ASSESSMENT OF ICRISAT RESEARCH ON PEARL MILLET DISEASES AND FUTURE PLANS

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Introduction

Research on pathology of pearl millet at ICRISAT Center began in 1974 under the leadership of Dr. Y.L. Nene. Drs. S.D. Singh and R.P. Thakur became a part of the subprogram in August 1974 and January 1976, respectively, and Dr. R.J. Williams was employed as subprogram leader (cereals) in September 1975. At the time of division of the Cereal Program into separate programs for sorghum and pearl millet, Drs. Williams, Singh, and Thakur continued with the millet pathology subprogram. Dr. Williams served as subprogram leader until his departure in December 1982 and I joined ICRISAT as subprogram leader in June 1983. In West Africa, ICRISAT has had three pathologists involved in millet research: Dr. N.V. Sundaram located at Samaru, Nigeria (1977-1981) and Dr. Frowd located at Kamboinse, Burkina Faso (1976-1981), both having responsibilities for sorghum and pearl millet, and Dr. E.J. Guthrie located at the ICRISAT Sahelian Center, Niamey (1981-1984) with responsibilities for pearl millet. Dr. J. Werder joined ICRISAT in February 1985 as millet pathologist at the ISC.

Considerable research on millet pathology has been done at ICRISAT Center. One of the early events which gave direction to the program was a consultants' group meeting on "Downy Mildew and Ergot of Pearl Millet" held in Hyderabad in October 1975 (5). Research was started early on downy mildew (Sclerospora graminicola), ergot (Claviceps fusiformis), and smut (Tolyposporium penicillariae), with emphasis on developing reliable, screening techniques in the field and identifying sources of resistance within the ICRISAT world collection of pearl millet and in breeding materials. The research effort also

focused on aspects of biology and epidemiology of these three diseases, and this has continued up to the present. A fourth disease, rust (Puccinia penniciti), has received relatively less attention, with research being limited to screening for resistance under conditions of natural inoculation in the field. The International Pearl Millet Disease Resistance Testing Program has been active for the four diseases since its inception in 1976 to 1978.

Achievements

Millet Pathology research at ICRISAT has been very successful and productive. This is a credit to the scientific leadership of Dr. R.J. Williams, and the deligence and dedication of Drs. S.D. Singh and R.P. Thakur and the support staff in the sub-program. Collaborative projects with the University of Reading on pathogenic variability in S. graminicola and with Imperial College on mechanisms of resistance to ergot have been most useful, and I am pleased that both were recently extended through March 1988.

I have briefly indicated below the areas which I believe represent the major research achievements in millet pathology at ICRISAT. This does not constitute a review of the literature, but it does highlight what I believe to be the most important achievements and publications of the subprogram. These represent a substantial contribution to knowledge on the pathology of pearl millet, and ICRISAT has reason to be proud of this record. However, there appears to be relatively little to show for almost 8 man-years of effort by ICRISAT in millet pathology research in West Africa.

Screening techniques

The most significant achievement has been the development of reliable, field-screening techniques for downy mildew (33), ergot (28), and smut (25). These techniques have been essential for the identification of sources of resistance and their utilization in the breeding program. Furthermore, we are extremely fortunate that they are effective at Patancheru where the major breeding effort is done and that they can be used successfully during two seasons each year. It is unfortunate, however, that there has not been a greater transfer of this screening technology to national programs in India and even ICRISAT programs in Africa.

An inoculation technique for glasshouse usage, which applies extremely high downy mildew pressure to seedling plants, has been developed (16). We anticipate considerable use of this technique in the future for screening select materials.

Multilocational testing

The International Pearl Millet Disease Resistance Program (IPMDRP) was initiated at an early stage in the program for downy mildew (6), ergot (7, 23), smut (8, 26) and rust (9). Data pertaining to years, number of locations in India and Africa, and number of entries tested per year are presented in Table 1. This program was the first of its kind to include India and Africa, although testing in Africa has generally been limited. The program has not only made it possible to determine the stability of resistances, but it has also provided an excellent opportunity for contact with scientists in

national programs, whose cooperation is essential for its success.

