for downy mildew of millet.

Seedling resistance presents a special problem with downy mildew, since systemic infection by oospores only occurs in the first 3 or 4 weeks of growth (though young tillers can be infected later). Excellent levels of general resistance to downy mildew undoubtedly exist in the later African land-races of the cooler damper areas (especially 'Maiwa' or 'Sanio' - late millets, and 'Dauro' transplanted millet).

In a crop such as millet where new improved genotypes can be produced rather rapidly there may be a use for some major gene resistances, with the qualification that loss of any general resistance should not be a consequence of such selection (vertifolia affect). It seems preferable that most of the breeding effort should be directed towards developing general resistances.

D. Cytoplasmic male sterility:

At present three practical systems have been described and one has been extensively used commercially. A_1 was discovered independently of A_2/A_3. The lines originally associated with them are:

System	Origin	Line(s)
A_1	Georgia USA	T F 23, $TF23D_2$, $TF18D_2$(USA)
A_2	Ludhiana India	L 66, L 103 (African)
A_3	" "	L 67, L 111

B-Lines for A_2 and A_3 maintain A_1 though the reverse does not hold but the maintainer for A_2 is a restorer for A_3 and vice versa. Some good restorers on A_1 act as B-Lines on A_2 and A_3. Maintainer/restoration apparently is governed

by single major genes, but modifiers can give partial fertility which can also be caused by environments. The situation is still not fully resolved since we have found for instance that good restorers on $23D_2A$ are not all good on 23A or $18D_2A$. Thus for forming complementary B and R composites for reciprocal recurrent selection it will be best to classify prospective entries on a single cytoplasmic A-line.

Restoration genes for these systems are not frequent (the reverse of the situation in sorghum where original ms_c maintainers are scarce). The fact there are three systems is advantageous because of the cytoplasmic diversity and because restoration on each system samples different genetic stocks. Thore appears to be no substantial disadvantage attached to any one of these systems though it must be noted that the current backgrounds of the A_1 lines are downy mildew susceptible, while A_3 lines seem more resistant. However there is no evidence to show that this is a cytoplasmic defect, or that susceptability is closely linked with any sterility gene since 'maiwa' A and B lines, resistant to downy mildew have been bred, starting from an A_1 source. In the numerous crosses made at ICRISAT $23D_2A$ has proved much the best combiner, and a greater frequency of good restorers have been found for it. Neverthless it will be our policy to develop B and R populations for all three systems, and also to make specific crosses to create new seed parents for each system.

Where strictly uniform hybrids are not required the possibility exists with pearl millet to make hybrids without the use of cytoplasmic male sterility by utilizing protogyny. The seed parent should be phenotypically uniform, shorter and less vigourous than the hybrid. Seed fields would be planted in the same manner as for cytosteriles, taking particular care to preserve uniformity

in the seed parent rows, and using a dense plant population to suppress tillering so that a high proportion of the heads come into flower at the same time. Cross pollination would exceed 80% in such conditions. However even if it were less the next crop will still give a yield approaching that of a pure hybrid, because of the competition between hybrid and selfed seedlings. This can be accentuated by thick sowing or as in the existing African systems, by planting in hills (or clumps) followed by thinning at a late stage. Experiments with such mixtures in forage pennisetum (without thinning) have shown 90% of the yield came from hybrid plants.

E. Grain weathering ability and seed dormancy:

The ability to ripen clean bold grain in moist conditions is possessed by many millet cultivars. This together with a measure of seed dormancy is essential for areas where millet is harvested when rainfall continues. A common African practice is to harvest the whole plants when ripe and stook them upright in the field where the heads will dry inspite of intermittent rain. In a week or so, during a dry spell the heads are removed.

Grain usually 'weathers' i.e. deteriorates, due to fungal damage. This may amount merely to superficial discolouration, or it may destroy the whole grain. Insect punctures, or physical damage to the pericarp greatly facilitate mould damage. There is no clear evidence on whether the more highly pigmented grains have better weathering ability. A great deal more needs to be known about the mechanism of resistance to weathering in millet.

