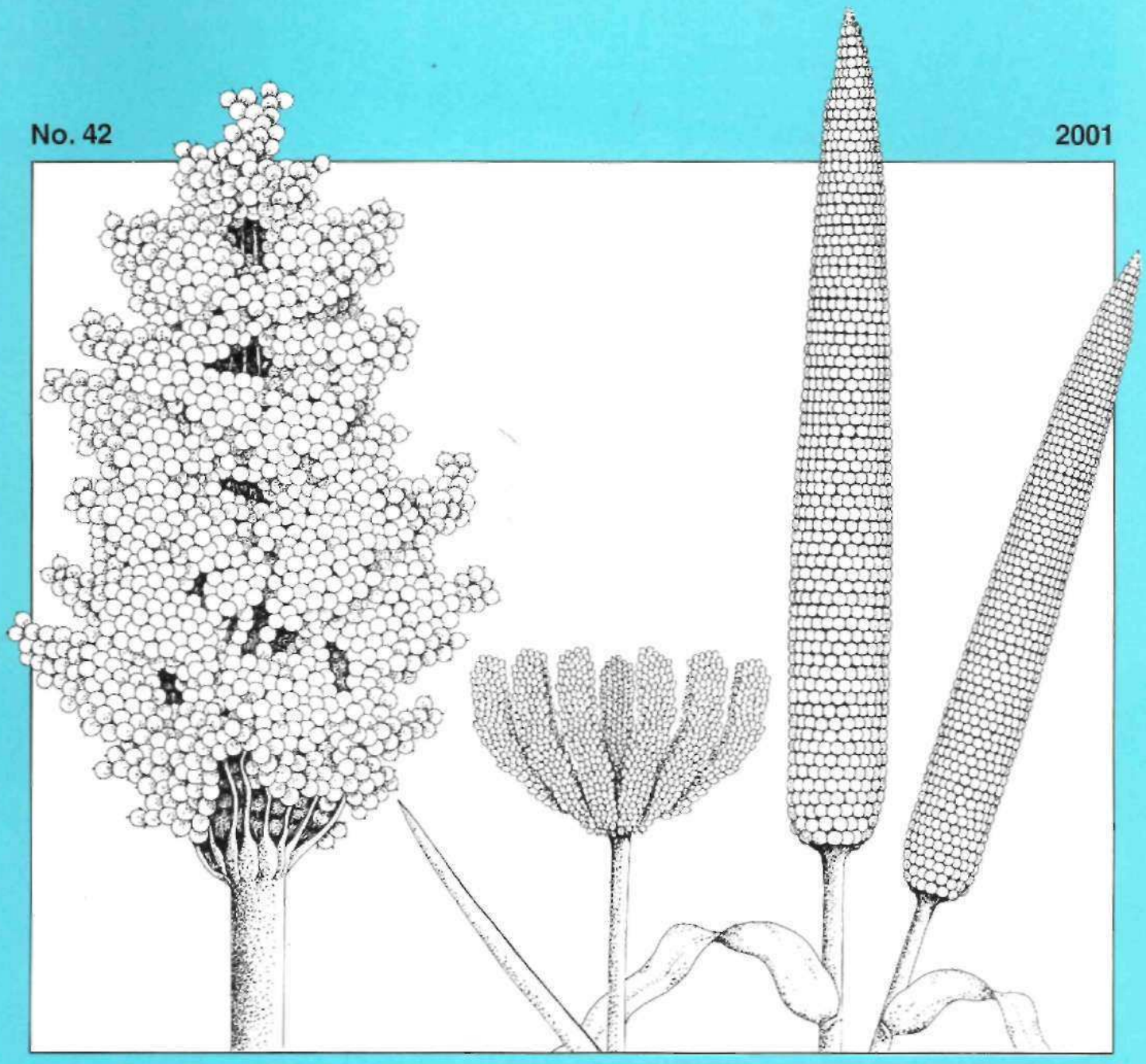
SICNA

International Sorghum and Millets Newsletter

No. 42 2001



International Sorghum and Millets Newsletter

Co-publishers

SICNA
Sorghum Improvement Conference of North America
(www.sorghumgrowers.com)

ICRISAT
Internutional Crops Research Institute for the Semi-Arid Tropics
(www.icrisat.org)

About SICNA

In 1947, sorghum breeders formed an informal working group to meet and review items of interest in sorghum breeding and genetics. This organization was named 'Sorghum Research Committee'. In the 1960s, with the advent of a number of severe disease and insect problems, special half-day sessions, particularly on diseases, became a part of the Sorghum Research Committee. In 1973, a concept was put forward that all sorghum workers, irrespective of discipline and employer, should meet twice a year to discuss mutual concerns with sorghum research and development. The Sorghum Improvement Conference of North America (SICNA) was that new organization. It is composed of eight disciplinary committees, dealing with genetics and breeding, pathology, entomology, chemistry and nutrition, physiology and agronomy, biotechnology, utilization and marketing, and agribusiness and commerce. SICNA meets formally once a year in conjuction with the National Grain Sorghum Producers Board. A general program of research, education, and developmental activities is prepared by the disciplinary committees. Funding is through membership participation and contributions from commercial donors. Essentially, SICNA represents the United States sorghum activities but accepts reports and encourages memberships from sorghum and millet researchers worldwide.

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political, international organization for science-based agricultural development. ICRISAT conducts research on sorghum, pearl millet, chickpea, pigeonpea and groundnut - crops that support the livelihoods of the poorest of the poor in the semi-arid tropics encompassing 48 countries. ICRISAT also shares information and knowledge through capacity building, publications and ICTs. Established in 1972, it is one of 15 Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

ISMN Scientific Editors 2001

JA Dahlberg CT Hash

Published in April 2005

Contents

Editorial V

Feature Articles - Pearl Millet Markers

Pearl Millet in Developing Countries 1
Gerard J Gill and *Cathryn Turton*

Pearl Millet Molecular Marker Research 6
CT Hash and *JR Witcombe*

Improving Pearl Millet Drought Tolerance 15
RS Yadav, FR Bidinger, CT Hash, GP Cavan, R Serraj and *CJ Howarth*

New Molecular Marker Technologies for Pearl Millet Improvement 16
MD Gale, KM Devos, JH Zhu, S Allouis, MS Couehman, H Liu, TS Pittaway, XQ Qi, M Kolesnikova-Allen and *CT Hash*

Variation in *Sclerospora graminicola* Detected with RAPD-PCR 23
Z *Mahmood, JR Witcombe* and *DS Shaw*

Sorghum Research Reports

Genetics and Breeding

Genetics and Cytology of a Minimized Sorghum Mutant from Somatic Cell Culture 27
Zhongyou Pei, Ruidong Huang and *Hongtu Ma*

Agronomy and Physiology

Moisture Stress and Potential Sorghum Yield 28
WG Wenzel and *PJ Van Rooyen*

Impact of FYM and Fertilizer Nitrogen on Yield and Soil Properties of Sorghum Grown on Vertisol 29
Syed Ismail, PB Adsul, GG Shinde and *AS Deshmukh*

Yield Maximization of Irrigated *Rabi* Sorghum 31
GG Shinde, PM Deshpande, MH Lomte, AS Deshmukh and *BN Algave*

Winter Season Adaptation Features in Sorghum 34
JE Jahagirdar and *ST Borikar*

Studies on the Adverse Effects of Low Night Temperatures on *Rabi* Sorghum
GG Shinde, PM Deshpande, MH Lomte and *AS Deshmukh* 36

Germination Behavior of Four Sorghum Genotypes at Supra-optimal Temperatures and Limited Moisture Conditions in Response to Seed Soaking Treatments
Mohamad A Kader and *S Jutzi* 38

Supra-optimal Temperature Stress and the Heat Treatment of Sorghum Seed
Mohamad A Kader 38

Varying Temperature Regimes Affect Osmotically Primed Sorghum Seeds and Seedlings
Mohamad A Kader 39

Pathology

Prevalence of Sorghum Diseases in Karnataka and Maharashtra States, India, during 2001 Rainy Season
AH Rajasab and *RA Frederiksen* 40

Experimental Parasitism on Sorghum of *Claviceps sorghi* recently 'Re-discovered' in India
PG Mantle 44

Inheritance of Resistance to *Sporisorium sorghi* in Grain Sorghum
HS Nzioki, LE Claflin, PJ Bramel and *BA Ramundo* 47

Entomology

Efficiency of a Pheromone-baited Trap for the Sorghum Stem Borer, *Busseola fusca*
D Dakouo and *A Ratnadass* 51

Effects of Systemic Seed Treatment Insecticides Imidacloprid and Thiamethoxam on Sorghum Hybrids
ED Brown, J Trybom, WA Colette, RC Thomason and *BB Pendleton* 52

Biotechnology

Quantitative Trait Loci for Head Bug Resistance in Sorghum
M Deu, A Ratnadass, MA Hamada, M Diabate, JL Noyer, S Togola-Fane and *J Chantereau* 54

Utilization

False Positives for Tannin Sorghum in Non-tannin Sorghum Using the Bleach Test
J Awika, CM McDonough, LW Rooney and *RD Waniska* 58

Millet Research Reports

Genetics and Breeding

Effects of Drying Time and Method on Viability of Stored Pollen of Pearl Millet 63
MD Sanogo and *WW Hanna*

Genetic Diversity in Relation to Heterosis and Combining Ability in Pearl Millet 64
R Madhusudhana and *OP Govila*

Genetic Analysis of Crosses Among Pearl Millet Populations 68
Yagya Dutt and *CR Bainiwal*

Combining Ability for Seedling Heat Tolerance in Pearl Millet 70
RV Singh and *TR Sharma*

Genetic Divergence for Anatomical Parameters Determining Blast Resistance in Finger Millet 72
AK Jain, SB Singh and *HS Yadava*

Germplasm

Meera (SR 16) - A Dual-purpose Variety of Foxtail Millet 75
SR Maloo, DP Saini and *RV Paliwal*

First Forage Pearl Millet Hybrid Released in India 77
SK Gupta

Agronomy and Physiology

Growth Analysis and Yield of Pearl Millet Hybrids and Varieties under Rainfed Conditions in Southwestern Haryana 77
B Singh, YP Yadav, J Singh, A Kumar and *SS Yadav*

Pathology

Reaction of Pearl Millet Varieties during Rust Epidemics in Haryana, India 79
MS Panwar and *JP Wilson*

Screening Pearl Millet against Eritrean Isolates of Downy Mildew 81
Negusse Abraha, Wendy A Breese, AG Bhasker Raj and *S Preston*

Evaluation of Pearl Millet Varieties for Resistance to *Striga hermonthica* 85
NA Gworgwor

Evaluation of *Striga* Resistance in the Secondary and Tertiary Gene Pools of Pearl Millet 87
JP Wilson, DE Hess and *WW Hanna*

Anatomical Factors Associated with Resistance to Blast in Finger Millet 89
AK Jain, SB Singh and *HS Yadava*

Biotechnology

Application of Anther Culture to Hybrid Breeding of Pearl Millet 41
Akiko Shigemune and *Tomohiko Yoshida*

Effect of Pollen and DNA Source on RFLP Pattern of Mitochondrial DNA in Pearl Millet 93
AK Chhabra, KN Rai, CT Hash, IS Khairwal and *S Sivaramakrishnan*

Utilization

Popping Quality and Sensory Quality of Small Millets 96
Sarita Srivastava, Sangita Kumari and *Shadab Masud*

Workshop Reports

Workshop on Breeding for *Striga* Resistance in Cereals 97
BIG Haussmann, DE Hess, ML Koyama, J DeVries, JG Kling, A Melake-Berhan and *HH Geiger*

Identification of Technological Research and Demands for Extending Pearl Millet Cultivation in Brazil: Final Report of the First International Pearl Millet Workshop Organized by JICA and Embrapa at Planaltina, Brazil, 9-10 June 1999 94
Mauricio Antonio Lopes

SMINET News - Vol. 3, No. 1 (July 2001)

Farmers in Targeted Area Using a Wider Range of Crop Management Options Leading to Increased Productivity in Zimbabwe 104
GM Heinrich

Seed Policy in Mozambique 106
DD Rohrbach

Fighting Food Insecurity through Seed Entrepreneurship at Community Level 107
MK Mbunji

Testing the Demand for Sorghum Meal in Tanzania: a Case Study with Power Foods 109
DD Rohrbach and *JAB Kiriwaggulu*

Breeding for Drought Tolerance in Sorghum in South Africa 110
WG Wenzel, K Ayisi, G Donaldson and *J Mohammed*

On-farm Seed Priming: a Key Technology to Improve Crop Establishment and Yield in Semi-arid Tropics 112
W Chivasa, D Harris and *P Nyamudeza*

Small-scale Farmers Venture into Commercial Seed Production 114
ES Monyo

Book Reviews 115

Sorghum and Millet Bibliography 119

Editorial

It is with considerable relief and some trepidation that this long overdue 2001 issue, number 42, of the International Sorghum and Millets Newsletter (ISMN) is finally being published. The delay in its publication is "all my fault" as I have not been able to keep up with my commitments following a substantial restructuring in research responsibilities within ICRISAT that accompanied my return from study leave in 2000, reductions in ICRISAT staffing at the end of 2001 due to budget constraints, and undiminished demands from ICRISAT's stakeholders globally. I can only offer my sincere apologies to the authors and readers of ISMN worldwide, as well as to my co-editor Dr JA Dahlberg and to the managements of SICNA and ICRISAT, for the serious inconveniences caused to one and all by the delayed publication of this issue. Along with this apology I offer my best wishes to Dr RP Thakur, who has taken over the ICRISAT side of the co-editorship for ISMN with effect from issue 43, and my sincere thanks to Mr VS Reddy and Mr K Chandrasekhara Rao of Communication Office, ICRISAT, and to my wife Deanna for their assistance in bringing ISMN 42 to its present form.

ISMN 42 opens with a set of feature articles related to the development and application of molecular marker techniques to support breeding of pearl millet in developing countries. The articles are based on presentations made at a workshop and training course on this subject conducted in Hyderabad, India in November 1997 (see McGaw et al., 1997. ISMN 38:19-28) and updates of these prepared for the 2001 Annual Report of the Plant Sciences Research Programme of the UK's Department for International Development (DFID). This section begins with a report on the importance of pearl millet in developing countries, emphasizing its importance in food security for the world's poorest people and identifying the most important constraints to pearl millet production that should be addressed by public crop improvement research (see Gill and Turton, pages 1-8 of this issue). The information that follows on approximate map location ... of a large number of putative quantitative trait loci for host plant resistance to pearl millet downy mildew detected through the end of 2001 (see Hash and Witcombe, pages 8-15 of this issue), the JIC consensus map for pearl millet molecular markers (see Gale et al., pages 16-22 of this issue), and the utility of RAPD markers for characterizing isolates of pearl millet downy mildew (see Mahmood et al., pages 22-26 of this issue), should all prove useful to teams of plant breeders, molecular biologists and plant pathologists working together to address the threat that downy mildew continues to pose to pearl millet production in Asia and Africa.