Resistance identification

Reliable, field-screening techniques together with the availability of a large diversity of pearl millet germplasm, both accessions of the GRU and lines/populations in pearl millet breeding, have been crucial for the identification of a number of sources of disease resistance (Table 2). Many of these have been tested in the IPMDRTP where some have demonstrated stability of resistance across locations and years (Table 3). These are the only known sources of disease resistance which have successfully passed through such rigorous testing. It was demonstrated that A_1 male-sterile cytoplasm is not involved in determining susceptibility to downy mildew (1).

The development of ergot resistance was a remarkable feat considering the fact that no resistant lines were found among the over 10,000 lines that were screened (28), however, highly resistant lines have been produced, however, through pedigree selection of progeny from less susceptible plants and crossing between them. These are the only sources of ergot resistance available, and their production was possible only because of the reliability of the screening technique used.

Another interesting, but somewhat different procedure for deriving highly resistant lines from highly susceptible ones was demonstrated for downy mildew in a landrace of pearl millet (20). In this case resistance was achieved by selecting seed from symptomless plants growing in the downy mildew nursery and reselecting symptomless

progeny for several generations under high downy mildew pressure.

Numerous sources of multiple disease resistance have been identified including 28 which are resistant to downy mildew and smut, 48 which are resistant to downy mildew and rust, and 22 which are resistant to downy mildew, ergot, and smut.

Resistance utilization

Utilization by breeders at ICRISAT Center of sources of disease resistance identified by the pathologists has been significant, and it has been increasing in recent years (Table 4). Most use has been made of smut resistant sources and this through the population breeding program where a smut-resistant composite has been formed and smut resistance is now being bred into three other composites. Smut resistance has also been used to breed smut-resistant synthetics, one of which (ICMS 8283) is now in advanced testing and will likely be promoted to testing by the All India Coordinated Millet Improvement Project (AICMIP).

Two sources of ergot resistance are being used in breeding both parents of two ergot-resistant hybrids, and four others are being used in breeding ergot-resistant, male-sterile lines. Additionally, an ergot-resistant composite of 52 ergot-resistant lines/populations is now being formed. Ergot-resistant synthetics were produced, but the yield levels were low and further advancement was abandoned.

Rust resistance based on a single, dominant gene (2) is being transferred to specific male-sterile lines, because rust is often a significant disease in the off-season when hybrid seed is produced. Hybrids involving these resistant male-sterile lines will be resistant.

Downy mildew resitance identified by pathologists has had little utilization in the breeding program although a few resistant lines were used in the Source Materials Project several years ago, the progeny of which are still in the breeding program. An effort has recently been initiated to breed downy mildew resistance into the Pollinator Project and Male-Sterile Project. The limited use of sources of downy mildew resistance is likely due to the fact that breeding lines and populations are routinely passed through the downy mildew screening nursery where resistance is improved by the process of eliminating susceptible plants. This screening procedure was used to produce resistant versions of 5141A and J 104, and thus a downy mildew-resistant version of the popular Indian hybrid, BJ 104. Seed of the resistant parents have been sent on request to breeders and pathologists in the National Program, and to private and state seed companies. Seed of hybrids involving one or both of these parents is now being produced.

Seed of many other sources of resistance have been supplied to millet breeders and pathologists upon request (Table 4), but we do not know to what extent these are being used in breeding programs. Cooperators are known also to obtain sefled seed of some entries in the international disease testing nurseries, but again the extent of utilization of this material is not known.