It is debatable whether compact packing of the grain on the head contributes to good grain, since although rainfall or dew is less likely to penetrate a compact head, moisture flow in the other direction is impeded.

However compactness is associated with more grains per head, and hence with more yield.

Seed dormancy begins to build up as the grain hardens. Probably there is a stage during the development of the grain when it becomes capable of germination before dormancy is developed. Adequate studies on dormancy have not been undertaken, but it seems that total inhibition of germination can exist for several weeks after physiological grain maturity. After this, until the effects of dormancy have disappeared, the seed may be actually capable of germination but the seedling will be weak because of the continuing partial immobilisation of seed reserves. Efforts have been made to find ways of breaking the dormancy but without great success though heat treatment and oxidants do speed up the process.

While dormancy is required on the farm, it provides a problem where planting soon after harvest is required to hasten the breeding programme. This would very rapidly select against dormancy. The most critical stage is where aliquot samples of seed are used to provide a random mixture. In such a situation even partially dormant seeds would be at a fatal disadvantage. Renewed attempts therefore need to be made on artifically reducing dormancy. During the breeding process, particularly in the composites, the dormancy of the progeny needs to be monitored to ensure the maintenance of an adequate level, and if necessary, sufficient time will have to be allowed between generations to allow for this.

F. Grain quality:

This term covers a multitude of factors expressing consumer preference. Where the crop has traditionally been grown for food, the land-races which

predominate represent the best quality as selected by the cultivators. Quality preferences often differ from place to place, and thus of course can be determined by studying the grain type(s) of the localities. Consumer-producers in the lesser developed countries are often more critical of quality than commercial buyers in developed countries. Fortunately cultivators are also yield-conscious and when there is a demonstrable yield advantage they will accept some trade-off of quality against yield. However, the importance of grain quality should not be underestimated especially for consumer-producers and should rank next to yield in value.

The important factors contributing to grain quality as desired by the consumer-producer are:

1. Appearance - good colour (often slate coloured in pearl millet - a grey-blue), medium to large 'bright' grain (bright being a combination of cleanness and plumpness)
2. Texture. Hard grains are preferred. A vitreous endosperm is more resistant to mould damage, and to storage insects.
3. Ease of preparation. This is usually done by women who are most critical of the amount of work involved - the time needed for grinding the grain, the percentage of bran, the texture and colour of the flour, the amount of water absorbed, cooking time and volume of the final product.
4. Taste. Most difficult to define but generally the sweeter the better.

Nutritional quality has not been included in the above list because it does not have a readily recognisable value to consumer-cultivators. A variety which is merely of superior nutritional value will appear to have no advantage to farmers. Such a variety will need to have other attractive features to "carry" the nutritional benefit.

Millet compares favourably with wheat, rice, sorghum or maize in nutrient values, and though deficient in lysine, is less so than sorghum, maize or wheat. Calorific values are reported to be good (356 cal/100 g) with 84% of the grain being edible with (on average) 67-72% carbohydrate, 11.6% protein, and 5.0% fat. In feeding trials with rats, millet compared with sorghum and maize gave 28 and 26% higher growth rates respectively with or without supplemented diets. There is scant information on digestable carbohydrates in millet but the range of variability appears to be small. In contrast there is much variability for protein, lysine and oil content, but there are also large environmental effects. (Nitrogen fertilizer applications will give up to 6% increase in N). Reports on crude protein (N x 6.25) content range from 8-21% (ICRISAT analyses 8-18.5% - 115 samples) but 7% of the total N may be of the non-protein type while the prolamine fraction ranges between 21-38%. Lysine content ranges from 1.4 - 3.8% (ICRISAT 2.3 to 3.75 - 21 samples) of protein in normal seeds, but reports on the relationship of lysine and protein are contradictory - from a slight negative relationship to none. High variability in isoleucine/leucine ratios have also been recorded from 1.37 to 3.65. Oil content determinations range from 2.3 to 7.9% with oleic and linoleic fatty acids accounting for 89% of the oil.