The section of sorghum research articles in this issue closes with an extremely important article on false-positives for tannins when the standard bleach test is used on weathered or insect-damaged non-tannin sorghum grain samples (see Akiwa et al., pages 58-62 of this issue). The color figures in this article should help those involved in grading sorghum grain samples to avoid this problem in future. A second important article in this section is that reporting on a field survey of sorghum diseases and insect pests in peninsular India that was conducted during the 2001 rainy season (see Rajasab and Frederiksen, pages 40-44 of this issue).

Workshop summary reports in this issue by Haussmann et al. on a workshop on breeding for *Striga* resistance conducted at IITA in August 1999, and by Lopes on a pearl millet workshop conducted in Brazil in July 1999 will provide useful entry points for readers seeking information on these topics. Finally, this issue of ISMN closes with a series of articles from the July 2001 issue of the regional newsletter of the Sorghum and Millet Improvement Network (SMINET), information on several recently published books of interest to sorghum and millet research workers, and a fairly comprehensive listing of journal articles published on topics related to sorghum and millets improvement in 2001.

I close my co-editorship of this newsletter with a heartfelt thank you to Jeff Dahlberg and to ICRISAT management for providing me the opportunity to contribute to publication of ISMN, which continues to help give voice to the many sorghum and millet research workers - especially those in developing countries - for whom this hard copy newsletter continues to provide both a source of relevant research information and an appropriate venue for communication of research findings relevant to the breeding, production, marketing and utilization of sorghum and millets for food, feed and fodder. I wish the newsletter and its readers many years of continued success through service, and enjoin the current and future editorship to learn from my mistakes so as not to repeat them.

C Tom Hash
Co-editor, ISMN issue number 42
c.hash@cgiar.org

April 2005

Feature Articles - Pearl Millet Markers

Pearl Millet in Developing Countries

Gerard J Gill and Cathryn Turton (Overseas Development Institute, Portland House, Stag Place, London SWIE 5DP, UK)

Editor's note: *This is an abridged version of a report with the same title, commissioned by the DFID Plant Sciences Research Programme, which was completed by the authors in March 1998.*

Introduction

Millets rank sixth in importance in terms of contribution to global cereal supply, after wheat, rice, maize, barley and sorghum. Ninety-four percent of the world's millet production is grown in developing countries. Millets as a whole occupy 5% of global cereal area, but produce only 1.5% of global output (FAO and ICRISAT 1996, p. 33). They grow in places to which very few other crops, and no other cereals, are suited: areas of high temperature, low and uncertain rainfall, and shallow or sandy soils with poor fertility and low water holding capacity. Furthermore, millet-growing areas are usually characterized by poor infrastructure, limited market access and low farm incomes.

Pearl millet [Pennisetum *glaucum* (L.) R. Br.] is the staple food of millions of the world's poorest and most food-insecure people, particularly in India and Africa, and is the most important millet globally in terms of area and production. The crop has relatively high nutritional value for a cereal. Its grain has higher protein and fat than wheat or rice (partly because of its relatively large embryo and low yields) and its amino acid balance is better than that of wheat and polished rice, and comparable to that of unpolished rice (which is not actually eaten). It also digests slowly, and so staves off hunger longer.

Pearl millet has impressive ability to withstand drought. If this occurs after the seedling stage, the plant will often go into "suspended animation" and then resume growth when a rainfall event occurs. At the seedling stage moisture is very critical, but it usually rains at that time, because the crop is not sown until the rains start.

Livestock typically play a crucial part in farming systems based on pearl millet. Pearl millet can provide grazing, green fodder or silage, while its stover is a valuable source of feed, making it a dual-purpose crop for subsistence farmers. The stover remains green to the point of grain harvest, thus lifting its nutritional value above that of other cereal residues, such as maize stover.

Production and Productivity Trends

Accurate figures on pearl millet production in developing countries in Africa are unusually difficult to obtain, because few statistics distinguish between the various botanical species of millet, and some countries combine millet figures with those of sorghum and other cereals, and include millet under the general category "other coarse grains" (FAO and ICRISAT 1996, p. 31). However, the general picture for pearl millet production and productivity for Africa is fairly clear, and is consistent with what is known about African subsistence farming systems generally. Yields are at best stagnating and production increases at present depend upon either reductions in fallow periods, expansion of cultivation into increasingly marginal areas, or both. This trend is particularly marked in the Sahel. Per capita production is highest in Niger, because of the dominance of the crop there, but this is falling. In eastern Africa per capita production has declined markedly, largely as a result of area contraction as better land is switched to preferred cereals such as maize.

In India productivity and production have increased, despite declining area. This is largely because of the development and popularization of improved cultivars in India and their distribution through an increasingly efficient private seed-marketing sector.

In India there have been some interesting developments in the agronomy of pearl millet in more favored areas such as Gujarat, where farmers have shifted nearly all production into the summer season, when they use irrigation, hybrids and fertilizer to produce all of their grain requirements, and to produce hybrid seed used in other parts of the country.

Trends in Commercial Production and Prices

Pearl millet is primarily a subsistence crop in the developing world. In Africa, because of the absence of large markets for the crop, virtually all millet production for sale is risky. Only an estimated 5 to 10% of African pearl millet production enters commercial markets, although in surplus years it is locally bartered with people both in the Sahara

and to the south (FAO and ICRISAT 1996, pp. 31 and 43). Nevertheless, commercial production of pearl millet in Africa is not unknown. For example, in West Africa there is an important triangle in which coarse grains arc traded, with Guinea, Mauritania and Mali at its comers, but no disaggregated information on its components (maize, millets and sorghum) is available (Debrah 1993, Figure 3).

The indigenous grain market in the northern part of Namibia, the country's main production area, is reasonably well developed, competitive and sophisticated by developing country standards (Keyler 1995a; Keyler 1995b. Ch. 5; Mukete and Sheuyange 1995; Rohrbach 1995). As in other countries of southern Africa, government controls, subsidies and other interventions are being phased out, a liberalization that is also helping to foster the gradual emergence of a commercial grain market.

The most important country for commercial pearl millet production in the developing world is India. Compared to other cereals, the crop has a short growing season, higher productivity per unit of inputs (such as seed, water and nitrogen) and lower opportunity costs for much of the suitable land, resulting in low production costs, which in turn are reflected in relatively low market prices.

Pearl Millet and Food Security

The importance of pearl millet to world food security is significantly greater than its contribution to world food supply due to the fact some of the world's poorest and most food-insecure people depend on it. Food security is usually considered on three levels: national, household and individual. At each level, three aspects should be considered: availability, stability and access (Thompson and Metz 1997, p. 4).

National level food security. Sub-Saharan Africa must be regarded as the major focus of concern. The situation there contrasts strongly with that found in India, the only major producer outside Africa. First, at the national level in India pearl millet is very much a minor food grain (although regionally it is important) compared with most African producers, particularly in the Sahel. Second, whereas India has made, and is expected to continue to make, substantial progress in improving productivity of this crop, Africa has not. Third, India, unlike Africa, has developed an efficient seed production and distribution system for pearl millet (and other crops). Fourth, Indian pearl millet production is increasing, while in Africa it is declining (FAO and ICRISAT 1996). Finally, India has much better developed transport infrastructure than the African producers, and is therefore able to move food grains from surplus to deficit areas much more efficiently.

Projections of falling cereal prices and growing per capita consumption to 2020 would be good news for national-level food security in Africa, if not for the steady withdrawal of food aid.

At the national level, net food importing countries are particularly vulnerable to food insecurity, and the number of these in sub-Saharan Africa will continue to grow, as growth of demand continues to outstrip that of supply and food import requirements mount.

Most countries of sub-Saharan Africa are not food secure in terms of availability, stability and access. Although food grain continues to be available on the international market at falling real prices, such countries' access to it is constrained by a combination of limited purchasing power, dwindling food aid, and rapidly growing import requirements of emerging economies in Asia.

Household level food security. Obviously, national level food security does not guarantee food security at the household level. In a cash economy, even if sufficient food is available on the market, poor families often do not have access to enough of it to meet their needs. Population pressure, reduced fallows and depleted soil fertility have caused the build up of disease and pest problems, so that yields are falling.

In the unimodal rainfall areas in which pearl millet is grown, it is often labor, rather than land, that is the critical factor (Debrah 1993, p. 56). Such areas have a single cropping season, so that the onset of the rains signals a frantic rush to get the land prepared and the crop established so as to give plants maximum access to soil moisture and avoid terminal drought, take advantage of the "nitrogen flush" (produced by a sudden upsurge in the activity of nitrogen releasing soil bacteria), and get a head start on weeds (Chambers et al. 1981, Ch. 1).

Although production is totally dependent on uncertain rainfall, and therefore varies greatly from year to year, a crucial feature of pearl millet that helps reduce farm households' vulnerability in this respect is its excellent storage properties. The crop is usually harvested and stored in dry weather conditions, while the hard hull covering the endosperm protects it against insect attack, even in traditional grain stores (FAO and ICRISAT 1996, p. 43). Provided the average level of production is adequate, and provided a reserve can be built up against emergencies, even quite extreme year-to-year variation in production need not cause food insecurity. A study in one of the more affluent pearl millet producing areas, the Ovambo region in northern Namibia, found that households habitually store enough of the crop to last between four and six and a half years before they would even consider selling it. Such high thresholds are an indication of the average household's perception of the

drought threat (Keyler 1995b, p. 131). Of course, the poorer the household the less likely is it to be able to build up stocks, even in good years. It is inconceivable that a significant proportion of poor households in the Sahel could build up stocks to such levels.

A facet of the stability aspect of food insecurity that requires wider recognition is seasonality of food supply. The existence of an annual hungry season is a feature of many third world farming systems, but none more so than those found in areas of unimodal rainfall pattern such as the Sahel. This means, among other things, that food produced during the hungry season has a much higher marginal utility to the household than food produced during the main harvest (Gill 1991, pp. 21-22). Even after a serious drought, as occurred in southern Africa in 1991/92, farmers were still looking for characteristics other than grain yield in the pearl millet seeds supplied under emergency relief. Farmers receiving such seeds often expressed a willingness to forego grain yield in favor of other characteristics, particularly early maturity (Friis-Hansen and Rohrbach 1993, p. 83).

Food security of the individual. This is the most fundamental level at which food security can exist, and, just as national level food security does not guarantee the same condition applies at the household level, so, too, household level food security does not guarantee the same assurance to its individual members.

Poverty and deprivation impinge differently on women and men, the old, the middle aged and the young, the healthy and the sick. Individual food security is bound up with economic and cultural factors that determine intra-household access to food. Case studies from many different societies indicate that among adults, women share a disproportionate share of poverty and among children, girls suffer more than boys (Bhatia 1995). In many communities there is a tradition of men eating first and the women and children waiting for what is left. Sons tend to eat before daughters. In famine years and hungry seasons, girls are first to suffer and their hunger is the last to be assuaged. An important implication of this is that short duration varieties that can be harvested in the hungry season are of greatest value to women and girls. The same is true of varietal characteristics that improve tolerance of or resistance to conditions that lead to scarcity and famine.

Not all intra-household differences in food security are attributable to social relations and cultural factors. Pregnant and lactating women (and most women in the developing world are always either pregnant or lactating during a large part of their adult lives), the sick or convalescent, people who have to do hard physical labor, and growing children all have special nutritional needs, and if these are not satisfied then that individual's food security suffers disproportionately. Weanlings are particularly vulnerable to intra-household food insecurity, and this is in fact the age group - around six months to two years of age - when death from malnutrition is most common (Gill 1991, Ch. 3).

In areas where it is an important component of food supply, pearl millet plays a vital role in alleviating this problem, because it is a high-energy food with high protein content. Compared to other cereals it is not as deficient in the amino acid lysine, so that, for a cereal, its protein efficiency is unusually high. These qualities make the crop especially suited to pregnant and lactating women, convalescents and weanlings.

Constraints on Improvement

Pearl millet is one of the mandate crops of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). This is a tough remit, as the crop has been described as "virtually unimprovable", having evolved both naturally and through farmer selection to suit environments so harsh that in some of them not even weeds will grow (ICRISAT 1996). Despite this, considerable improvement has already been achieved. The earliest research on this crop was conducted under the auspices of the colonial agricultural research services and agricultural colleges in West Africa and the Indian subcontinent, and the United States Department of Agriculture, and dates from at least the 1930s. The Indian agricultural research system began releasing newly developed hybrid cultivars in the mid 1960s, and these have now been adopted by Indian farmers on a large scale. More than half of India's pearl millet area is now under modern varieties and the proportion continues to grow.

Optimism regarding the potential for pearl millet improvement has increased with recent breakthroughs in developing a molecular marker-based genetic linkage map for pearl millet and the identification of key markers associated with traits such as downy mildew resistance and drought tolerance.

Hybrids and improved open-pollinated varieties have helped address the yield constraint, as has development of cultivars that are resistant to diseases like downy mildew. ICRISAT's development of short duration varieties (from African landrace such as *Iniadi)* has meant that the threat of end-of-season drought has been reduced. Although there is a trade-off between yield and length of season, the short duration cultivars confer their own advantages by providing grain in the hungry season as well as reducing the risk of crop failure and improving opportunities for double-cropping.

All in all, the impact of HYVs of pearl millet has been greatest where the production environment has been least

hostile. In India, improved cultivars are grown on more than 90% of the area in Gujarat, where of all pearl millet growing areas soils are relatively fertile, water control is good and there is a strong input and seed delivery system. However, in western Rajasthan, only a few farmers grow improved cultivars under rainfed conditions, and then only small areas (ICRISAT 1997, p. 9). In Africa, where production environments can be even harsher than those of western Rajasthan, adoption rates of improved cultivars can be extremely low. In Niger, improved cultivars account for only an estimated 5% of the area under this crop (FAO and ICRISAT 1996, p. 39).

Downy mildew remains the most widespread disease of pearl millet, with continuing potential to cause catastrophic loss. Grain yield losses of 10 to 60% have been reported from various African and Asian countries (Singh et al. 1993). Evolution of this disease is a major problem with genetically uniform single-cross pearl millet hybrids, so that as resistant hybrids of the crop become popular, they quickly succumb to new strains of the pathogen. Smut and ergot are panicle diseases in which fungal reproductive structures replace the grain. They are episodic diseases, peaking when there is heavy rainfall at the time of flowering. Informal estimates put losses at just 1 or 2% in normal years and less than 5% in bad years. The nutritional value of pearl millet stover would be improved if foliar diseases such as rust and *Pyricularia* leaf spot could be controlled.