Pathogenic variability

The so-called 'breakdown' of resistance to downy mildew in pearl millet cultivars in India has been a matter of concern since the first millet hybrid (HB 1) grown on a large scale in India succumbed to downy mildew about 15 years ago. For this reason, ICRISAT has been involved in research to illucidate the cause of this problem. Although the reasons for breakdown are still not clearly understood, the determination of heterothallism in S. graminicola (11) clearly demonstrates that this fungus has a very good mechanism for undergoing genetic change. Work done by collaborators at the University of Reading has confirmed this finding, and further more it has demonstrated that the mating types found in Africa and India are compatable with each other (10). Indications of pathogenic variability in S. graminicola have been observed in data obtained from multilocational testing in the IPMDMN (6), and clear differences in aggressiveness among isolates from India and Africa have been demonstrated at the University of Reading (3). One isolated, but clear demonstration of pathogenic difference in S. graminicola has been shown in a cooperative study by ICRISAT and the National Program at Durgapura, Rajasthan (18).

Variations in morphology and pathogenicity among isolates of the ergot fungus (C fusiformis) in India have been investigated in a cooperative study between ICRISAT and Punjab Agricultural University (4), but distinct differences in pathogenicity were not found.

Seed transmission of S. graminicola

At the time ICRISAT began its pearl millet research, the question of transmission of S. graminicola in pearl millet seed was a 'hot' issue in India, one which was of vital concern to ICRISAT because of quarantine implications this matter had on bringing collections of pearl millet into India from Africa. A joint study of this question was done by ICRISAT and two National Laboratories in India. Although evidene was found to suggest that the fungus might on occasions be harboured within the seed, it could not be demonstrated that downy mildew infected plants could be produced from surface-sterilized seed (14, 30). A study at ICRISAT further showed that a technique demonstrate viability of oospores using triphenyl tetrazolium chloride was not a for valid use on S. graminicola (31).

Alternative control measures

Millet pathology has done signifiant research on methods other than host resistance which might be used to control diseases of pearl millet. A series of studies demonstrated rather convincingly that the systemic fungicide, metalaxyl, can be used as a seed treatment and/or a foliar spray to control downy mildew (15, 17, 32). Similar results have been found in several studies by scientists in the national program.

Following a study on the inhibition of ergot infection by timely pollen application (27), a study was conducted to see if this phenomenon could be exploited to reduce ergot infection in hybrids in a field situation (29). The results obtained clearly indicated that

if a pollen donor line were planted with a hybrid so that pollen was available during the protogyny stage of the hybrid, significant control of ergot could be obtained. An experiment to demonstrate these findings multilocationally was considered by AICMIP, but unfortunately the study was never implemented.

Biology and epidemiology

Field studies clearly demonstrated the importance of sporangia in the epidemiology of downy mildew during both the rainy and post-rainy seasons [19], and these experiments lead to refinement of the downy mildew screening technique which is based on sporangial production, dispersal, and infection of pearl millet under conditions of high humidity and moderate temperature (33). Investigations into the biology, epidemiology, and pollenation effects on ergot [22, 27] and smut [21, 24] were instrumental in the improvement of screening techniques and led to a better and more complete understanding of these two floral-infecting diseases. Research conducted through the collaborative project on the biology and etiology of C. fusiformis and on the associations between pollen and stigma interactions led to the discovery of stigmatic constriction in the gynoecia of pearl millet which could play an important part in avoidance of infection of the pearl millet ovary (34).

Future Research Priorities

General

1. In India, downy mildew research should receive first priority, followed by ergot and smut as second priority, and rust as third

priority. In West Africa, downy mildew should receive first priority, followed by smut then ergot. Striga hermonthica is an important parasite which should receive attention from pathologists and researchers in other disciplines, but it should not be placed ahead of downy mildew research in West Africa, at least not in the near future. Little is known about the disease situation in Southern Africa, but downy mildew, ergot, smut and rust are probably the most important diseases and disease severity is likely to vary significantly with changes in elevation. Disease surveys in the region should be considered, at least on a limited scale.

.. Reliable disease screening techniques must be established at ICRISAT locations in Africa. Efforts to encourage the national program in India to raise the level of reliability in disease screening should continue, and these efforts should be intensified in Africa.