The breeding implications of the nutrient information is that selecting for very high levels of protein would be difficult because of the negative correlation with yield - even at static protein contents increased yield would mean increased protein production per acre and more N which has to come from somewhere. Selection for higher lysine content may be much more feasible, but the consideration of both these attributes should be made in the context of the overall diet of those consuming millet. A rather small quantity of animal or vegetable protein can remedy the "deficiencies" in the cereal. It is therefore more realistic to maintain moderately good levels of protein (?14%) and pay some attention to lysine while selecting primarily for higher grain yield. It may be noted here that in wheat, apart from grain size, nitrogen content has been found to be positively correlated with seedling vigour (embryo size was not reported). Higher oil content though apparently nutritionally desirable may be disadvantageous since the flour goes rancid more quickly during storage.

G. Intercropping:

This practice, used by tropical farmers for centuries, exploits the situation where one crop ecotype alone cannot make the maximum use of the environmental potential.

A frequent form of environmental excess is an overlong period for growth. Here a combination of ecotypes which have peak requirements separated by time are best, rather than just by space, energy, water or mineral requirements where there is less differential. Thus growing short and long duration crops together is a common practice and millet fits well here as the short duration component though there are instances where photosensitive millet is the longer duration component. Not much work has been done on what, if any, should be the

difference between sole crop and intercrop cultivars. Some plasticity in plant population responses is evidently required for an intercrop cultivar, and for the early component in a combination a quick getaway to achieve a dominant position is essential together with complete senescence after grain filling. Only intra-crop competition is effective in sole crops whereas in crop mixtures inter-crop crop competition also becomes important. Genotypes which have differing external competitiveness should perform differently in a crop mixture. However, it has yet to be shown that yield improvements attained while breeding for sole crop performance do not also apply in an intercropping situation. Presumably this is because lowered intracrop competition also contributes to intercrop yields. Still, a check should be kept on the situation, to indicate whether it might be necessary to breed for the intercropping environment.

H. Adaptation and stability of yield:

Three characteristics describe the yield performance of desirable genotypes in different environements.

1. A high mean yield, accompanied by:
2. A uniformly superior performance in all environments relative to the average regression of performance (b = 1.0) - which indicates broad adaptability, and
3. Low deviations (s_d) from the regression of performance indicating good stability.

It should be noted that this usage of stability differs from the previously accepted meaning where a stable variety was one which gave similar yields in different environments, and which were therefore relatively high in poor environments but relatively low in good environments thereby showing a

high genotype x environment (G x E) interaction. This describes many unimproved varieties and their b values (above) would be considerably less than unity.

It has now been demonstrated with several crops including wheat, barley, maize, sorghum, tobacco and oats that genotypes can be identified which differ radically in their (b) and (s_d) values. Also that yield performance and adaptability appear to be inherited independently, so that it should be possible to combine high yield with broad adaptability.

Those factors which principally affect adaptation are genotype duration, rainfall amount and duration, temperature and light radiation. Adaptation can be seriously distorted by pest and disease susceptibilities so these are also prime considerations. To detect and select for adaptability and stability it is necessary to expose segregating material to different environments. Eventually it may be possible to simulate different environments for selection purposes or even define enough physical parameters for a critical judgement, but at present, to handle large numbers of genotypes, there is no alternative but to use natural environments. Different years at the same site constitute different environemnts, but also effective and more desirable is the use of widely different sites in the same year, with different dates of planting and fertility levels within sites if possible. Some measure of plant response to the environment such as yield, is taken as the environmental index, and individual genotype performances are compared to the average performance of all genotypes at all environments.

In effect this principle was used by Borlaug in the Mexican wheat program where selection was performed over a range of productivity levels (fertilized and unfertilized), at different altitudes and latitudes.

G x E interactions can constitute an important limiting factor in the efficiency of selection programs. For instance if one works within genotypes where flowering is in response to photoperiod, the application of research is limited to only those zones where favourable conditions for yield production coincide with the previous occurrence of a given day length.

