In your hands you hold the global sorghum and millet pathology community's decennial (more or less) summary of diseases and work in progress. It is not a summary of all of the work that has ever been done with sorghum and millet pathology, nor is it a guide to disease identification. Instead, it is a considered summary of the current critical problems and an evaluation of the community's progress since its previous meeting in Harare, Zimbabwe in 1988. It is the third of these efforts, and both the meetings and the books that have resulted from them have been important in defining the research agenda for these crops in the succeeding ten-year interval. The contents of this volume are based primarily on contributions to the Third Global Conference on Sorghum and Millet Diseases in Guanajuato, Mexico in September 2000. Indeed, all but one of the invited talks and all but one of the working group reports are represented here in some form. I also solicited some additional chapters that were not based on any of the presentations to help round out the volume, and I have included as many contributions as possible from African scientists who were unable to attend the meeting due to their inability to obtain visas for travel from the Mexican government.

This volume is somewhat different from its predecessors in that it is not being published by ICRISAT but, instead, by Iowa State Press, with the goal of expanding the readership beyond the immediate sorghum and millet research community. It also is different in that there is only a single editor, and that this editor is not Dick Frederiksen (Fig. P-1), although perhaps it should have been. Dick has been a dominant figure in this field for the last 30-40 years, and a major organizer of what have become nearly institutional meetings. His contacts and efforts in organizing sessions, dispersing participants into effective working groups, and cajoling contributors until they find time to finish a chapter or to strengthen a presentation should be neither underestimated nor undervalued. He has been a good friend and colleague, and as he goes to “fossilize” (his words not mine) in retirement, we can all but wish him the best. The meeting in Guanajuato was his last formal contribution to the sorghum and millet research community, but for those who know him, there undoubtedly remains more to come.

The chapters in this book have all been reviewed by at least one person, and authors have had an opportunity to make revisions in response to these comments. Although I have read each chapter at least four times, the important points raised by other reviewers have made this volume much better than it could have been were one person alone responsible for editing its content. I greatly appreciate the help these colleagues have provided and the advice they have given both to me and to the authors of the various chapters. Persons who reviewed at least one chapter (and some did far more) include: Ranajit Bandyopadhyay, Larry E. Claflin, Thomas Crawford, Jeff Dahlberg, Walter A. J. de Milliano, Richard A. Frederiksen, Liane R. Gale, Laura M. Giorda, Dale E. Hess, Clint W. Magill, Peter G. Mantle, Walter F. O. Marasas, Neal W. McLaren, Gary N. Odvody, Rodomiro Ortiz, Sylvia Pažoutová, John P. Rheeder, Malcolm J. Ryley, Claude P. Seletrinikoff, Ram P. Thakur, Paul W. Tooley, Jeff Wilson, and John Yohe.

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Botanic Garden-Sydney, and St. Paul's College of the University of Sydney for their funding and for hosting me while on sabbatical when much of the editing of this book was completed, and to my wife, Ingelin, for sharing my time with all of these manuscripts. I also thank the corresponding authors of all of the chapters, who have been (generally) prompt and efficient in their revisions and gracious in helping me as I learn about systems and methodologies that are not those that I use in my own research.

Looking forward to the successor meeting (and volume) to this one, the meeting's global geographic rotation should take us to Asia or Australia around 2010. If this volume wears as well as does its predecessor, which is cited numerous times in this volume, and is still of relevance in 2010, then the work required to assemble it will have been time and effort well spent.

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Part I

Transition from the Previous Millennium
Transition from the Second to the Third World
Review of Sorghum and Millet Diseases

Walter A. J. de Milliano

The present commodity crops, sorghum \textit{[Sorghum bicolor (L.) Moench]} and pearl millet \textit{[Pennisetum glaucum (L.) R. Br.]}, are important and sometimes indispensable for the survival of man and domestic animals in austere dry environments. In addition, their genetic diversity and numerous uses (24) are likely to be appealing to citizens of the third millennium searching for food diversification for reasons of enjoyment, health, convenience, eagerness for change, and fashion. This desire for food diversification could extend to other, lesser-known cereals such as \textit{Coix lachryma-jobi L.}, \textit{Digitaria exilillis Stapf}, finger millet \textit{[Eleusine coracana (L.) Gaertn.]}, \textit{Eragrostis tef} (Zucc.) Trotter, \textit{Panicum} spp., \textit{Paspalum} sp., and \textit{Setaria} spp. Hopefully these markets will develop further, stimulating both higher levels of production and increased farm income.