Striga hermonthica and *S. asiatica* are parasitic weeds that attach themselves to the roots of pearl millet, sorghum, maize, rice, sugarcane and other grasses, and rob them of nutrients. *Striga* is regarded as the single most important biotic constraint on grain production in sub-Saharan Africa. It is estimated to affect 44 million hectares and to cause yield losses valued at US$7 billion a year (ICRISAT 1997). The weed also exists in Asia, but strains there are much less virulent, and it is therefore less of a scourge. The problem is growing in seriousness in sub-Saharan Africa because of repeated cropping on the same land as a result of falling fallows. This provides the weed with successive generations of hosts, so that its seed load builds up in the soil. Lightly infested fields can be hand-weeded, but when infestation becomes severe, farmers are forced to abandon their fields altogether. *Striga* seeds can remain viable in the soil for up to 15 years. The parasite is able to attack its hosts successfully because the latter are in poor nutritional condition. A viable approach may be to tackle the difficult and growing problem of poor soil fertility, which leaves the plants undernourished and open to parasite attack.

In West Africa there is an estimated US$100 million loss per annum from stem borer and head miner damage to pearl millet. Head miner is a major pest and there is as yet no genetic solution. Spraying is a possible solution, but poor farmers cannot afford it. Early flowering millets, which are bred to escape terminal drought stress, are especially vulnerable. There is no problem with late flowering types. Stem borers can be very effectively controlled by simple inexpensive chemical-filled traps. Bird damage can be severe in pearl millet, especially with early-sown early maturing cultivars that fill grain when birds have little else to eat. The damage can be controlled partially by sowing cultivars with sharp bristles on their panicles, as these make it difficult for the birds to reach the developing seed.

Problems of poor soil fertility and unreliable rainfall have been mentioned several times as major constraints to increasing pearl millet productivity. However most plant physiologists now agree that water is not the most limiting factor except in drought years. Negative nutrient balance is a major problem in the Sahel, and phosphorus is the major limiting factor. Even 5-10 kg of P per hectare significantly improves a pearl millet/cowpea intercrop, raising the cereal yield from 300-400 kg ha^{-1} to 600-700 kg ha^{-1}. The International Fertilizer Development Center (IFDC) and ICRISAT have been exploring means of using locally produced rock phosphate fertilizer both alone and in combination with commercial phosphatic fertilizers and crop residues. Early results are encouraging, with yield increases of up to 250% and a long-term improvement in soil fertility (ICRISAT 1997, p. 74). Another promising approach is micro-dosing - placing a very small basal fertilizer application in individual hills while sowing the millet seed.

Agroforestry offers further interesting prospects. One system would be to plant widely spaced rows of leguminous trees, so that broad alleys of pearl millet could be grown between them. The trees would then act as a windbreak. In West Africa good results have been obtained in experiments growing pearl millet in association with the leguminous tree species *Faidherbia albida* (previously known as *Acacia albida;* Sivakumar et al. 1994). In addition to being nitrogen-fixing, this tree is summer-deciduous, so that it produces foliage in the dry season and drops it in the wet. In parts of Africa where *F. albida* is a native species, farmers make great use of what has been called this "perverse phenology", feeding the leaves to their livestock when fodder is otherwise very scarce, and growing crops in the under story during the wet season. Not only does no leaf canopy remain to shade the crop, but any leaves left on the ground act as a mulch and provide additional nutrients (Leakey 1996, Sall 1992). Improved feed for livestock also translates into more organic manure.

Falling fallows and extension of pearl millet cultivation into more marginal areas indicate that the availability of land is an increasingly limiting factor in some areas. Labor scarcity during the planting season can be a major

constraint. Male migration and a growing level of school enrolment means that the burden of labor supply is often thrown onto women, whose time is already severely constrained (Holtland 1996). This particular constraint is sometimes eased by labor circulation, i.e., the men migrating seasonally back to the land for peak period operations such as land preparation and harvesting, and also by older children absenting themselves from school. However, it has been made more severe by the HIV/AIDS pandemic.

In India the greatest constraint on pearl millet HYV adoption in the least favored areas that can be addressed is lack of a reliable supply of quality seed of adapted improved cultivars. India's commercial seed suppliers - especially the larger and more responsible ones - are concentrated in the areas with the best production potential and the most commercialized pearl millet production, i.e., in states such as Maharashtra and Gujarat. In the less favored areas like Rajasthan, and most especially western Rajasthan, weakness of the organized seed market is one of the main reasons for the low level of uptake of improved pearl millet cultivars. This is accentuated by industry perceptions that seed demand in the region is rainfall-dependent and therefore not sufficiently predictable.

In sub-Saharan Africa the position regarding seed supply is quite heterogeneous. A few countries, such as South Africa and Zimbabwe, are somewhat similar to India in that they have developed a commercial market for inputs, including seed. However, in most of Africa there is no commercial seed market. Instead farmers rely on public sector supply, NGOs and farmer-to-farmer sales, particularly the latter. The situation in the Sahel tends to be the least favorable. There are now five or six good pearl millet improved open-pollinated cultivars available off-the-shelf in several Sahelian countries, but there is little or no seed production and marketing infrastructure.

The situation regarding product marketing parallels that for inputs. In the more favored agro-climatic areas, the situation is relatively good and often improving. However in the least favored areas there is no commercial market for the crop. This does not mean there are no prospects for improvement. Processing and marketing experiments indicate prospects for adding value to the domestic product and making it more competitive with imports. Examples are the development of a pearl millet-cowpea infant food formula in Mali (Debrah 1993) and the use of pearl millet flour as a partial substitute for wheat flour in baked products in Kenya (ICRISAT 1997).

Research Prioritization

Traditionally the agendas of publicly-funded agricultural research organizations have been set by their scientists, who were assumed to know what the problems were. However, with an essentially subsistence crop like pearl millet, the producer is also the consumer, and it is particularly important to ensure that rural households play a central role in helping to set the research agenda, and evaluating the outputs of the research-extension system. In recent times, the situation has been changing with the adoption by the CGIAR centers, and some of the NARCs, of the participatory approach to research agenda setting and prioritization.

ICRISAT now explicitly accepts that "farmer participation in the design of new crop varieties is essential if these are to meet users' needs" (ICRISAT 1997, p. 76). For example, in partnership with the Southern African Development Community, ICRISAT has developed the concept of the "diverse germplasm observation nursery" (DGON). Here a large number of contrasting types of sorghum and pearl millet are grown in order to let farmers see for themselves the different possible combinations of crop traits. A scoring card then allows farmers to evaluate and rank the varieties. The results revealed, "A significant difference of emphasis between farmers' priorities and those traditionally adhered to by plant breeders. Breeders, at least of the old school, tend to focus narrowly on yield, whereas for farmers a range of other traits appears more important" (ICRISAT 1997, p. 78). The methodology for this approach is still being evaluated and refined in the light of experience. The addition of women to panels is crucial, partly for reasons given earlier about intra-household discrimination in food allocation, but also because of customary gender division of labor. For example, in Namibia it was found that men preferred a particular variety of pearl millet on taste grounds, whereas the women gave it a low score because it was difficult to dehull, and dehulling is women's work.

One can postulate at least three different levels of participation by farmers in setting the research agenda. The DGON type of approach, in which farmers are presented with as wide as possible a range of choices and then asked to evaluate them, is *ex-post* evaluation of completed work. It represents a huge improvement on what went before, but it is still based on scientists setting the research agenda in the first place. The second approach, an *ex-ante* design, is one in which the farmers set the criteria first and the scientists then search to see if they can come up with appropriate varieties off the shelf. The third level would be for the farmers to state their criteria and the scientist to then breed to order. A major problem with this approach, however, is that with a 10-year time lag the traits desired by farmers could well have become obsolete by the time the ideotype was developed into an experimental cultivar ready for testing. An important question arising from this is whether new

techniques such as molecular markers can reduce both the time lag and the cost of developing new cultivars to the point that it becomes feasible to design varieties to order. The new techniques certainly offer considerable benefits over conventional breeding techniques in this line, notable shortening the time frame to develop hybrids, simpler and cheaper screening for more difficult characteristics, and simpler screening for resistance to pathogens from other regions.

It is clear that at the institutional level ICRISAT has made a firm and wholehearted commitment to adopting a participatory approach to setting the research agenda. On the basis of its track record, no one could reasonably argue that this is just a public relations exercise. However, some scientists are more firmly committed to participatory approach than others. There are many who have made the commitment, but some scientists are still struggling with the concept and its philosophical underpinnings.

Conclusions

Pearl millet is produced mostly by poor people in marginal areas of India and Africa. Grown primarily as a subsistence food crop, relatively little grain enters the market. This combination - direct consumption of the crop by those who grow it and the consequent lack of means to escape poverty by selling their surplus - is a stark prospect for the food security of the millions of people who depend on this crop.

With poverty alleviation a central feature of aid policy and the increasing cultivation of marginal areas, the crop is likely to attract growing attention in the coming decade. The key questions and challenges will center around:

- the allocation of resources in terms of geographic areas,
- the need for policy reform,
- the balance between investment in research vis-a-vis investment in strengthening uptake pathways, and
- the balance between strategic and adaptive research.

From a geographical perspective the status of pearl millet production varies considerably. At a broad level, there are striking differences between India and Africa. While production of pearl millet in Asia is concentrated in a few heavily populated states of India with cultural and linguistic similarities, production in Africa is spread thinly across political boundaries and across disparate cultural traditions. In India, although pearl millet remains regionally important, it makes only a minor contribution to national food security. On the other hand, for many African countries, particularly in the Sahel region, national food security relies on pearl millet production. There are also considerable differences regarding the status of production within India and Africa. It is worth emphasizing that advances in pearl millet production have occurred in areas where the contribution of pearl millet to national or regional food security is relatively less important. In contrast, in areas where pearl millet production is critical to regional and national food security, the situation has deteriorated.

At a macro level, unfavorable policy environments, in particular policies relating to coarse grain marketing, continue to undermine prospects for pearl millet production. In India, the development of an efficient marketing system for pearl millet is frustrated by government support prices for more preferred cereals such as wheat and rice. Similarly, in many parts of Africa, grain policies have evolved in response to urban demand for alternative staples, reinforced by market distortions.

An important constraint affecting pearl millet production continues to be the non-availability of seed. Again there are stark differences between the Indian and African situations. Farmers use hybrids extensively in India, and the Indian private sector is heavily involved in supplying hybrid seed (which must frequently be replaced and is therefore more profitable than open-pollinated varieties). In die Sahel, on the other hand, hybrids are not used at all, and the private seed sector is still in an embryonic stage of development, although it should be noted that the infrastructure for seed production and marketing is relatively better developed in southern Africa.

Questions over future research priorities center around the allocation of resources along the research spectrum. There have been considerable advances with the identification of molecular markers for downy mildew and drought tolerance. Some progress has been made toward the identification of markers for phosphorus uptake efficiency. To date, research has focused on minimizing yield losses as a primary objective. In the Sahel, however, other factors may be more important than yield. Varieties that enhance food security in the hungry season are extremely attractive to poor farmers in general and the most disadvantaged family members in particular. The easing of constraints on production is also extremely important.

The central question remains the allocation of resources geographically and along the research and development spectrum. The subject of future support must be discussed with two different scenarios in mind: those of India and Africa. India's experience has demonstrated that improvements in production can dramatically change the comparative advantage of pearl millet production.

Sahelian Africa, on the other hand, has limited public research capability, very few examples of private seed companies, and volatile unstable markets. For the foreseeable future, the Sahelian countries are likely to rely on the public sector. Open-pollinated varieties and landraces are widely grown, and hybrids are in their

infancy. This suggests that the emphasis should be on adaptive research with a major investment in strengthening uptake pathways. The exploration of complementary ways of improving productivity (such as the earlier mentioned examples of agroforestry and the use of rock phosphate) should continue to receive close attention in research policy. Significant information gaps still exist for the Sahelian region in particular, on farmers' decision-making processes with regard to pearl millet production.

It is easy to justify the case for increasing investment in pearl millet research and development. However, difficult decisions relating to important trade-offs need to be made. On the one hand, the best use of funds might be to focus on the poorest farmers in the Sahelian countries who have yet to feel the benefit of research. To support this strategy considerable resources would need to be invested in gaining a clearer picture of constraints to adopting new varieties and strengthening uptake pathways - the thrust would therefore be on adaptive research. On the other hand, this strategy must be balanced against the enormous gains to be made through the application of new technologies in more favorable environments as illustrated by the dramatic improvement in pearl millet production in India. Rajasthan may represent an exciting opportunity where infrastructure is relatively supportive to the wider uptake of new varieties. Some difficult decisions will need to be made. What is not in doubt is mat there are still opportunities - through both policy and research interventions - to improve the status of pearl millet production in the future.

References

Bhatia KS. 1995. Rhetoric and reality: a gender analysis. Kathamandu, Nepal: Dolakha-Ramechhap Community Forestry Development Project, Swiss Development Cooperation.

Chambers R, Longhurst R and Pacey A. 1981. Seasonal dimensions to rural poverty. London, UK: Frances Pinter.

Debrah SK. 1993. The competitiveness of sorghum and millet in the food system of West Africa. *In:* National Workshop on Sorghum and Millet Marketing and Utilization in Tanzania (Minde IJ and Rohrbach DD, eds.). Arusha, Tanzania: Sokoine University of Agriculture, Ministry of Agriculture, SADC/ ICRISAT, IDRC.

FAO and ICRISAT. 1996. The world sorghum and millet economies: facts, trends and outlook. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO), and Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Friis-Hansen E and Rohrbach DD. 1993. SADC/ICRISAT 1992 drought relief emergency production of sorghum and pearl millet seed: impact assessment. Working Paper 93/01. PO Box 776, Bulawayo, Zimbabwe: ICRISAT Southern and Eastern Africa Region.

Gill GJ. 1991. Seasonality and agriculture in the developing world: a problem of the poor and powerless. Cambridge, UK: Cambridge University Press.

Holtland G. 1996. Farmers' priorities for new sorghum and pearl millet varieties based on on-farm trials in semi-arid Tanzania. Pages 71-80 *in* Drought-tolerant crops for southern Africa: Proceedings of the SADC/ICRISAT Regional Sorghum and Pearl Millet Workshop, 25-29 July, Gabarone, Botswana (Leuschner K and Manthe CS, eds.). Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

ICRISAT. 1996. Improving the unimprovable: succeeding with pearl millet. Food From Thought, No. 3. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

ICRISAT. 1997. ICRISAT report. 1996. Patancheru. Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Keyler S. 1995a. Informal and commercial millet marketing in Ovambo and Kavango. *In* Second National Pearl Millet Workshop: Proceeding of a Workshop held at Windhoek, Namibia. Bulawayo, Zimbabwe: ICRISAT Southern and Eastern Africa Region.

Keyler S. 1995b. Economics of the pearl millet subsector in northern Namibia: a summary of baseline data. Working Paper 95/03. Bulawayo, Zimbabwe: SADC/ICRISAT Sorghum and Millet Improvement Program.

Leakey C. 1996. Biomass, man and seasonality in the tropics. *In* Seasonality and poverty (Longhurst R, ed.). IDS Bulletin Vol. 17, No. 3. Institute for Development Studies and the University of Sussex, UK.