Therefore it is most desirable to detect those genotypes which have broad adaptation at an early stage in the breeding program so that research resources are subsequently used to the most effect.

So far we have been discussing adaptability and stability in reference to individual genotypes but since the variance of a mean is less than the variance of an individual, a mixture of adaptable genotypes should show a lower G x E interaction than a single genotype. This is in addition to the concept that populations or multiline bulks have lower G x E's due to the dominance of the more successful components relative to the particular environment.

I. Outreach Program

This is understood as consisting of a supply information and genetically useful material available to agriculturalists in the semi-arid tropics. It does not include those parts of the breeding program (the International program) external to Hyderabad but concerned with the development of the core program. Return of information will be sought from outreach activities which may well assist with genotype evaluation, but this should not be the prime aim.

The outreach program will consist of:

1. Hybrids (parents of which can be supplied)
2. Segregating populations from variety crosses.
3. Composites
4. Inbred lines (should be few in number)
5. Information (from anywhere in SAT). Results, breeding methods,
   - possibly a millet newsletter.

HD:psn

CEREAL (SORGHUM AND PEARL MILLET) PATHOLOGY
(Program for 1975)

(Y.L. Nene, K.N. Rao, and S.D. Singh)

We know that both sorghum and pearl millet suffer from a very large number of diseases. Most of these are caused by fungi and a few by bacteria and viruses. At ICRISAT we have now identified some problems on which we wish to concentrate our attention. Following is the brief outline of our program for 1975.

I. Sorghum

A. Head moulds

1. Identification

Already we have identified seven species involved in producing mouldy heads. These are (i) *Curvularia verruculosa* (ii) *Collotortrichum* sp. (iii) *Fusarium* spp. (iv) *Olpitrichum* sp. and (v) *Phoma* sp. (vi) *Penicillium* sp. (vii) *Helminthosporium* sp. Since species of moulds attacking sorghum heads show seasonal variations in their occurrence, we wish to continue our surveys to find out what other fungi might be involved. We also plan to collect information on head moulds from different countries through correspondence. Based on the type of growth, colour, and other characters visible to the eye, we propose to work out a procedure to identify the genera involved in causing the mouldy heads.

2. Effect on seed quality and germination

We have already found out that the seed infected by species of Curvularia and Fusarium fails to germinate. We wish to continue these investigations with other species. This will give us information on more serious fungi so that we could concentrate our efforts on controlling the serious ones first.

3. Screening for resistance

It may be difficult to locate material having true resistance to all the moulds. However, it may be possible to identify material which is resistant to one or two moulds. We therefore propose to work out techniques to artificially screen the germplasm against species of Fusarium and Curvularia as the first phase of our program of screening for mould resistance.

In addition, data on the natural incidence of moulds on all the breeding material will be collected to locate material which might have promise.

B. Downy mildew (Sclerospora sorghi)

1. Developing "sick plot"

The primary infection is through oospores present in plant debris. It is an established fact that oospores constitute a major source of infection under natural conditions. It is possible to get good infection by incorporating diseased plant material in a plot prior to planting. For the screening of a

large amount of germplasm and early generation breeding material, it is very convenient to have a "sick plot". We therefore propose to develop a "sick plot" by adding large quantities of the fungus inoculum.

2. Studies on oospore survival

Since oospores constitute a major source of inoculum, as pointed out earlier, we wish to study the survival of the oospores. Although several workers have studied oospore survival before, these studies have suffered from some weaknesses. For example, most of these studies have been carried out by storing oospores in paper bags/ containers in laboratories or by incorporating them in sterilized soil in pots or trays. These situations are not the ones which the oospores get exposed to under natural conditions. Also in these studies influence of non-host crops on oospores survival has not been looked into. Therefore information on survival obtained from these experiments may not be correct. We have therefore initiated experiments where these studies are carried out under conditions as close to the natural ones as possible.

It is known that exudates from sorghum roots stimulate oospore germination. We plan to study influence of root exudates of different non-hosts of the downy mildew on oospore germination. If we do find exudates from non-hosts stimulating germination of oospores, we could use these non-hosts in rotation with sorghum and thereby reduce the fungus inoculum in the soil.