Sorghum and millets have been affected by many diseases in the past (51) and still are today (17). Potentially, each disease can cause economic losses and jeopardize the food security of the farmer and his/her family. Each previous global review (12, 58, 60) has provided the opportunity to make a unique long-term analysis of different issues over the last quarter century.

Venue, Objectives, and Demonstrations
The first global single crop reviews were in India, where sorghum and pearl millet are both staple foods. “State of the art” discussions were held on diseases and disease resistance breeding (58, 60).

The second review was in Zimbabwe. In this review we were reminded of the widening food gap in the third world, the relative importance of many diseases was established, and strategic plans were developed that were mutually beneficial for both developing and developed nations (12). Technology transfer, seed health, and germplasm utilization were discussed. This meeting also gave many African scientists a rare chance to meet foreign colleagues in both meeting rooms and the field. The practical demonstrations at Zimbabwean research and development stations showed the importance of selective use of ecological zones, trained manpower, and infrastructure development. The unique, international, disease hot spot screening approach of the SADCC (Southern Africa Development Coordination Conference) region also was demonstrated.

The third global review was in Mexico. It focused on integrated management of sorghum and millet diseases for the twenty-first century and the importance of these crops in agro-ecosystems. Disease status was reviewed in national, regional, and global contexts as priorities were altered for the next decade. Also, the importance of proper pathogen identification and the use of population biology approach was emphasized. Panicle diseases, such as ergot and grain mold, and the plant parasite \textit{Striga} received special attention. The Mexican host scientists gave on-farm and on-station demonstrations. In this “home of maize,” the area planted to sorghum has been increasing in recent years, and Mexican farmers produce crops with grain yields of up to 15 t/ha. Millets, however, remain of minor importance.

Participation and Publication in the Global Reviews
No national scientist participated in all three global reviews. For sorghum, only three scientists participated in all three global sorghum reviews: Richard A. Frederiksen, Darrel Rosenow, and Nat Zummo. All three of these scientists were from the United States and were participants in INTSORMIL. For millets, S. D. Singh, Ram P. Thakur, and Walter A. J. de Milliano participated in the three pearl millet reviews in association with either ICRISAT or INTSORMIL. Thus, for sorghum, about 5%
### TABLE 1-1. Papers by continent, region, and country presented during the previous (12, 58, 60) and current world reviews for sorghum and pearl millet.

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* = no presentation, y = single-country presentation, r = regional presentation.

(first meeting had > 59 participants) of the scientists were still participating 22 years later, and for millet < 3% (first meeting > 100 participants) were still participating 13 years later. Between 30-40% of the participants attended at least two meetings, including both national scientists and those from the international organizations. For both crops, 30-35% of the authors published in at least two of the reviews.

Why did so few national scientists (< 1%) participate actively in more than two of these ten-year reviews? Part of the problem is financial. Simply finding enough money to pay for plane fare, hotel, and *per diem* can be very difficult. A second reason is that active developing-country scientists often are quickly promoted to administrative positions or hired by the private sector. A third problem is inevitable difficulties with visas, schedule conflicts, and travel arrangements. Thus, the fact that over a period of 10 years, 30-40% of the active national and international scientists continue to participate is more impressive than it first appears and, at the least, demonstrates significant continuity. From these statistics, it is clear that the evaluations of regional and continental is-
sues and of long-term trends depend heavily on the published literature. In this sense, the published proceedings of this meeting and its predecessors are of particular importance.

The individual reviews of sorghum in 1978 (58) and pearl millet in 1986 (60) were followed by joint reviews in 1988 and 2000. In the joint reviews, there were distinctly (up to five times) more sorghum than millet articles (Table 1-I). That trend continues in this volume. Beginning in 1988, there also were a few manuscripts on finger millet research (e.g., 1, 28). With the progress in molecular mapping, related cereal crops may benefit through synteny. Thus, progress in one crop may benefit the others. In addition, these “minor” cereals may provide an opportunity to identify disease resistance genes that are not available or do not exist in the major cereals.

Both sorghum and pearl millet have become global crops. Because the crops are grown in many countries, it is difficult to have a complete and balanced report of all the new developments. Initially, there were individual country and regional reviews (Table 1-I), in which, as a rule, the host country received some extra attention. There are now some combined reports, both in terms of having regional summaries instead of those only for individual countries (e.g., 15, 23, 34, 39), and in terms of combined reports for both sorghum and millet (e.g., 23, 34, 50). Stronger efforts to combine reports are recommended.