Mukete M and Sheuyange A. 1995. Characteristics of mahangu producers, traders and retailers in former Ovambo Region and Kavango: findings from an informal survey. *In* Second National Pearl Millet Workshop: Proceeding of a Workshop held at Windhoek, Namibia. Bulawayo, Zimbabwe: ICRISAT Southern and Eastern Africa Region.

Rohrbach DD. 1995. Millet production and marketing policy options in Namibia. *In* Second National Pearl Millet Workshop: Proceeding of a Workshop held at Windhoek, Namibia. Bulawayo, Zimbabwe: ICRISAT Southern and Eastern Africa Region.

Sall PN. 1992. Site effects of *Acacia albida* Del. Pages 103-105 *in Faidherbia albida* in the West African semi-arid tropics, Proceedings of a Workshop, 22-26 April 1991, Niamey, Niger (Vandenbeldt R., ed.). Patancheru, Andhra Pradesh. India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). and Nairobi, Kenya: International Centre for Research in Agroforestry (ICRAF).

Singh SD, King SB and Werder J. 1993. Downy mildew disease of pearl millet. Information Bulletin no. 37. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Sivakumar MVJ, Kenard C, Bationo A, Powell JM, Weber J and Goli AE. 1994. Inter-center collaboration at the ICRISAT Sahelian Center. Research Bulletin no. 18. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Thompson A and Metz M. 1997. Implications for economic-policy for food security. Training Manuals for Agricultural Planning No. 40. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Pearl Millet Molecular Marker Research

CT Hash[1,*] and JR Witcombe[2] (1. ICRISAT, Patancheru 502 324, Andhra Pradesh, India; 2. Centre for Arid Zone Studies, University of Wales, Bangor, Gwynedd LL57 2UW, UK)
*Corresponding author: c.hash@cgiar.org

Accumulating Stores of Knowledge: Disease Resistance QTLs in Pearl Millet

The slow magic of agricultural research relies on accumulation of knowledge that future generations of scientists can use. New technologies, such as molecular markers, are expensive to develop, and returns from the research take a long time. However, once the knowledge reaches a critical level, gains accelerate and provide a deeper, more flexible, resource. Research on molecular markers to aid in breeding pearl millet [*Pennisetum glaucum* (L.) R. Br.] for resistance to the downy mildew pathogen *Sclerospora graminicola* (Sacc.) J. Schrot., which has been largely funded by the Plant Sciences Research Programme of the UK's Department for International Development (DFID), provides a classic example.

In 1990, there were no pearl millet molecular markers, no marker-based genetic linkage map, and, of course, traits could not be linked to marker locus positions on a non-existent map. By 2001, hundreds of pearl millet molecular markers had been created (Liu et al. 1994; Allouis et al. 2001; Qi et al. 2001), detailed marker-based genetic linkage maps produced (Liu et al. 1994 and 1996; Devos et al. 2000), and using those maps, genomic positions of quantitative trait loci (QTLs) for pearl millet downy mildew resistance flagged (Jones et al. 1995 and 2002; Azhaguvel 2001; Kolesnikova-Allen 2001; Breese et al. 2002; Hash et al. unpublished). What is surprising, even to the researchers involved, is how many genomic regions contributing to downy mildew resistance have already been identified (Fig. 1, see pages 9-12).

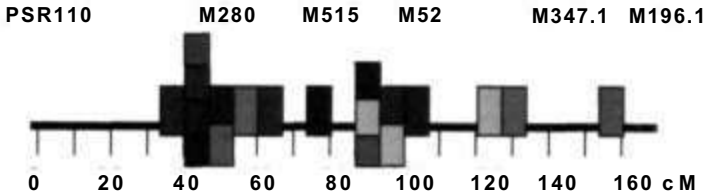
Not only have QTLs for downy mildew resistance been mapped, but genotypes produced or tested in the mapping studies have provided a valuable genetic resource. They are donors of naturally occurring host-plant resistance genes, and a well-chosen set of lines can differentiate among many different populations of the causal agent of pearl millet downy mildew. All of this new information allows breeders, both now and in future decades of pearl millet breeding, to incorporate and pyramid resistance genes into cultivars grown by resource-poor farmers. The information is widely available and there is little risk of its loss. The genetic resources that have been generated are more fragile, but by appropriate storage and distribution this crop germplasm can also be a long-term resource for plant breeding.

Such accumulated knowledge contributes to the speed of cumulative gains that plant breeding can make. The extent of this knowledge provides flexibility (different gene deployment strategies), depth (many genes for potential pyramiding), and breadth (many geographical targets).

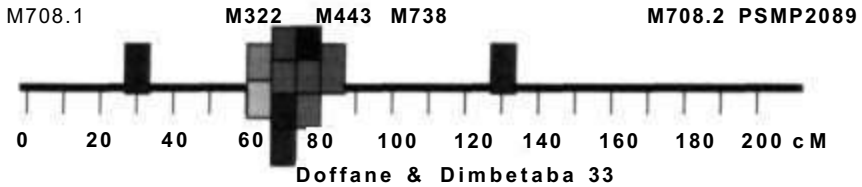
We describe below the application of these stores of knowledge to the specific improvement of pearl millet hybrid HHB 67, which is only grown in India. Although HHB 67 is, in practice, a public good for India, the knowledge generated in its improvement is an international public good.

Figure 1 (see pages 9-12 of this issue). Distribution of pearl millet downy mildew resistance QTLs across the seven linkage groups of a consensus skeleton linkage map of the pearl millet genome. The letter/number combinations above each linkage group are abbreviated names of anchor loci on the RFLP-based pearl millet consensus map. The approximate length of each linkage group is indicated in Haldanc centiMorgans. Each linkage group corresponds to a pearl millet chromosome pair. QTLs for downy mildew resistance have been mapped to all seven pearl millet linkage groups. Colored blocks indicate approximate genomic positions of downy mildew resistance QTLs; the color of the block indicates the parental line mat contributed resistance mapping that position in the pearl millet genome. Pearl millet downy mildew pathogen populations (named after the locations from which they were collected) against which the resistance QTL is effective are listed in the same color directly below the QTL position. The number that follows each pathogen population name in the portion of disease incidence variation in the particular pearl millet mapping population x pathogen population combination that is accounted for by the host plant resistance QTL mapping to this position.

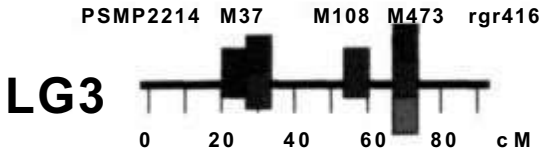
Pearl millet downy mildew resistance QTLs



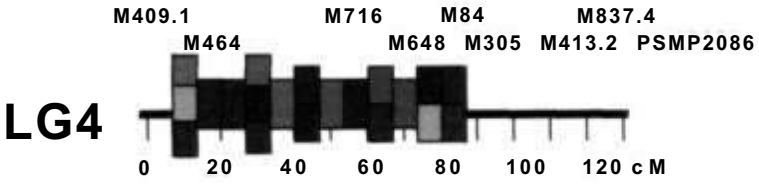
PatancheruB 40 **PatancheruB 9**
PatancheruP 19
PatancheruP 40
Jalna 34 Jodhpur 12
PatancheruP 77
PatancheruB 64
Sadore 41 Maiduguri 9
Kordofan 85 Bamako 13
Benin Kebi 11
Jalna 87 Sadore 8
Jamnagar 16 Jamnagar33
Jodhpur 21 PatancheruP 9
Patancheru 13 PatancheruP 62
Jodhpur 36 Jodhpur 56
Sadore 36 PatancheruP 21
PatancheruP 20 PatancheruB 63
PatancheruB22 Jamnaga55
Kordofan 39 Kordofan 60
Maiduguri 50 Nguru 67
Jalna 19 Bamako 59
Jaipur 24 Bamako 55
PatancheruB55 Kordofan55



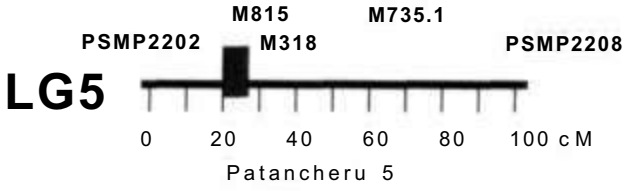
Doffane & Dimbetaba 33
Jalna 57 PatancheruP 38
Jodhpur 6 **PatancheruB 53**
Bamako 22 Bamako 39
Sosana 12
Jaipur 50 Jodhpur 16
Jamnagar 62 PatancheruP 23
Jamnagar 52
Jalna 24
PatancheruP 14
Bamako 29
Jaipur 7
PatancheruB 10



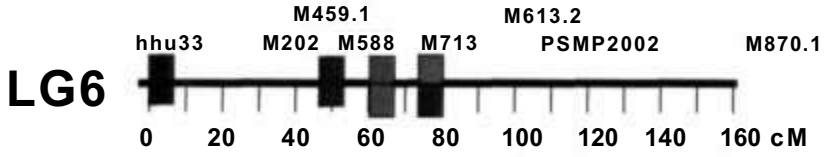
Benin Kebi 13
PatancheruB 14
Mysore 15
PatancheruP 8
Jalna 40 **Jalna 4**
Jodphur 21
Jamnagar 16
Kordofan 12
Patancheru 5
Jamnagar 19
Kordofan 12
Jaipur 13
Jodhpur 27



Bengou 30
Maiduguri 29
PatancheruP 11 Sadore 47
Jalna 11 Bamako 32
Jodhpur 15 Sosana 38
Sosana 12 PatancheruB 16
Benin Kebi 56
Jamnagar 23
PatancheruP 64
Jaipur 20
Sosana 38
Sadore 40 **Jodhpur 74**
Bamako 27 **Jalna 32**
Sadore 26 **Sadore 26**
PatancheruP 37 **PatancheruP 8**
PatancheruB 36
Kordofan 57 **PatancheruB 7**
Bamako 20 **Kordofan 15**
Jodhpur 61 **Maiduguri 18**
Jodhpur 30
PatancheruP 62
Jalna 24 **PatancheruP 61**
Jalna 9 **Jaipur 20** **Jaipur 17**
Nguru 60 Nguru 58
Bamako 16
Sadore 77 **Sadore 78**
Kordofan 48



Patancheru 5



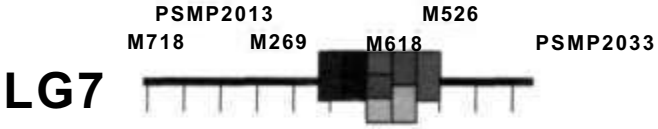
PatancheruP 8

PatancheruB 10
PatancheruP 9
Doffane & Dimbetaba 10
Bengou 8

PatancheruB 15
Jalna 11

Sadore 10
Kordofan 12
Jodhpur 12

PatancheruP 7
Sadore 47
PatancheruB 63



Doffane & Dimbetaba 10
PatancheruB 10
PatancheruP 8

PatancheruB 28
Sadore 15

Sadore 21
Maiduguri 9
Bamako 15
Sadore 18
Bamako 9
New Delhi 9

Pearl millet mapping populations contributing the more resistant allele:

Red = ICMP 85410-P7 Blue = LGD 1-B-10	Jones et al. (1995)
Orange = 81B-P6 Green = ICMP 451-P8	Hash et al. (unpublished)
Sky blue = ICMP 451-P6 Plum = H 77/833-2-P5(NT)	Breese et al. (2002) and Cavan et al. (unpublished)
Pink = 841B-P3 Purple = 863B-P2	Hash et al. (unpublished)
Grey = PT 732B-P2 Brown = P 1449-2-P1	Hash et al. (unpublished)
Teal - W 504-1-P1 Gold = P3I0-17B	Kolesnikova (2001)
Turquoise = IP 18293-P152	Azhaguvel (2001)
Bright green = P 7-3	Jones et al. (2002)

Sources of pearl millet downy mildew populations (and years of collection) used in greenhouse disease screens of pearl millet mapping populations used to detect QTLs for host plant resistance to *Sclerospora graminicola:*

Screens conducted at the University of Wales, Bangor:

- **Sosana, Barentu, Eritrea (2000)**
- **Patacheru, Andhra Pradesh, India (1989 and 1994) = PatancheruB**
- **Bamako, Mali (1996)**
- **Sadore, Niger (1996)**
- **Bengou, Niger (1992)**
- **Benin Kebi, Nigeria (1996)**
- **Maiduguri, Nigeria (1991 and 1994)**
- **Nguru, Nigeria (1994)**
- **Doffane & Dimbetaba, Senegal (1992)**
- **Kordofan, Sudan (1997)**

Screens conducted at ICRISAT-Patancheru, India:

- **Jaipur, Rajasthan, India**
- **Jalna, Maharashtra, India**
- **Jamnagar, Gujarat, India**
- **Jodhpur, Rajasthan, India**
- **Mysore, Karnataka, India**
- **New Delhi, Delhi, India**
- **Patancheru, Andhra Pradesh, India = PatancheruP**

Improving Pro-poor Public Goods

Pearl millet seeds are tiny - in one kilogram there are typically over 100,000 seeds - so farmers need only a small amount to sow their crop. This makes the more expensive hybrid seed a profitable option, even for poor farmers, so it is unsurprising that single-cross hybrids are now the most widely grown pearl millet cultivar type in India and they are grown by all categories of farmers. There are many pearl millet hybrids from private-sector breeding programs, but hybrids bred in the public-sector, such as HHB 67 from CCS Haryana Agricultural University, are also widely grown. This particular hybrid was released in 1989 (Kapoor et al. 1989) and has many traits that farmers appreciate, including early maturity that allows it to escape end-of-season drought stress. It is probably the most popular public-sector pearl millet hybrid in India and occupies over half of the pearl millet area in Haryana (over 300,000 hectares during the rainy season of 2001). It is grown in rainfed farming systems where its short duration allows farmers ample time to prepare land for any following crop grown largely on residual moisture, such as chickpea (*Cicer arietinum* L.), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), or oilseed mustard (*Brassica* sp.).

Pearl millet farmers in India have no public-sector alternative to HHB 67 in this maturity class, and all private-sector hybrids mature later than HHB 67. However, its popularity makes it vulnerable to an epidemic of downy mildew. In the past, every single highly popular pearl millet hybrid in India has ultimately succumbed to this disease. When this happens, farmers not only suffer the direct losses caused by the epidemic, but they lose the management options associated with growing their most preferred hybrid. The hybrid seed industry also faces economic losses as it takes time to gear up seed production of the next best alternatives, and for farmers to then identify which of these best match their needs.