.. Multilocational testing should be conducted at fewer, more important sites in India (Table 5), and at more sites and with a higher degree of reliability in Africa. Each site should be visited by a pearl millet pathologist at least once during the growing season. Site selection should consider more critically the likely probability of suitable environmental conditions for reliable screening, facilities available for screening, and interest of the cooperator. We should be prepared to help materially and financially (eg. fertilizer, labor, inoculation equipment, selfing bags) if necessary.

4. We should generally suspend the screening of more accessions of the world collection of pearl millet for disease resistance, at least for the immediate future. Resistance evaluation should concentrate more on breeding material and obtaining more information on sources of resistance already identified.

5. More ways should be sought to use the resources available at ICRISAT Center to advance research on diseases and their control by both ICRISAT and national programs in Africa.

6. Continued effort is needed to improve the expertise of both Indian and African scientists and their support staff in millet pathology research techniques. Sources of stable disease resistance in desirable agronomic backgrounds should continue to be an objective, and these should be made available to national programs.

7. Micro-computers should be introduced into the subprogram to reduce time spent in data recording and transfer of data to the Vax.

8. I would like to see the pearl millet research of ICRISAT extended on a larger scale to Rajasthan, because of the important part this crop plays in the agriculture of that State. Resistance evaluation would likely be the principal activity of millet pathology.

Downy mildew

1. Although numerous sources of resistance to downy mildew have been identified, practically nothing is known about the nature of resistance. We do not know, for example, if a given source of

resistance prevents the fungus from infecting, or if it allows infection but eventually stops colonization, or if it supports colonization but at a much reduced rate. The nature of resistance should receive attention because it might lead to a better understanding of the types of resistance which are likely to be longer lasting. Inoculum concentration may be an important component in the characterization of resistance, and therefore it should receive some research attention. Better techniques are needed to assess inoculum concentration.

2. Related to the question of the nature of resistance is the inheritance of resistance. Several attempts have been made to determine the inheritance of resistance in pearl millet to downy mildew (12, 13), but none have given results which can be interpreted unequivocally. This is likely a reflection of the variability for virulence in the pathogen population and the variability for resistance in the host population. Regarding the pathogen, we could probably produce sporangial inoculum in which all individuals are genetically identical; however, we would have difficulty maintaining these cultures in a pure form on plants in the glasshouse since the fungus cannot be cultured on artificial media and techniques for long-term storage have not been developed, although this is being persued at the University of Reading. Regarding the host, it may be necessary to solicit the help of a mentor institution to investigate the possibility of obtaining pure lines by means of producing doubled haploids. As there is currently no solution for dealing with these problems, I believe it would be unwise to attempt now to embark on a program to identify

resistance genes in the host and corresponding virulence genes in the pathogen, as was recommended by the EPR. However, attempts to reduce variability in both the host and pathogen for genetics studies through the help of mentor institutions should be persued in the future. A study on the inheritance of resistance to downy mildew is already underway at ICRISAT Center, and, although a special effort was made to breed highly inbred lines of pearl millet for this study, no attempt was made to produce and use a genetically uniform isolate of the pathogen.

3. A long-term, multilocational nursery designed to monitor shifts in virulence of S. graminicola and to gain an estimation of the durability of resistance to downy mildew within commercial cultivars of pearl millet in use in India was initiated through the All India Coordinated Millets Improvement Project (AICMIP) in 1984. Sufficient seed for approximately 15 years of testing is being kept in cold storage at ICRISAT Center to ensure that changes in downy mildew reaction with time cannot be attributed to changes in the genetic constitution of the cultivars. This experiment should give more definitive information than is currently available on shifts in virulence of the pathogen population and on the durability of resistance of commercial cultivars. Collaborative work on pathogenic variability in downy mildew at the University of Reading should also maintain large quantities of seed of genotypes used in experiments.

4. We should continue multilocational testing, but reduce the number of locations in India to five or six. Special effort should be

made to have more locations in West Africa where reliable screening is possible.