In this volume, there is a first global sorghum (35) and also a global finger millet disease review (14). For sorghum and pearl millet there is a single continental review for Asia, including, for the first time, reports for China, Iran, Myanmar, and Syria (23). Africa has no continental review, although there is a summary of the working group’s meeting (20), but there are regional reviews for southern, western, eastern, and central parts of the continent (15, 34, 39). As a result of political changes since the second world review, South Africa is now actively represented (e.g., 37). Probably as a desire to solve common disease problems, Australia is included in this volume for the first time (50), as is Russia (26).

There was no review from Europe primarily because these cereals are not major crops on that continent. Nevertheless, European scientists made significant technical and scientific contributions (e.g., 5, 33, 45).

Publication results from meeting publication standards timely. Thus, some of the presentations from Mexico are not in these proceedings, and some of the invited papers that could not be presented, usually because the scheduled presenter was unable to obtain a visa from the Mexican government, are in this volume.

### Disease Control

**Method.** Duncan and de Milliano (13) suggested that up to modest disease control can be achieved for many sorghum and millet diseases. They compiled assessments by experts in the field for obtainable control and used a scale of 0 to 1, with 0 = no control, 0.1 = limited control, 0.5 = modest control, and 1 = absolute control. Genetic resistance (mean over all diseases = 0.46), seed treatments and tests (mean = 0.42 each), and chemical control in crops and in seed production (mean = 0.39 each) were expected to be the most effective in sorghum. Genetic resistance (mean = 0.5) and chemical control in seed production (mean = 0.35) were expected to be the most effective in pearl millet.

**Genetic resistance.** In the last two global reviews, genetic resistance received considerable attention through reviews of countries and regions or of specific subjects. Considering the high frequency of this type of review, and the many efforts devoted to obtaining suitable genetic lines, genetic resistance was and is an important control method.

Both for sorghum and pearl millet, there are fewer articles on genetic resistance in this volume than in its predecessor. Major specific subjects for sorghum in the preceding volume were the reviews of the use of genetic resistance (49), the use of the world germplasm collection assembled by ICRISAT and INTSORMIL (41, 49), sweet stem sorghums (61), anthracnose (7), grain mold (40), and downy mildew resistance (9). In this volume, disease resistance breeding and screening for several diseases are reviewed (48, 55), but Striga and ergot dominate for sorghum, and for pearl millet, downy mildew (19).

**Other forms of control, including “Know your enemy.”** In this volume, the emphasis has shifted toward more in-depth subject matter reviews. In the preceding volume, there were reviews for specific disease organisms—their biology, taxonomy (e.g., 8), biodiversity (e.g., 7), technology transfer (44), and the toxicology of pearl millet ergot (32). In this volume, there were again reviews of specific disease organisms, but also reviews of interspecific relationships, intraspecific variation (e.g., 45), antifungal proteins (e.g., 57), specific disease triangles—host, pathogen and environment (e.g., 37), mycotoxins (e.g., 47), quarantine (43), the use of the Internet (e.g., 11), methods to improve collaboration and funding (e.g., 46), and last, but not least, on the involvement of the private sector (e.g., 10, 25).

In the preceding volume, two significant contributions for the future were reported as short communications. Butler (6) provided the first insight into the
host/pathogen relationship that underlies the changes in breeding strategy that have lessened the importance of the *Striga* parasitic weeds. The abstract by Frederickson and Mantle (16) provided the first evidence for the aerial dispersal of conidia of the African sorghum ergot fungus. This research became of global importance when this disease spread to Australia and the Americas in the 1990s.

**Crop and disease management, including disease forecasting.** In this area, two major new examples are described in this volume: the use of disease prediction models, in particular for the prediction of annual sorghum ergot epidemics (*e.g.*, 37), and a dynamic multilinear for pearl millet (59). In the preceding volume (12), the reviews were only for sorghum and were focused on races of anthracnose (*e.g.*, 7), and a case study was presented on the epidemiology of sorghum diseases in Central America (56). In this volume, there are reviews of: cultural (including intercropping) and IPM (Integrated Pest Management) strategies for control of *Striga* (2, 21), and of biodiversity as a strategy for both disease and pest management (59). For pearl millet, the management of downy mildew resistance was reviewed (19, 22).

**Other methods of control.** Overviews of chemical control (38), seed treatments, biological control, and seed tests receive little or no attention in this volume. Chemical control in seed production, which was previously identified as an important disease control method, is barely perceptible in the global reviews. However, seed transmission of sorghum pathogens was a subject of special emphasis in the 1988 conference (36). In the 2000 conference, a determined effort was made to involve the private sector (10, 25, 53), in addition to a presentation on the practical value of a systemic seed treatment against downy mildew in pearl millet (52).