Marker-assisted backcrossing (MABC) has been used to improve the disease resistance of the parental lines of HHB 67 (Sharma 2001). MABC is rapid, and more effective than conventional breeding where it is often impracticable to deliberately add several resistance genes (so-called gene pyramiding) into a particular crop genotype. In conventional breeding, once a single effective resistance gene is included it is often impossible to detect the presence of a second without expensive and time-consuming progeny testing every backcross generation. MABC also allows the introduction of the resistance genes while, because of the inherent properties of the backcross breeding method, ensuring that other genetic changes are minimal. Indeed, marker-assisted selection can be not just for the resistance gene from the donor, but to select for the original parent genotype over other regions of the genome that are not tightly linked to the targeted resistance gene(s). These minimal genetic changes greatly facilitate adoption by the seed industry and farmers of the improved products. All that is needed is the replacement of new lines for old in the seed multiplication chain. This can be done once it is confirmed that: the new parental lines have better disease resistance; are otherwise identical to the old lines as far as seed certification is concerned; and that the new version of the hybrid performs at least as well as the old. This may sound complicated but it is much faster and easier than releasing a new hybrid that requires more extensive trials and complex and uncertain release procedures.

MABC provides a new model for hybrid breeding - incremental breeding - rather than relying on the chance results of random re-assortment of genes from crosses. The process of building on a successful public-sector hybrid need not end by simply ensuring it does not succumb to a downy mildew epidemic. MABC can be applied for other traits to produce further incremental improvements in a popular hybrid such as HHB 67. Over time, more and more desirable traits can be added, and the hybrid becomes closer and closer to the farmers' ideal. The crucial advantage of building on an already popular hybrid is that the process is participatory. Farmers have demonstrated demand by voting with their cash when they buy the hybrid seed, and incremental gains can be made for any weaknesses identified by farmers or the seed industry.

Table 1. The pearl millet hybrid seed multiplication chain (after Khairwal et al. 1990).

Stage	Year	Season	Responsibility
1. Parental line Breeder Seed	1	Summer season	Breeder
2. Parental line Foundation Seed	1	Rainy season	Seed producer
3. Certified Hybrid Seed production	2	Summer season	Seed producer
4. Certified Hybrid Seed use	2	Rainy season	Input suppliers & farmers

What Is Needed to Now Deliver Improved Versions of HHB 67 to Farmers?

The simplest option for getting seed of improved versions of HHB 67 to farmers would be to replace the seed without following release procedures. Local seed laws permitting, all that is required is to simply replace the seed lots that are used for Breeder Seed production of the hybrid parental line(s), and the improved version of the hybrid will reach farmers through the seed multiplication chain 18 months later (Table 1).

This strategy has been possible in India for private-sector seed companies that produce 'truthfully labeled' seed, the quality of which is marketed on the strength of the companies' reputations rather than by employing government-supported seed certification. Following positive perceptions of farmers in on-station and on-farm trials in 2001, this replacement process could begin within the private sector in 2002. Seed of the new versions would then first reach farmers in the rainy season of 2003.

However, for hybrid seed multiplied and marketed by private and public seed production agencies that rely on government-supported seed certification to ensure seed quality, this substitution of the improved version for the original is delayed for at least one year for field trials. The field trial data are then used to support the official release of the new version of the hybrid. The release documents include revised descriptions of the parental lines for seed certification purposes. In this case, the shortest possible path for the new hybrid to reach farmers would involve rainy season trials in 2001 and 2002 followed by a state release proposal in early 2003. By simultaneously producing Breeder Seed of the new versions of the hybrid parental lines during the summer season of 2003, Certified Hybrid Seed of the new versions of HHB 67 could first reach farmers in the rainy season of 2004.

Indeed, initial field trials have documented that some of the improved versions of HHB 67 actually are superior to the original for traits other than downy mildew resistance - the original target of our marker-assisted backcrossing program. For example, multilocational trials of hybrids produced with two new versions of the pollinator suggest that grain yield gains of 15% may have been achieved while simultaneously making significant improvements in downy mildew resistance without adversely affecting the early maturity of HHB 67 that farmers appreciate so much. This is a yield gain of 3% per annum, over and above the returns from improved disease resistance, in a breeding program that did not target grain yield improvement *perse.* This is remarkable, because yield gains from conventional yield-focused hybrid breeding are typically on the order of 1-2% per year.

This is a novel and systematic way for plant breeders to generate positive variation for economic yield in very elite, farmer-accepted genetic backgrounds. The genetic integrity of the hybrid parental lines of HHB 67 has largely been maintained by the backcrossing process, and the donor parents have contributed genomic segments conferring improved downy mildew resistance, along with genomic regions tightly linked to those conferring improved downy mildew resistance. In at least some cases, resistance donor parent alleles in genomic regions tightly linked to the downy mildew resistance genes contribute positively to grain yield, even in the absence of disease, and these favorable variants have been detected and selected from conventional line x tester experiments conducted as multilocational yield trials.

Now we are set to start targeting QTLs that are expected to confer increased grain and stover yields. For example, we have already used a morphological marker that is tightly linked to a gene for a flowering-date-indcpendent increase in plant height to increase the straw yield of HHB 67, which is identified by farmers as one of the few weaknesses of this popular hybrid. In addition, we have just completed transfer to the male parent of this hybrid a genomic region expected to confer enhanced tolerance to terminal drought stress. Hybrids produced with these new versions of the male parent will be screened under a range of drought stress regimes during 2002.

Acknowledgments. This document is an output from several projects of the Plant Sciences Research Programme funded by the UK Department for International Development (DFID) and administered by the Centre for Arid Zone Studies (CAZS) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

The authors gratefully acknowledge the contributions of many scientists, students and support staff from ICRISAT-Patancheru, JIC-Norwich, UW-Bangor, IGER-Aberystwyth, and CCS HAU-Hisar to the mapping population development, genotyping, phenotyping, and data analysis required for identification of the QTLs for pearl millet downy mildew resistance that are summarized in Figure 1 of this document, and to the development and testing of the improved versions of pearl millet hybrid HHB 67 and its parental lines.

References

Allouis S, Qi X, Lindup S, Gale MD and Devos KM. 2001. Construction of a BAC library of pearl millet. *Pennisetum glaucum.* Theoretical and Applied Genetics 102:1200-1205.

Azhaguvel P. 2001. Linkage map construction and identification of QTLs for downy mildew (*Sclerospora graminicola*) resistance in pearl millet (*Pennisetum glaucum* (L..) R. Br.). PhD thesis, Department of Agricultural Botany, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India. 204 pp.

Breese WA, Hash CT, Devos KM and Howarth CJ. 2002. Pearl millet genomics - an overview with respect to breeding for resistance to downy mildew. Pages 243-246 *in* Sorghum and Millets Pathology 2000 (Leslie JF, ed.). Ames, Iowa, USA: Iowa State Press.

Devos KM, Pittaway TS, Reynolds A and Gale MD. 2000. Comparative mapping reveals a complex relationship between the pearl millet genome and those of foxtail millet and rice. Theoretical and Applied Genetics 100:190-198.

Jones ES, Liu CJ, Gale MD, Hash CT and Witcombe JR. 1995. Mapping quantitative trait loci for downy mildew resistance in pearl millet. Theoretical and Applied Genetics 91: 448-456.

Jones ES, Breese WA, Liu CJ, Singh SD, Shaw DS and Witcombe JR. 2002. Mapping quantitative trait loci for resistance to downy mildew in pearl millet: Field and glasshouse screens detect the same QTL. Crop Science 42:1316-1323.

Kapoor RL, Kakkar PS, Khairwal IS, Bainiwal CR, Nijhawan DC and Yadav HP. 1989. Bajra hybrid HHB 67 - a major break through. Haryana Farming 18:17, 21.

Khairwal IS, Ram C and Chhabra AK. 1990. Pearl millet seed production & technology. New Delhi, India: Ramesh Jain Manohar Publications. 224 pp.

Kolesnikova MA. 2001. Mapping new quantitative trait loci (QTL) for downy mildew resistance in pearl millet. PhD thesis, Russian National Academy of Sciences, Moscow, Russia. (English and Russian). 266 pp.

Liu CJ, Witcombe JR, Pittaway TS, Nash M, Hash CT, Busso CS and Gale MD. 1994. An RFLP-based genetic map of pearl millet *(Pennisetum glaucum).* Theoretical and Applied Genetics 89:481-487.

Liu CJ, Devos KM, Witcombe JR, Pittaway TS and Gale MD. 1996. The effect of genome and sex on recombination rates in *Pennisetum* species. Theoretical and Applied Genetics 93:902-908.

Qi X, Lindup S, Pittaway TS, Allouis S, Gale MD and Devos KM. 2001. Development of simple sequence repeat markers from bacterial artificial chromosomes without subcloning. BioTechniques 31:355-361.

Sharma A. 2001. Marker-assisted improvement of pearl millet (*Pennisetum glaucum*) downy mildew resistance in elite hybrid parental line H 77/833-2. PhD thesis, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India. 131 pp.

Yadav RS, Hash CT, Bidinger FR and Howarth CJ. 1999 QTL analysis and marker-assisted breeding of traits associated with drought tolerance in pearl millet. Pages 211-223 *in* Genetic improvement of rice for water-limited environments (Ito O, O'Toole J and Hardy B, eds.). Los Banos, Philippines: International Rice Research Institute (IRRI).

Yadav RS, Hash CT, Bidinger FR, Cavan GP and Howarth CJ. 2002. Quantitative trait loci associated with traits determining grain and stover yield in pearl millet under terminal drought-stress conditions. Theoretical and Applied Genetics 104:67-83.

Improving Pearl Millet Drought Tolerance

RS Yadav[1] *, FR Bidinger[2], CT Hash[2], GP Cavan[1], R Serraj[2] and CJ Howarth[1] (1. IGER, Aberystwyth, SY23 3EB, UK; 2. ICRISAT, Patancheru 502 324, Andhra Pradesh, India)

*Corresponding author: rattan.yadav@bbsrc.ac.uk

Quantitative trait loci (QTL) have been identified for drought tolerance of grain yield in pearl millet (Yadav et al. 1999 and 2002). Marker-assisted selection (MAS) is being used to develop improved parental lines by introgression of QTLs into a homozygous inbred line background for the subsequent production of improved hybrids (marker-assisted back crossing), and by transforming them into topcross pollinator populations that are more heterogeneous than inbred lines. Until - and unless - it is clearly demonstrated that the incorporation of these QTLs into elite breeding lines will significantly enhance the performance of cultivars based on those lines, the benefits of these QTLs are unlikely to ever reach farmers' fields.

Three topcross pollinator populations (TCPs) were developed by selecting and inter-mating individual genotypes from within the $F_{2:4}$ mapping families of a pearl millet population used for mapping QTLs for drought tolerance (Fig. 1). The three TCPs produced were selected according to the following methods and criteria:

- Marker-assisted selection: genetic composition at the drought tolerance QTL (to constitute a MAS-based TCP);
- Phenotypic selection: field performance (best 16) in the drought trials used to identify QTLs (to constitute a phenotype-based TCP); and

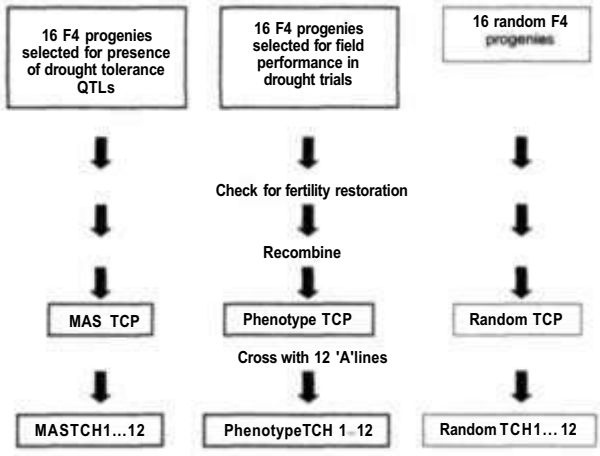


Figure 1. The scheme used to test marker-assisted selection for pearl millet QTLs controlling drought tolerance using topcross pollinators. Topcross pollinators based on phenotypic and random selections are controls for the pollinator based on marker-assisted selection.

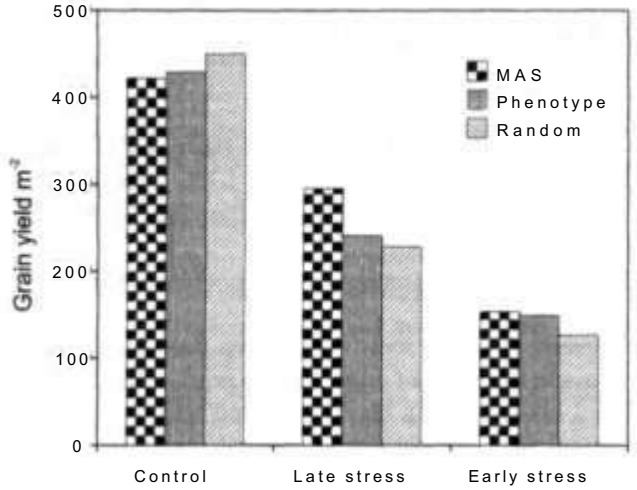


Figure 2. Grain yield performance of pearl millet hybrids made between three topcross pollinators and male-sterile line ICMA 92777 in a range of summer season drought nursery moisture environments, ICRISAT 2001.

- A random control: a random sample from within the mapping population (to constitute a random TCP).

The three TCPs were subsequently used as pollinators on 12 A-lines (male-sterile lines) to produce topcross hybrids, as shown in Figure 1. Compared to hybrids of the phenotype and random TCPs, the MAS TCP hybrids had better drought tolerance indices and grain yields (Fig. 2) in the drought-stress environments, although they had a lower yields in the irrigated control environment. Selecting simply on the basis of field performance under drought was ineffective, but MAS was able to produce improvement in this character, which is notoriously difficult to breed for using conventional methods.

Acknowledgments. This document is an output from a project (Plant Sciences Research Programme R7375) funded by the UK Department for International Development (DFID) and administered by the Centre for Arid Zone Studies (CAZS) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

References

Yadav RS, Hash CT, Bidinger FR and Howarth CJ. 1999. QTL analysis and marker-assisted breeding of traits associated with drought tolerance in pearl millet. Pages 211-223 *in* Genetic improvement of rice for water-limited environments (Ito O, O'Toole J and Hardy B, eds.). Los Banos, Philippines: International Rice Research Institute (IRRI).

Yadav RS, Hash CT, Bidinger FR, Cavan GP and Howarth CJ. 2002. Quantitative trait loci associated with traits determining grain and stover yield in pearl millet under terminal drought-stress conditions. Theoretical and Applied Genetics 104:67-83.

New Molecular Marker Technologies for Pearl Millet Improvement

MD Gale[1,*], KM Devos[1], JH Zhu[1], S Allouis[1], MS Couchman[1], H Liu[1], TS Pittaway[1], XQ Qi[1], M Kolesnikova-Allen[2] and CT Hash[2] (1. John Innes Centre, Norwich, UK; 2.ICRISAT, Patancheru 502 324, Andhra Pradesh, India)

*Corresponding author: mike.gale@bbsrc.ac.uk

At a time when most of the world still viewed molecular technology as a luxury, for use only with major staple crops, a DFID-JIC-ICRISAT project anticipated as early as 1991 the application of molecular diagnostics in the breeding of orphan crops for developing countries.