Likewise soil extracts are also known to stimulate germination. It is quite possible that certain soil organisms might be attacking the oospore wall and thus stimulate the oospore to germinate. We plan to run a few experiments with some organisms to see if these stimulate the oospores to germinate.

C. Leafspot fungi

We plan to continue surveys to identify serious leaf pathogens. Also we will collect disease severity data under natural conditions in breeding material. Already we have identified a species of Helminthosporium (tentatively identified as H. turcicum) which has caused a severe leaf blight in many sorghum entries. We plan to initiate detailed studies on leafspots only after identifying the more serious ones.

II. Pearl Millet

A. Downy mildew (Sclerospora graminicola)

1. Developing "sick plot" and oospore survival studies

The background information given under the downy mildew of sorghum holds true in this case also. We therefore plan to carry out similar studies on the pearl millet downy mildew. We propose to develop about 1 hectare "sick plot" to accommodate a large number of germplasms and breeding material.

2. Fungicidal seed treatment

The work done elsewhere indicates that the asexual stage (zoospores), although produced abundantly, plays almost no role in the spread of the disease. It is possible that the

spread of downy mildew by zoospores depends on environmental conditions which may not occur commonly. Therefore the sexual stage, the oospores, is the major inoculum. Although the controversy whether the downy mildew fungus is also internally seed-borne continues, for all practical purposes, oospores present on the seed or close to seed constitute the major source of inoculum. We therefore propose to use fungicides for seed treatment to see as to what extent we can control the disease. We plan to use some newly developed systemic fungicides, which have been found effective against pythiaceous fungi, for seed treatments to protect seedlings for a longer time.

B. Ergot (Claviceps microcephala)

1. Standardization of technique to screen for resistance

We have already confirmed that if the "honey dew", which contains a large number of conidia, is mixed in water and then sprayed on ears which have emerged and have open spikelets, a high degree of infection could be obtained. We plan to work on standardizing this technique for the purpose of having a uniformity in the screening procedure. Hopefully we should be able to initiate screening of germplasm during the year by following the procedure.

2. Survival studies

We plan to initiate experiments to find answers to the following:

(a) how long can the conidia survive ?

(b) how long can the sclerotia survive?

(c) what are the collateral hosts of the ergot fungus around the ICRISAT site?

C. Rust *Puccinia penniseti*

1. Estimation of losses in yield

Although the rust incidence appears severs in Kharif plantings, it usually comes late in the season. It is therefore necessary to knew the extent of loss which the rust causes. We propose to carry out this study by using frequent fungicide sprays to control the rust and compare the yields with unsprayed plots.

2. Screening for resistance

In Kharif 1974 season, we identified about 500 germplasm cultures which showed less than 10 percent severity rating on modified Coob's scale. We plan to further screen this material under artificial conditions by spraying the rust inoculum.

PROPOSALS FOR THE SORGHUM MILLET ENTOMOLOGY PROGRAMME 1975,

UNDP COMMITTEE J.C.DAVIES AND SHESHU REDDY

It is proposed to continue to assess general pest incidence by means of sampling and light trapping during 1975 in order to build up a comprehensive picture of the occurrence of the major pests of cereals over the years.

Screening

1. Atherigona Some 730 lines will be screened in the rabi season under conditions of high shoot fly incidence. The established interlard/ fish meal technique will be utilized. Studies will continue on oviposition behaviour, primary resistance, and utilising better fertility levels than last year, recovery resistance. The objective will be to identify lines with resistance for use in the breeding programme. All material will be duplicated in breeding blocks so that crossing can proceed as results become available.

2. Contarina Sufficient seed from 51 lines obtained from Nigeria/ Texas will be available for testing in the rabi season. Assessments will be made at Patancheru where lines will be deliberated sown late with interlard CSH_1. There is evidence from preliminary trials that a fair degree of pest resistance to midge occurs in the EE lines which have already been partly screened for shoot fly and on instances Chilo (V lines). Other material to be sown includes material of 250 fertiles produced by the breeders.