5. There should be established a West African pearl millet downy mildew nursery. This could contain a few selected lines from ICRISAT Center, but the vast majority of entries should be contributed by researchers in various parts of West Africa. Such a nursery should not be begun, however, before 1986 as screening facilities are currently very limited in the region. Additionally, this nursery could also be evaluated at the University of Reading against several isolates of S. graminicola from other West African locations.

6. Priority should be given to development of a second site in India (possibly Bhavanisagar) and two sites in West Africa for reliable testing of resistance to downy mildew including testing of the resistance of advanced breeding materials produced at ICRISAT Center. These sites could expose genotypes to potentially four different populations of S. graminicola. Limited, but valuable service could also be provided to the Indian national program for testing advanced material for stability of downy mildew resistance. ICRISAT and national programs in Africa could utilize the two locations in Africa. The infector row system and perfospray irrigation, if possible, should be used, and screening should be under ICRISAT control.

One of the Africa sites should be in Niger, either at the ISC or at Gaya, and the other site should preferably be in northern Benin at a location easily accessible by road from Niamey. Experience has shown that Kano and Samaru, Nigeria, are locations with the highest levels of downy mildew pressure in West Africa, and as one moves westward the aggressiveness of the pathogen populations seem to decline. For a number of reasons, however, Nigeria currently does not appear to be a suitable place to conduct screening, although the situation could change in the future. Niger and Benin, because of their close proximity to Nigeria with locations having environments similar to Kano and Samaru might be the next best alternative. Hopefully, at some later date reliable screening would also be possible at the site of the Regional Sorghum Center. Additionally, it is hoped to establish reliable screening facilities at Cinzana, Mali, and Bambey, Senegal, in cooperation with national programs in those countries. Locations in Southern Africa will need to be identified.

7. Dependable field inoculations at night of emerging pearl millet seedlings should be possible at ICRISAT Center as a method for increasing downy mildew pressure in the absence of perfospray irrigations although further experimentation is needed to confirm the reliability of this inoculation technique. Inoculum in the form of a sporangial suspension could be applied with hand-held pressure sprayers, and as has been done in the past, a few tube lights powered by a pickup truck-mounted generator could be used to facilitate the operation. Isolation plots could be inoculated in this manner to reduce the chances of increasing seed of susceptible

plants of ICRISAT-finished products, as was suggested by J.R. Witcombe in his seminar report. If successful, the technique could be extended to at least some breeders' fields.

8. Downy mildew inoculation techniques should be improved. This has already been initiated in the 6 ha downy mildew nursery where we are now inoculating infector rows at emergence at night with a sporangial suspension. This procedure eliminates the need for "infector pots" which involve considerable expense and labor each season. The glasshouse technique presently being used to inoculate emerging seedlings generally gives high downy mildew pressure and has considerable scope for expanded use; however it should be more standardized and be made less labor intensive.

9. The line 7042 has been demonstrated to be universally susceptible to pearl millet downy mildew. Therefore, it should be included in multilocational nurseries. However, the super-susceptible version of 7042 should no longer be considered as a suitable susceptible check, because it is too highly susceptible. Under low downy mildew pressure, even moderately susceptible entries can appear to be resistant when 7042 registers a high frequency of downy mildew. A genotype which expresses moderate susceptibility to downy mildew in the downy mildew nursery at ICRISAT Center should be identified as a susceptible check and sufficient seed for several years of use should be increased. Susceptible checks and genotypes suitable for infector rows should also be identified for use in Africa.

10. An attempt will be made to determine if genotypes from West Africa

can be improved for their resistance to downy mildew at ICRISAT Center. Seed of select West African varieties will be brought to ICRISAT Center, and after passage through quarantine, they will be screened twice under high downy mildew pressure using the glasshouse screening technique, and surviving plants transplanted to the downy mildew nursery. Seed will be harvested and this reselected seed will be returned to West Africa for comparative testing with remnant seed of the varieties.