The first molecular marker-based genetic linkage map of pearl millet [*Pennisetum glaucum* (L.) R. Br.] was built with restriction fragment-length polymorphisms (RFLPs), the marker system of choice in the early 1990s (Liu et al. 1994). This map has served as the base for subsequent pearl millet marker-based studies at J1C (Busso et al. 1996, 2000; Devos and Gale 2000; Devos et al. 2000; Liu et al. 1996, 1997). The RFLP framework in the consensus map now available (Fig. 1, see pages 18-19 of this issue) is based on 173 (out of 500 available) mapped *Pst*I genomic clones from inbred line Tift 23DB, which has now become the base genotype for pearl millet molecular genetics. The clones are available as DNA or, in some cases, as DNA sequences, and have been distributed freely worldwide.

ICRISAT was able to build one of the very early molecular marker facilities in the CGIAR system in the early 1990s, and has used this facility for pearl millet diversity assessment (Bhattacharjee et al. 2002), mapping population skeleton map construction (Azhaguvel 2001; Kolesnikova-Allen 2001), and marker-assisted backcrossing (Sharma 2001). The markers and maps have also been used at CAZS and IGER in the UK, Universite d'Orsay in Paris, and Tifton in the USA, to map and tag genes controlling important traits in the pearl millet crop. These include downy mildew resistance (Jones et al. 1995 and 2002; Azhaguvel 2001; Kolesnikova-Allen 2001), foliar disease resistance (Morgan et al. 1998), drought tolerance (Yadav et al. 2002), plant height (Azhaguvel 2001), flowering time, and the multiple phenotypic changes mat occurred when pearl millet was domesticated - the so-called 'domestication syndrome' (Poncet et al. 2000, 2002).

Molecular marker technologies have moved on, particularly with the development of the polymerase chain reaction (PCR) that allows the rapid and inexpensive amplification of small quantities of DNA precisely targeted to known regions. The amplification commences from small lengths of DNA of known sequence known as primers.

Depending on the primers, different segments of DNA are amplified in the PCR reaction. The program was quick to develop the first microsatellite markers (simple sequence repeats - SSRs) in pearl millet (Allouis et al. 2001; Qi et al. 2001). Some 100 markers, of which 60 are mapped (Fig. 1), are now available either as DNA primers for laboratories without the facility to make them themselves, or as DNA sequences of the flanking regions of the SSR. A silver-staining detection system has been developed that is more suited for SSR applications in developing countries because it does not require the use of radioactive labeling. We aim to continue development to about 200 SSRs but are already anticipating the next technological development, single nucleotide polymorphism (SNPs) for application in pearl millet (Fig. 2), which can also be handled by PCR.

The uptake of molecular marker technology at ICRISAT is central to the program, not only for applications in the breeding program, but also as a developing country-based test bed, and as an intermediate technology for further transfer to commercial and national laboratories in India and Africa. Recent work with the new SSR markers has determined that optimum working conditions - for example, amplification regimes and Mg^{+} levels - can vary markedly with locally supplied chemical resources.

The development of the pearl millet maps and markers has provided a nucleus around which other millet resources and technologies have been developed. Among these is the first pearl millet bacterial artificial chromosome (BAG) library (Allouis et al. 2001). This library is necessary for experiments that identify the precise location of particular pearl millet genes in order to be able to clone them.

The very first UK plant genome database is MilletGenes, which is based at JIC. MilletGenes was initiated with DFID funding and has now been incorporated into the BBSRC-funded UK CropNet programme. MilletGenes collates all genome related data - maps, markers, DNA sequences and images - on pearl millet, finger millet (*Eleusine coracana* Gaertn.), foxtail millet [*Setaria italica* (L.) P. Beauv.], and tef [*Eragrostis tef (Zucc.)* Trotter], a related crop of importance in Ethiopia. Among the new technologies is genetic transformation of pearl millet, achieved both in a small PSP-funded project at Bangalore in India, in an EU-INCO project at the University of Hamburg, Germany, and at Foodtek in Pretoria, South Africa.

Integration of the Pearl Millet Map in the Grass Consensus Map

Today we know quite a lot about the 2,400 million base-pair *Pennisetum glaucum* genome. The seven chromosomes that make up the haploid complement are well mapped and have an unusual profile in which recombination is exceptionally biased towards the chromosome ends. As with other 'diploids' we are detecting several ancient duplications in the genome, and some 28% of the RFLP probes map to more than one locus. Some of the linkage groups now include the chromosome ends (the telomeres), although alignment with the cytological map has still to be achieved.

These results show complex relationships, within which can be detected the now classical evolutionary translocations that define the Andropogonae group within the grasses. These alignments are quite adequate to allow the rice genomic sequence, which is now becoming available, to be applied directly to pearl millet improvement. A comparative analysis of the small foxtail millet genome (C=450 Mb), a member of the *Paniceae* tribe which also includes pearl millet, with rice (C=400 Mb) revealed a simple relationship between the chromosomes of the two species (Devos et al. 1998). The larger pearl millet genome, on the other hand, appears to have undergone many rearrangements relative to foxtail millet and rice (Fig. 3, see color plate on page 21 of this issue) with the maps of rice, although gene orders have remained conserved within each of the translocated segments (Devos et al. 2000). Most of these rearrangements are likely to be specific to pearl millet. However, at least two could be identified that are common to all *Panicoideae* species analysed to date. Nevertheless, since both foxtail and pearl millet belong to the same tribe, it is clear that some species undergo and fix rearrangements more readily than others, and that the number of gross structural rearrangements alone is not a measure for evolutionary divergence. The comparative data further demonstrated the presence of a major duplication between

Figure 1 (see pages 18-19 of this issue). Updated JIC consensus map for pearl millet showing distribution of RFLP, SSR and isozyme loci across seven linkage groups and a linkage fragment. Because this is a consensus map derived from several mapping populations, not all markers are mapped against one another and therefore some markers are positioned with less precision than others. Black bars to the right hand side and green bars to the left hand side of each linkage group indicate the limits of precision of placement of some markers. The chromosomes of pearl millet (*Pennisetum glaucum,* 2n = 2x = 14) are now well mapped with restriction fragment length polymorphism (RFLP in black), sequence tagged site (STS in red) and microsatellite (SSR in green) markers. The markers are used both by breeders for marker-aided selection of genes controlling agronomic traits, and also by researchers for discovering new agronomic genes and for map-based gene isolation.

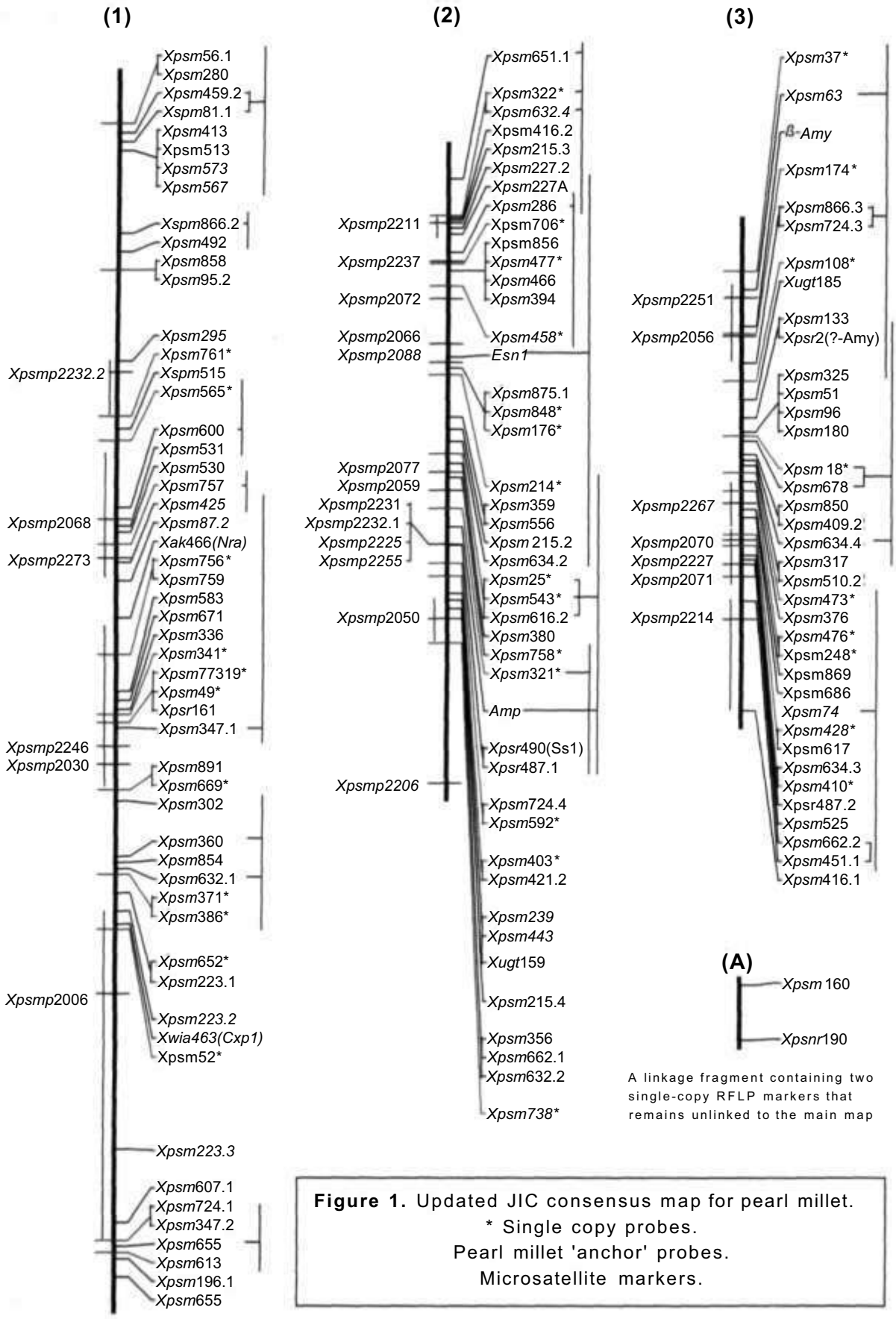
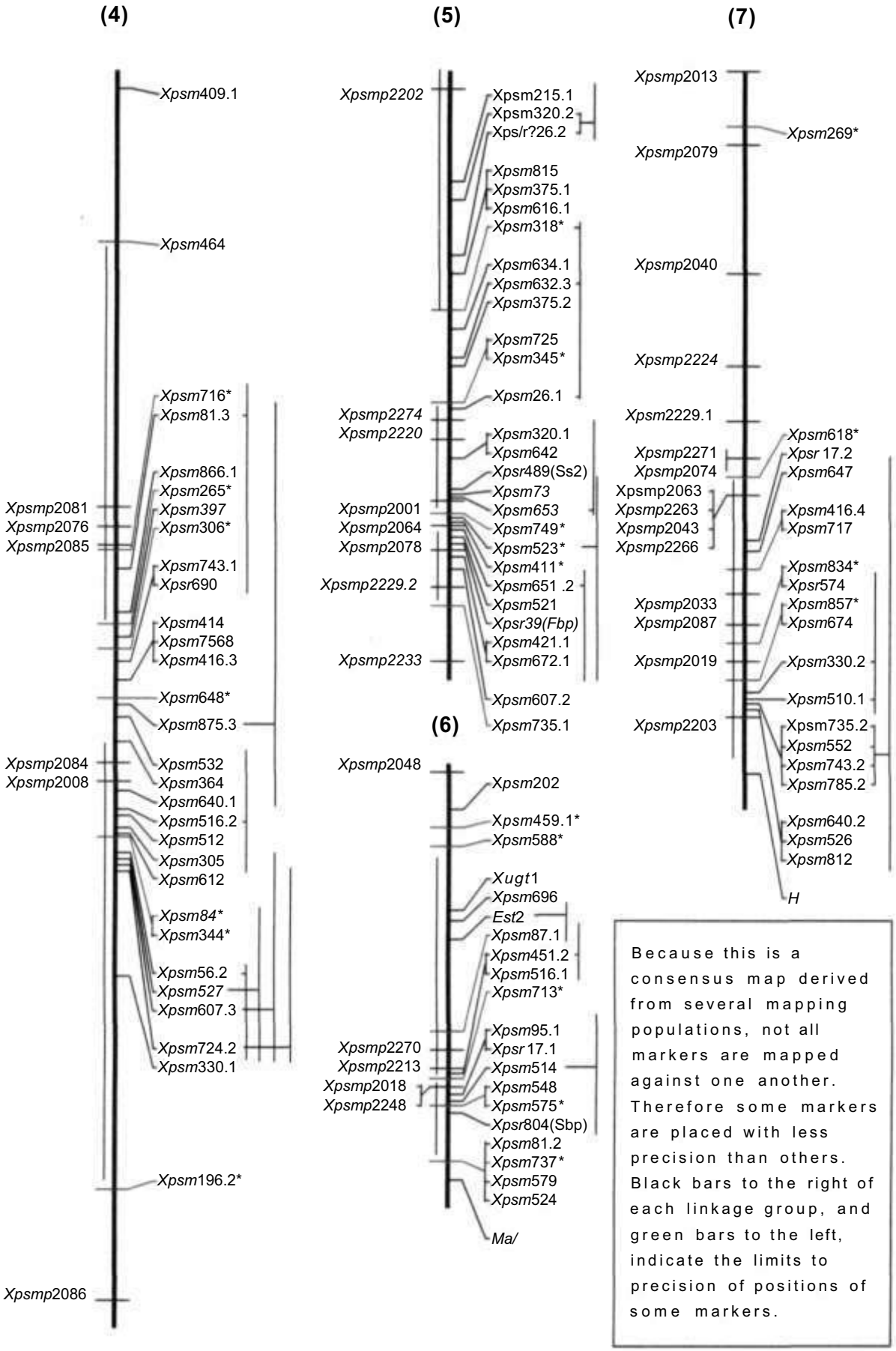


Figure 1. Updated JIC consensus map for pearl millet.
* Single copy probes.
Pearl millet 'anchor' probes.
Microsatellite markers.



Because this is a consensus map derived from several mapping populations, not all markers are mapped against one another. Therefore some markers are placed with less precision than others. Black bars to the right of each linkage group, and green bars to the left, indicate the limits to precision of positions of some markers.

regions of pearl millet linkage groups 1 and 4. The same duplication is present in rice and foxtail millet, and must therefore predate the divergence of the *Panicoideae* and *Oryzoideae* subfamilies. The integrated maps can now be exploited for a range of applications, including gene prediction, fine-mapping, identification of candidate genes, and elucidation of metabolic pathways.