3. Chilo A screening system for Chilo will be developed. This will make use of established techniques dependent on artificial infestation of

plants with viable eggs. Adults will be reared on medium food rather than plants. It is hoped that the programme will get underway as soon as electricity supplies are available and the egg punch machine arrives. In the meantime lines will be screened under the moderate infestations present at Patancheru and methods of assessment developed.

Promising lines from these programmes will be tested in due course at a range of sites in the SAT.

Observation

A further area of sorghum will be sown in the kharif to enable pest damage assessments to be made on a standard crop. Information on the relative importance of the various pest species is still far from adequate. Differential spray will be applied to plots to guage the effect on yield. Spray cover will be based on the results obtained in the 1974 season. It is hoped to use area BA 25 for insecticide free studies but to introduce a basal level of fertility and eradicate rats which severly affected establishement in 1974.

Control of Pests

Contacts have been established with CIBC (Biological Control), COPR and the Royal Botanic Gardens, Kew (studies on factors influencing host plant resistance) and the Boyce Thompson Institute (possible virus control of pests) These will be developed. It is not felt that the programme at ICRISAT should be geared towards straight forward application of insecticides since (1) a range of insecticides to cover individual pest species are already known and have proved effective (2) in general the sorghum crop is one

which will not 'stand' expensive pesticide inputs (3) economic benefits are unlikely to be achieved at the levels of agronomy currently practiced throughout much of the SAT.

PLANT PHYSIOLOGY

II PROPOSAL FOR SORGHUM/MILLET WORK IN 1975

The cereal physiology projects will be developed so as to be of direct or potential use in the breeding programmes for the development of efficient plant types in terms of growth, use of nutrients and endurance to water stress.

1. Growth and development physiology

Genotypes will be screened and evaluated for growth, developmental and morphological characters. Major emphasis will be on seedling vigour, lengths of GS1, GS2, GS3, dry matter production and partition, grain number and seed size. Studies will also be developed on aspects which may be of potential value and these are grain size plasticity, dry matter partitioning in GS2 and the associates morphological changes and their effects on yield components, effects of time and nature of formation of abscission layer in the grain on grain size, and translocation of previously accumuled carbon to the head.

2. Nutrition physiology

Genotypes will be screened and evaluated for efficient use of nutrients. Major emphasis will be on pattern of nutrient uptake in space and time, translocation of nutrients from negative parts to reproductive parts, and the association between grain yield and grain nutrients. Studies will also be developed to identify variation between genotypes in tissue nutrient concentration and intra-plant nutrient source-sink relationships.

3. Water relations and water stress physiology

Genotypes will be evaluated for ability to endure water stress. Emphasis will be on the most sensitive growth stages and the nature of recovery

after water stress at these growth stages. Studies will also be conducted to identify buffer mechanisms of potential value in overcoming effects of water stress. It is hoped to have a research associate to work on this project and the position has been advertised.

4. Seedling vigour

Studies will be conducted into developing techniques for screening genotypes with seedling vigour. It is also hoped to study seed and seedling characteristics associated with seedling vigour under stress (water, nutrient and temperature) and no stress conditions.

5. Panicle development

Studies will be initiated to understand in detail changes which occur in the panicle through the whole course of its development from initiation to physiological maturity. This may help in understanding factors which influence seed number and seed size under stress and no stress conditions.

6. Root studies

Some preliminary studies will be initiated in understanding the growth and development of roots under stress and no stress conditions. This may help in developing techniques for screening genotypes with efficient root system.

7. Rhizosphere fixation of nitrogen

A little work will be initiated on rhizosphere fixation in selected genotypes using the acetylene reduction assay technique to measure root nitrogenase activity. Dr. Peter Dart at Rothamsted has agreed to assay the gas sample from ICRISAT.

8. Physiology of striga resistance

Preliminary studies may be initiated on the anatomical aspects of haustoria root attachment and penetration subject to discussions with the breeders.