11. Numerous sources of downy mildew resistance have been identified from among the world collection of pearl millet. Further screening of new accessions should be suspended, however, until it seems advantageous to take it up again. Many of the resistant accessions have been further screened under downy mildew pressure to improve their levels of resistance and to improve their agronomic worth. Furthermore, many breeding lines with downy mildew resistance have been identified and the resistance of others has been improved through selection in the downy mildew nursery. More attention should be given to improving breeding materials, especially from composites, for downy mildew resistance. These are already agronomically elite materials, and they should be more useful to our breeding program and to national breeding programs than sources of resistance which are agronomically less attractive.

12. There is a need at ICRISAT Center and at the ISC for field data on physical aspects of the micro-environment of millet plants in relation to the development of downy mildew. We are in process of ordering data loggers for both locations and expect to be able to

acquire data on wind velocity, temperature at the soil surface (at emergence), the leaf temperature of the crop (especially at GS1 and early GS2), relative humidity, duration and intensity of dew on the leaf surface, and radiation. These data together with spore trapping data should help us to better relate environmental factors, spore production, and disease development. This type of information is especially needed at the ISC, and should help to determine how readily this technology can be transferred to locations other than ICRISAT Center.

13. A repeatable technique for the germination of oospores of S. graminicola is not known. At ICRISAT Center we are initiating efforts to germinate oospores based on techniques which have been used with oospores of related fungi. In addition, Dr. A.F. Schmitthenner, who was a consultant with us in September 1984, is attempting to secure a grant from USAID to pursue studies on the germination of oospores of S. graminicola from foxtail millet (Setaria italica) in the United States. S. graminicola does not occur in the United States on pearl millet, but it does occur on Setaria. Any techniques which are successful in the germination of oospores of Setaria could be attempted on S. graminicola from pearl millet at ICRISAT Center. Identifying a reliable technique for oospore germination could be useful in several ways, for example it could allow us to make comparitive studies to identify reaction of genotypes to oospores vs. sporangia, and it might make possibile effective use oospore coated pearl millet seed for screening purposes. At locations where perfospray irrigation is not available, resistance screening could possibly be enhanced by

coating seed with oospores before planting. These oospores would be pretreated for ready germination.

Ergot

1. It is hypothesized that in a field situation inoculum for ergot infection of pearl millet florets comes in the form of ascospores produced from germinating sclerotia in the soil. However, the inoculum used in inoculations for screening at ICRISAT (and elsewhere) is a water suspension of conidia (both macro- and microspores) from the honeydew exuded from infected florets. It is generally held that conidia require 12-16 hrs to germinate after coming into contact with the stigma. As the interaction between pollination/inoculation of the stigma and subsequent fertilization/colonization of the ovary are apparently critically dependent on timing, it would seem appropriate to acquire data on the physiology of spore germination (collaborative project, Imperial College) and length of time required for the germination of ascospores on stigmas.

2. Studies on variability in pathogen populations should continue. These should include morphological variability (in reference to collateral hosts), pathogen variability in India and possibly later in Africa, and biochemical variability with reference to alkaloid pattern.

3. The mechanism of resistance to ergot demands further investigation. In light of earlier findings at ICRISAT and more recent findings at Imperial College, resistance which has been identified should be

characterized with respect to initiation and rate of stigma emergence, initiation and rate of anthesis, timing of ageing constriction relative to first stigma emergence, and viability and/or self compatability of pollen. An attempt should be made to prove whether or not one or more of these factors are responsible for the resistance which has been identified following ergot inoculation. Can, in fact, ergot resistance be totally accounted for by the factors involved in the events of flowering? If we can confidently say that the answer to this question is 'yes', then it is conceivable that breeding for ergot resistance could be done with less frequent exposure of breeding generations to the fungus and the environmental factors (moderate temperature and high humidity) which presently are necessary at every breeding generation for identification of resistance following inoculation. An experiment to further investigate this matter has just been initiated in pearl millet breeding. Further work is needed. Hopefully we can have a fairly clear answer to this question by April 1986.