Applications

Knowledge of the relationship between the pearl millet genome and those of other grass species has many applications. Firstly, the number of markers available for genetic studies has greatly increased. The availability of comparative maps will allow the use of sequences from the target species as well as genes from other grasses as probes in mapping and tagging studies. Secondly, since conserved colinearity extends to genes controlling key traits, comparative genetic maps may be used to predict the presence of genes. Extrapolation and prediction from one species to another will benefit all crop plants, but especially those 'orphan' species for which only limited genetic information is available. Comparative genome analysis provides a link between genetics and taxonomy. The occurrence of genome rearrangements that are common between some species and differentiate others are good indicators of phylogeny. It may also pave the way to gene isolation in pearl millet. The high degree of colinearity that exists at the gene level between grass species irrespective of their total DNA content, has already promoted the use of small genome species such as rice and sorghum as intermediates for map-based cloning of genes in large genome species such as wheat and maize (Kilian et al. 1995; Foote et al. 1997; Chen et al. 1997).

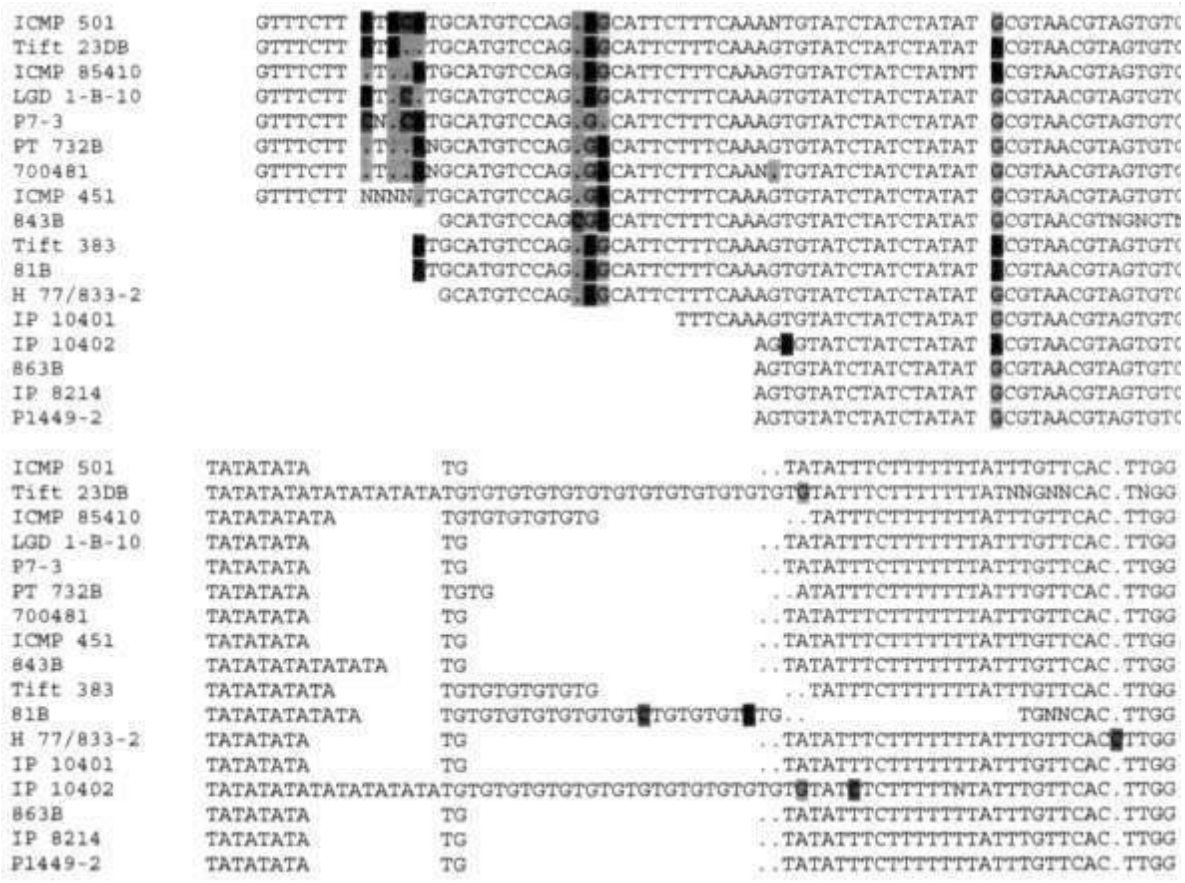


Figure 2. Single nucleotide polymorphism (SNPs) in pearl millet inbred lines. Molecular marker technology has moved on from the early days of restriction length polymorphisms (RFLPs), which are slow and expensive to apply, to simple sequence repeats (microsatellites or SSRs), which can be analyzed on automatic sequencing machines. We are now anticipating the next generation of markers, SNPs. In this DNA sequence analysis of 17 pearl millet inbred lines, variation in tandem repeat number at a microsatellite locus is shown (different numbers of TA and TG di-nucleotide repeats) along with SNPs and 'indels' (inserted or deleted base pairs shaded) in the flanking DNA sequence. SNPs are amenable to yet faster and more economic analysis than SSRs.

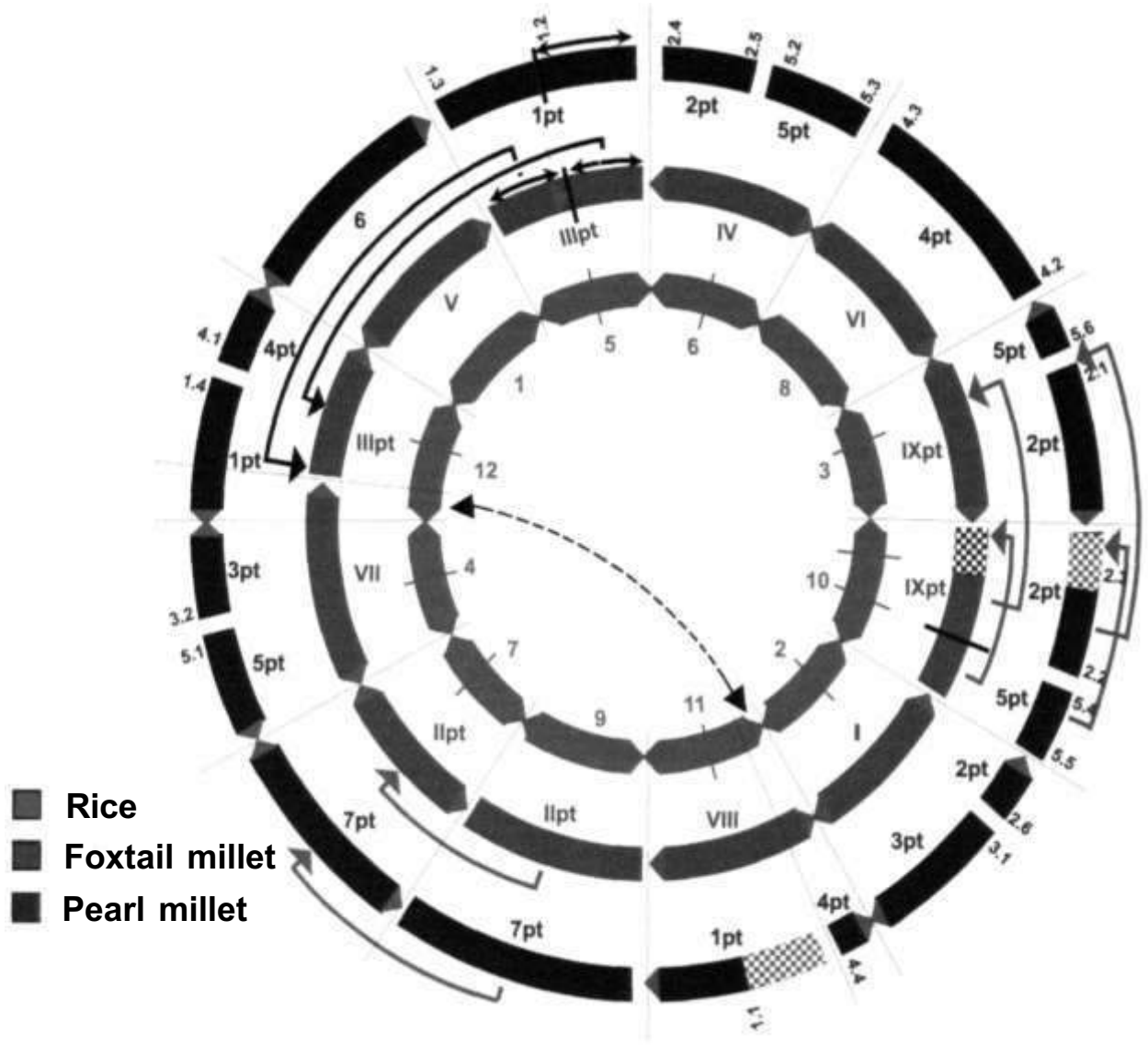


Figure 3. Relationships among the genomes of rice, foxtail millet and pearl millet based on comparative RFLP mapping studies (Devos et al. 1998, 2000). Rice chromosomes (in red) are numbered from 1 to 12 with arabic numerals. Foxtail millet linkage groups (in pink) are numbered with roman numerals and pearl millet linkage groups (in blue) are numbered with arabic numerals. Hatched areas indicate regions with little available comparative data. Red triangles indicate telomeres, double-headed arrows show inversions, and single-headed arrows denote evolutionary translocations. In pearl millet, due to the large number of rearrangements relative to rice, the majority of the arrows are omitted. The dotted arrow indicates the rice 11S/12S duplication.

Acknowledgments. This document is an output from several projects of the Plant Sciences Research Programme funded by the UK Department for International Development (DFID) and administered by the Centre for Arid Zone Studies (CAZS) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

References

Allouis S, Qi X, Lindup S, Gale MD and Devos KM. 2001. Construction of a BAC library of pearl millet, *Pennisetum glaucum.* Theoretical and Applied Genetics 102:1200-1205.

Azhaguvel P. 2001. Linkage map construction and identification of QTLs for downy mildew (*Sclerаspora graminicola*) resistance in pearl millet (*Pennisetum glaucum* (L.) R. Br.). PhD thesis, Department of Agricultural Botany, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu. India. 204 pp.

Bhattacharjee R, Bramel PJ, Hash CT, Kolesnikova-Allen MA and khairwal IS. 2002. Assessment of genetic diversity within and between pearl millet landraces. Theoretical and Applied Genetics 105:666-673.

Busso CS, Liu CJ, Hash CT, Witcombe JR, Devos KM, de Wet JMJ and Gale MD. 1995. Analysis of recombination rate in female and male gametogenesis in pearl millet (*Pennisetum glaucum*) usng RFLP markers. Theoretical and Applied Genetics 90:242-246.

Busso CS, Devos KM, Ross G, Mortimore M, Adams WM, Ambrose MJ, Alldrick S and Gale MD. 2000. Genetic diversity within and among landraces of pearl millet (*Pennisetum glaucum*) under farmer management in West Africa. Genetic Resources and Crop Evolution 47:561-568.

Chen M, SanMiguel P, de Oliveira AC, Woo S-S, Zhang H, Wing RA and Bennetzen JL. 1997. Microcolinearity in *sh2*-homologous regions of the maize, rice and sorghum genomes. Proceedings of the National Academy of Sciences (USA) 94:3431-3435.

Devos KM and Gale MD. 2000. Genome relationships: the grass model in current research. Plant Cell 12:637-646.

Devos KM, Wan, ZM, Beales J, Sasaki T and Gale MD. 1998. Comparative genetic map of foxtail millet (*Setaria italica*) and rice (*Oryza sativa*). Theoretical and Applied Genetics 96:63-68.

Devos KM, Pittaway TS, Reynolds A and Gale MD. 2000. Comparative mapping reveals a complex relationship between the pearl millet genome and those of foxtail millet and rice. Theoretical and Applied Genetics 100:190-198.

Foote T, Roberts M, Kurata N, Sasaki T and Moore G. 1997. Detailed comparative mapping of cereal chromosome regions corresponding to the *Ph1* locus in wheat. Genetics 147:801-807.

Kilian A, Kudrna DA, Kleinhofs A, Yano M, Kurata N, Steffenson B and Sasaki T. 1995. Rice-barley synteny and its application to saturation mapping of the barley *Rpg*1 region. Nucleic Acids Research 23:2729-2733.

Kolesnikova MA. 2001. Mapping new quantitative trait loci (QTL) for downy mildew resistance in pearl millet. PhD thesis, Russian National Academy of Sciences, Moscow, Russia. 266 pp. (English and Russian)

Liu CJ, Witcombe JR, Pittaway TS, Nash M, Hash CT, Busso CS and Gale MD. 1994. An RFLP-based genetic map of pearl millet (*Pennisetum glaucum*). Theoretical and Applied Genetics 89:481-487.

Liu CJ, Devos KM, Witcombe JR, Pittaway TS and Gale MD. 1996. The effect of genome and sex on recombination rates in *Pennisetum* species. Theoretical and Applied Genetics 93:902-908.

Liu CJ, King IP, Pittaway TS, Abbos S, Reader SM, Miller TE and Gale MD. 1997. Physical and genetical mapping of rDNA sites in *Pennisetum* (pearl millet). Heredity 78:529-531.

Morgan RN, Wilson JP, Hanna WW and Ozais-Akins P. 1998. Molecular markers for rust and pyricularia leaf spot disease resistance in pearl millet. Theoretical and Applied Genetics 96:413-420.

Poncet V, Lamy F, Devos KM, Gale MD, Sarr A and Robert T. 2000. Genetic control of domestication traits in pearl millet (*Pennisetum glaucum* L., Poaceae). Theoretical and Applied Genetics 100:147-159.

Poncet V, Martel E, Allouis S, Devos KM, Lamy F, Sarr A and Robert T. 2002. Comparative analysis of QTLs affecting domestication traits between two domesticated x wild pearl millet (*Pennisetum glaucum* L., Poaceae) crosses. Theoretical and Applied Genetics 104:965-975.

Qi X, Lindup S, Pittaway TS, Allouis S, Gale MD and Devos KM. 2001. Development of simple sequence repeat markers from bacterial artificial chromosomes without subcloning. BioTechniques 31:355-361.

Sharma A. 2001. Marker-assisted improvement of pearl millet (*Pennisetum glaucum*) downy mildew resistance in elite hybrid parental line H 77/833-2. PhD thesis, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India. 131 pp.

Yadav RS, Hash CT, Bidinger FR, Cavan GP and Howarth CJ. 2002. Quantitative trait loci associated with traits determining grain and stover yield in pearl millet under terminal drought-stress conditions. Theoretical and Applied Genetics 104:67-83.