A major change for the control of diseases is the addition of molecular biology-based solutions for all of the crops. Considerable progress has been made since the previous global review and the 1995 strategic meeting in Bellagio (29). Diseases to which such analyses are being applied include sorghum grain molds (3), sorghum anthracnose (18), sorghum head smut (42), sorghum ergot (45), sorghum leaf blight (31), sorghum oval leaf spot (4), "*Fusarium moniliforme"* (30), pearl millet downy mildew (54), and finger millet blast (5). The coming challenge is the practical and efficient use of the basic information now being generated.

**Sorghum Diseases**

Sorghum has a number of diseases of continuing importance. Many of the important diseases are caused by fungi including grain molds, anthracnose, stalk rots, ergot, smuts, and downy mildew. A novelty at the 2000 meeting was the two-man tag-team review of a single fungal species, *Fusarium moniliforme*, which now is being subdivided into 20+ species and whose present name was retired at this meeting. The importance of various *Fusarium* spp. in relation to human health, food quality and other post-harvest problems, suggests both threats and opportunities. In relation to maize, is sorghum grain a healthier food because of the mycoflora that it does, or does not, support? Therefore, the *Fusaria* deserve continued attention. *Striga* also continued to receive attention. In particular, research at Purdue University has made steady progress, and prospects for the control of these parasitic weeds are greatly improved.

Viruses received attention in both reviews, and their taxonomy is now established. However, the global importance of these viruses is not well demonstrated. Bacterial diseases were reviewed in the preceding volume (8), but not in this one. Nematodes have received little attention, although a review of sorghum nematode problems is included in this volume (27). Insects have been avoided in these global reviews, as have rodents and birds, but these organisms are important, and, in particular, insects can be vectors and facilitators of fungal, bacterial, and viral diseases. With the movement toward IPM, the inclusion of reviews by entomologists and other biologists in the next global review might encourage the development of research and production synergies.

**Millet Diseases**

Millets also clearly have a number of diseases of continuing importance, of which ergot and downy mildew are receiving the most attention. During the Mexico review, remarkable and somewhat unexpected progress was reported by Breese *et al.* (5) on the development of molecular markers for studying finger millet leaf blast (*Pyricularia* spp.). Blast control in finger millet also may benefit from the recent developments in rice (14). *Striga* also continued to receive attention (2, 21). Though focus in research is desired, and appears to have been attained, the lack of progress caused by the absence or lack of staff is a concern.

**Take-Home Messages**

In terms of growth measured as planted area or yield, there are few successes with sorghum and millets, as the global popularity of these crops has been decreasing. Yet in Mexico, "the home of maize," growth in both planted area and grain yield is occurring in sorghum. For millets, major successes have not yet occurred, and these crops continue to languish and remain of minor importance.
The supporting technologies provided unexpected tools and unprecedented progress with the development of molecular maps for both the host crops and the causal agents of some of the diseases. Thus, a move from empirical selection for disease resistance to marker-assisted breeding either has or will shortly occur. This shift means that for disease resistance screening, we may no longer be totally dependent on the presence of the pathogen. Dependence on demanding, and often difficult and unpredictable, disease resistance-screening tests also may be reduced. Breeding against quarantine diseases that are not in the country also may be possible if suitably characterized resistant and susceptible germplasm is available. We also can distinguish homozygous and heterozygous resistant plants, without the complications caused by “escapes” in the screening process. DNA analysis is usually a nondestructive test that can be done in the laboratory with material from almost any plant tissue or growth stage, and could accelerate the breeding process. In addition, the molecular technology provides a chance to select systematically for QTL quantitative resistances.

Molecular technology also has provided laboratory tools to identify (quarantine) strains. Through the data generated with these tools we can better understand and evaluate the genetic evolution of pathogens and better understand genetic diversity. In particular, the reviews on ergot (45) and Fusarium spp. (30) could become classic examples. Though the development of genetically modified cereals was not a primary topic of the meeting, new opportunities for control of previously uncontrollable diseases and other biological agents, e.g., insects and nematodes, may be possible.

Clearly in the twenty-first century, more than work in the field will be needed for effective disease control. The key for impact will be the management, design, and implementation of multidisciplinary collaborative research. Several issues are of importance to secure this future:

- How can the consumer be involved more effectively?
- Joint planning of regional targets and activities and regular control of the agreed progress.
- Joint planning for actions between INTSORMIL, ICRISAT, and the private sector (e.g., the National Grain Sorghum Producers in the United States) could strengthen sorghum and millet research through complementary efforts and provide a better focus for national and regional targets.
- Food safety, e.g., traceability, methods to measure the quantity of key toxins, food security, and models to predict grain quality all need greater attention.
- Academic training of plant pathologists from developed and developing countries in molecular biology should become essential.

References