4. The research on breeding ergot resistant hybrids should continue to determine the success of the first test-crosses (likely 1987). Furthermore, work recently began on the formation of an ergot resistant composite using ergot resistant lines should be continued to breed resistant varieties. The multilocational evaluation of the IPMEN should be continued in India and Africa, but at only about 4 locations in India.

5. Screening of more accessions from the genetic resources unit for

ergot resistance should be suspended in order to devote more time to testing the hypothesis of resistance based on events of flowering. For the same reason it seems appropriate to suspend further studies on inheritance of resistance to ergot.

6. More definitive information is needed on the importance of ergot in West Africa and southern Africa.

Smut

1. Studies on smut are needed 1) to better understand events relating to infection including the path of infection, 2) to illucidate the mechanism of resistance to smut, and 3) to determine the existence of virulence differences in the pathogen. Very little definitive information on these aspects is now available. Some of this research could possibly be done by research scholars and/or by collaborative work with a mentor institution.

2. There is a need to measure factors of the microenvironment which affect smut development in the field, especially the effect of temperature and relative humidity on spore germination, formation and growth of dikaryotic mycelium, and infection of florets.

3. Efforts to improve the Smut Resistant Composite and to add smut resistance to three other composites should continue. Lines derived from these composites should be further improved for smut resistance. More effort should be made to insure that, in addition to downy mildew resistance, our advanced breeding material is also resistant to smut. This is especially important in light of the

fact that smut can be severe in southern Africa and testing to date suggests that pearl millets bred in India are well adapted to conditions in southern Africa.

4. We should examine the feasibility of improving at ICRISAT Center the level of smut resistance in advanced breeding lines being bred in West Africa.

5. Studies on inheritance of smut resistance should continue, as should the transfer of resistance into hybrid parents.

6. The multilocational testing of the IPMSN should continue at more locations in Africa, but not at more than four locations in India. An exchange of smut resistant material should be made with the USDA at Tifton, GA.

Rust

1. Several areas of the biology of rust require attention. These include clarification of the taxonomy of the pathogen (with assistance from CMI), determination of the importance of various factors of the microenvironment on the development of disease in the field, and determination of the effects of light, temperature, and relative humidity on viability and longevity of uredospores.

2. Quantitative data on the relationship of rust severity to plant age and yield loss are needed, and an improved and more meaningful disease rating scale would be useful.

3. Major screening is now done at Bhavanisagar. An attempt is being made to increase the reliability of screening in a rust nursery at ICRISAT Center. Inoculation of breeders' fields could possibly be done after more is understood about environmental factors necessary for spore germination, infection, and subsequent disease development.

4. Several sources of rust resistance, including stable resistance, have been found. A single dominant gene for resistance has ben identified and potentially similar types of resistance have been noted in accessions of the germplasm collection. These require further testing to determine if the resistance is based on single dominant genes and if they are the same or different. Additional screening of the world collection is currently not a priority item.

5. Rust resistance should continue to be utilised in the production of hybrid parents as the disease is especially important in seed production fields during the off-season.

6. Multilocational testing should be reduced to about four locations in India, and a special effort should be made to identify cooperators interested in managing the nursery in Southern and Eastern Africa. Additional single dominant genes for resistance, when identified, should be tested for their stability in multilocational testing. An exchange of rust resistant material should be made with the USDA at Tifton, GA.

Material Disease Resistance

1. Screening for multiple disease resistance should continue in lines/populations known to have resistance to at least one disease.

2. As mentioned by Dr. J.R. Witcombe in his seminar, there should be increased effort to incorporate smut resistance into breeding materials so that at some time in the future all advanced breeding lines/populations have resistance to smut, in addition to the downy mildew resistance which is now being screened for on a routine basis.

3. We should consider the possibility of establishing a nursery of agronomically elite, breeding materials with multiple disease resistance, and evaluating this multilocationally.

Communications

1. The multilocational nursery results obtained to date should be summarized and published as journal articles in which cooperators are included as authors. Two such articles (23, 26) have been submitted for publication in Plant Disease. Manuscripts need to be prepared for the other two nurseries.

2. More effort should be made to identify areas of collaborative research with pathologists and/or breeders in national programs in India and Africa. These projects should be relatively small and well defined, and they should be designed to ensure as much as possible joint publication of the results, preferably in internationally-recognized journals.

3. The "Sorghum and Millet Disease Identification Handbook" will soon be out of print. I recommend that for pearl millet, this be replaced with a "Pearl Millet Disease and Insect Identification Handbook".

4. Bulletins should be prepared for each of the four major diseases of pearl millet, describing the causal organism, life cycle, symptoms, resistance screening techniques, sources of resistance, and possible alternative methods of control.

5. A workshop on pearl millet diseases should be planned for West Africa in 1987.

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Table 1. Number of locations in India and Africa from which data were received on international pearl millet disease nurseries during the years 1976 through 1984[a].

Year	IPMDMN		IPMEN		IPMSN		IPMRN	
	India	Africa	India	Africa	India	Africa	India	Africa
1976	12	3	-	-	-	-	-	-
1977	11	5	8	4	2	2	-	-
1978	12	4	11	2	2	4	8	0
1979	11	1	10	1	2	2	5	0
1980	9	3	7	2	3	3	6	0
1981	9	5	10	2	3	4	7	0
1982	8	2	7	1	4	5	5	0
1983	8	4	10	2	5	4	8	0
1984	7	0	8	0	4	0	6	0

[a]IPMDMN = International Pearl Millet Downy Mildew Nursery (44-45 entries/year)
IPMEN = International Pearl Millet Ergot Nursery (21-32 entries/year)
IPMSN = International Pearl Millet Smut Nursery (29-38 entries/year)
IPMRN = International Pearl Millet Rust Nursery (30-45 entries/year)

Table 2. Numbers of confirmed sources of disease resistances identified by the millet pathology subprogram, through 1984.

Disease	Number screened		Total no. resistant sources identified
	Accessions of the GRU	Breeding lines/ populations	
Downy mildew	2753	7076	124
Ergot	2800	7800	24(+60 lines developed)[a]
Smut	1800	8200	34(+150 lines developed)[a]
Rust	2562	507	86

[a]Inbreds and sib bulks

Table 3. Pearl millet lines/populations with stable disease resistance which have been identified through the international disease testing program, 1976-1984.

Downy Mildew	-26 lines/populations resistant at 7-12 Indian locations for 2-9 years and at 1-5 locations in Africa for 2-9 years.
Ergot	-13 lines/populations resistant at six Indian locations for at least 3 years and at Samaru, Nigeria for 2 years.
	-9 lines/populations resistant at seven locations in India for at least 2 years.
Smut	-6 lines resistant at three Indian Locations and at Bambey, Senegal for at least 4 years.
	-12 newly developed populations at three Indian locations for at least 2 years.
Rust	-15 lines resistant at 5-8 Indian locations for 2-7 years.

Table 4. An indication of the extent of utilization of sources of disease resistance identified by the millet pathology sub-program through 1984.

Disease	No. of lines utilized in ICRISAT millet breeding	No. seed samples sent to cooperators	
		In India	Outside India
Downy Mildew	5	500	60
Ergot	6(hybrid parents) 52(ergot resistance composite)	700	20
Smut	37(population breeding) 20(synthetics breeding) ??(resistance used by two breeders in West Africa)	350	8
Rust	12	150	12

Table 5. Proposed locations for future testing of international pearl millet disease nurseries in India

Downy mildew	Ergot	Smut	Rust
ICRISAT Center	ICRISAT Center	ICRISAT Center	ICRISAT Center
Mysore	Mysore	Bhavanisagar	Bhavanisagar
Bhavanisagar[a]	Jamnagar	Jamnagar	Ludhiana
Hisar	Aurangabad	Hisar	Aurangabad
Jamnagar			
Aurangabad (possibly)			
Cuddalore (possibly)			

[a]Provision for overhead irrigation should be made

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