Variation in *Sclerospora graminicola* Detected with RAPD-PCR

Z Mahmood, JR Witcombe and DS Shaw* (Centre for Arid Zone Studies, University of Wales, Bangor, Gwynedd LL57 2UW. UK)
*Corresponding author

Introduction

Downy mildew, caused by the obligate pathogen *Sclerospora graminicola* (Sacc.) J. Schrot., is the most damaging disease of pearl millet [*Pennisetum glaucum* (L.) R. Br.] (Singh 1995). Study of this host-pathogen system is complicated as both the host and pathogen are allogamous in nature. We currently use oosporic inoculum to initiate multiplication of pathogen isolates for greenhouse screening of host populations (as potted seedlings). The isolates used for screening are therefore expected to contain variable frequencies of different virulence phenotypes, which could account, at least in part, for the quantitative nature of the screening results obtained (e.g., Jones et al. 1995). The current study was undertaken to characterize variation among and within populations of S. *graminicola* in order to identify single genotypes for use in screening pearl millet host populations for downy mildew resistance. The ultimate aim was to refine the screening technique for pearl millet downy mildew by using genetically uniform, characterized pathogen isolates to allow more precise mapping of quantitative trait loci for host plant resistance.

Random amplified polymorphic DNA (RAPD) markers (Williams et al. 1990) were used to characterize the pathogen isolates. This simple technique, based on the polymerase chain reaction (PCR), was chosen because it requires only small amounts of DNA, it is reportedly robust if PCR conditions can be appropriately optimized/ standardized, and there is a plentiful supply of inexpensive arbitrary primers.

Sources of DNA for RAPD-PCR Fingerprinting of *S. graminicola*

DNA samples isolated from zoospores, infected host plants, and healthy host plants were compared as template for RAPD-PCR in order to ascertain whether the DNA in infected plant tissues could be used for reliable fingerprinting of *S. graminicola* isolates. DNA samples from infected plant tissues gave banding patterns much more like those from zoospore DNA than those from DNA of healthy plants (Fig. 1) indicating that DNA samples from infected host tissue can be used for initial RAPD-PCR fingerprinting of *S. graminicola.* Hoewever, the remainder of this study was based on DNA samples isolated from zoospores.

RAPD Markers Detect Polymorphism between *S. graminicola* Populations

A selection of polymorphic 10-mers were first identified and 11-mers based on these selected 10-mers were then tested. These 11-mers were even more polymorphic than the selected 10-mers (Table 1).

Data from RAPD analysis was used to test two hypotheses about variation among populations of *S. graminicola.* The first of these hypotheses was that Indian and African populations of the pearl millet downy mildew pathogen are distinct. The second was that relatedness between populations of this pathogen decreases with distance. 5. *graminicola* populations obtained from India (14), Senegal (1), Niger (1) and Nigeria (4) were used to test the first hypothesis. Results obtained indicate that

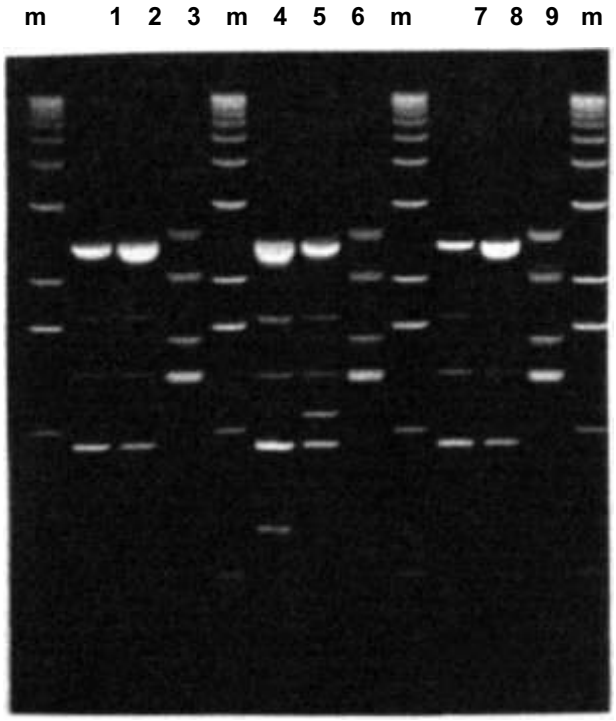


Figure 1. RAPD marker banding patterns detected by primer OPY20 using template DNA isolated from *Sclerospora graminicola* zoospores (lanes 1, 4 and 7), infected plants (lanes 2, 5 and 8) and healthy plants (lanes 3, 6 and 9). Pathogen populations used were from Gashua (lanes 1 and 2), Maiduguri (lanes 4 and 5) and Nguru (lanes 7 and 8), Nigeria, m = molecular weight markers.

differences in RAPD banding patterns (Fig. 2) can be used to characterize variation between populations for *S. graminicola* from India and from Africa. Cluster analysis of the RAPD banding pattern data set demonstrated that the African populations of this pathogen were largely distinct from those from India, and that the degree relatedness between populations of this pathogen often decreases with distance (Fig. 3).

RAPD Markers Detect Variation within Populations

To test for within-population variation, an attempt was made to generate single-oospore isolates of *S. graminicola* from Patancheru (ICRISAT) in India, and assess these for RAPD banding pattern differences. The working hypothesis for this experiment was that every oospore is a zygote with a unique genotype, and that if a pearl millet seedling is infected by a single oospore and the pathogen is then maintained asexually, that it would be genetically uniform. Such genetically uniform pathogen isolates could be useful in detecting qualitative gene-for-gene differences in disease reactions of genetically uniform host entries. Pathogen isolates likely to be the result of host seedling infection by single oospores were obtained by sowing a highly susceptible host in compost containing a very small quantity of oosporic inoculum, and asexually propagating individual isolates from treatments having low infection frequency (<1%).

Table 1. RAPD polymorphism detected by thirteen 10-mers and their derived 11-mers among *Sclerospora graminicola* populations from Dioffior, Senegal, and Kaudal, India.

Primers	Amplified	Polymorphisms per primer
10-mers	11	5.36
10-mer + A	9	7.22
10-mer+C	II	6.64
10-mer + G	12	6.17
10-mer + T	12	6.58

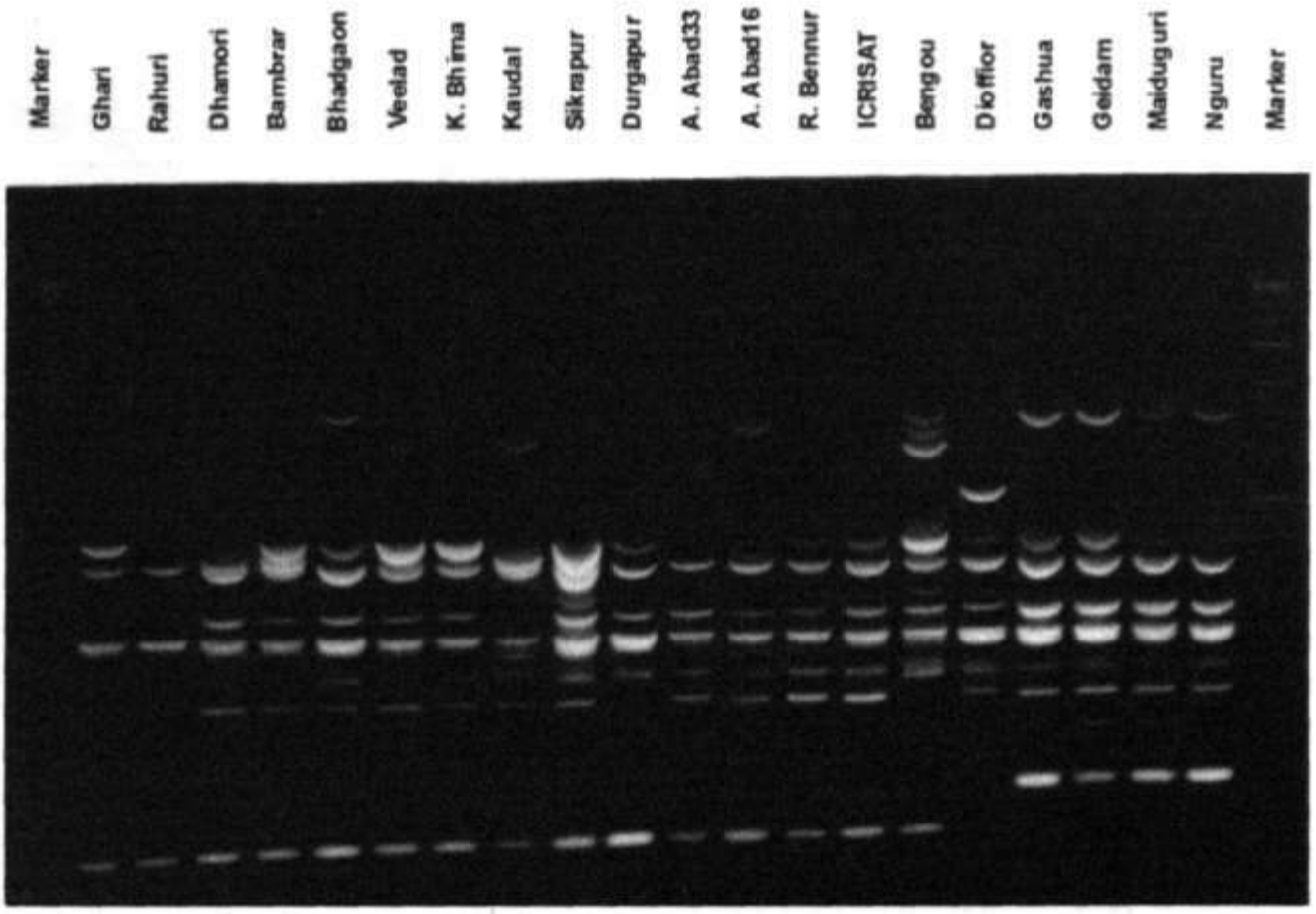


Figure 2. RAPD banding patterns detected with 11-mer OPY02A between 20 populations of the pearl millet downy mildew pathogen *Sclerospora graminicola* from India and Africa.

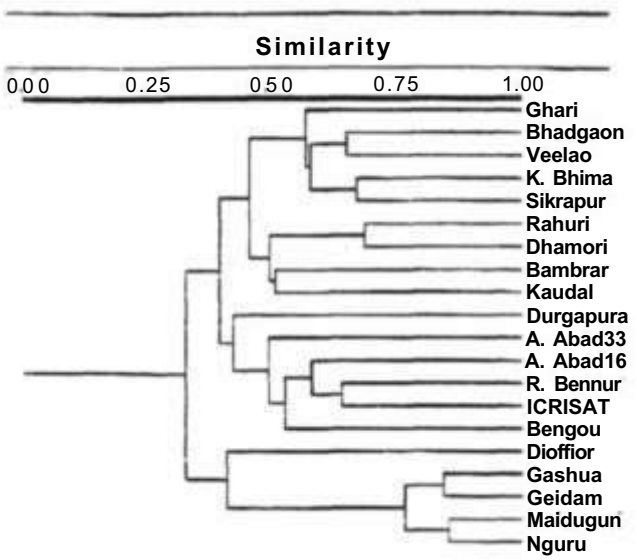


Figure 3. Dendrogram showing relationships, based on banding pattern differences detected using 34 RAPD primers, between 20 populations of the pearl millet downy mildew pathogen (*Sclerospora graminicola*) from India (14 populations) and Africa (6 populations).

Individual single-oospore isolates obtained by this procedure are expected to have a single mating type, and hence not be able to undergo sexual recombination that is a pre-requisite for forming a subsequent generation of oospores. PCR using RAPD primers allowed detection of differences between 15 putative single-oospore isolates obtained using oosporic inoculum from the ICRISAT-Patancheru population of *S. graminicola* (Fig. 4), and these RAPD banding pattern differences were used to generate a dendrogram showing the relationships between these diverse isolates (Fig. 5).

RAPD Markers Detect Selection Response

Once a pearl millet downy mildew isolate has been obtained by infecting a susceptible host using heterogenous oosporic inoculum, it is maintained asexually by serial transfer to successive host plants. Assuming that more than one oospore is involved in initiating the pathogen isolate, it is hypothesized that the fittest pathogen genotypes will be selected and that there will be a gradual reduction in diversity within the isolate. We tested this hypothesis by

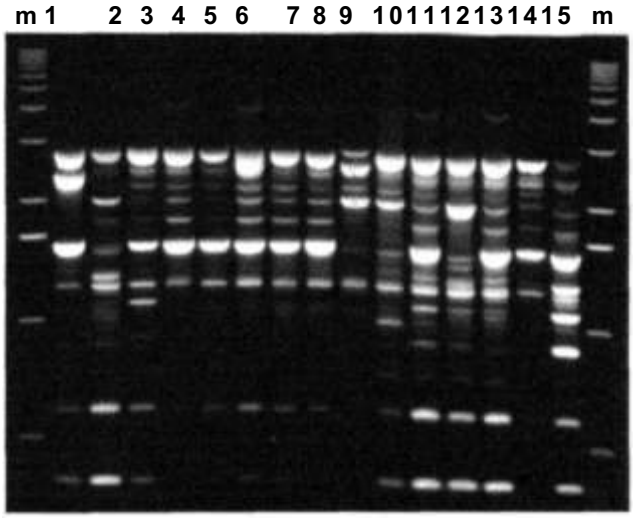


Figure 4. RAPD banding patterns detected with primers OPA10 + M13F between 15 putative single-oospore isolates from the ICRISAT-Patancheru population of *Sclerospora graminicola*.

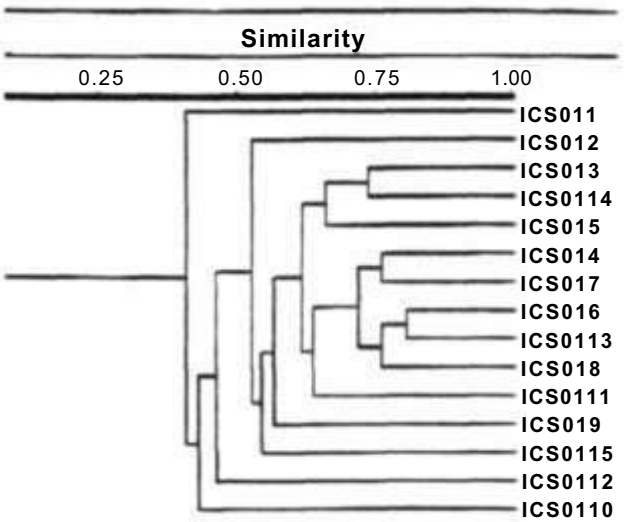


Figure 5. Dendrogram showing relationships, based on banding pattern differences detected using 22 RAPD primers, between 15 putative single-oospore isolates from the ICRISAT-Patancheru population of *Sclerospora graminicola*.

comparing RAPD banding patterns over three successive asexual generations of zoospores following initiation of infection with an oospore population of *S. graminicola.* Figure 6 shows that some bands increased in intensity while other bands decreased in intensity across the asexual generations, with an end result of fewer and more sharply defined bands in the third generation. This indicates that the initially variable pathogen isolate did indeed respond to selection while being maintained asexually on the susceptible host and diversity within the isolate declined over time. Development, maintenance and use of genetically uniform pathogen isolates, such as single oospore isolates, should minimize the problems that could be caused by host-directed selection during maintenance of genetically variable pathogen isolates.

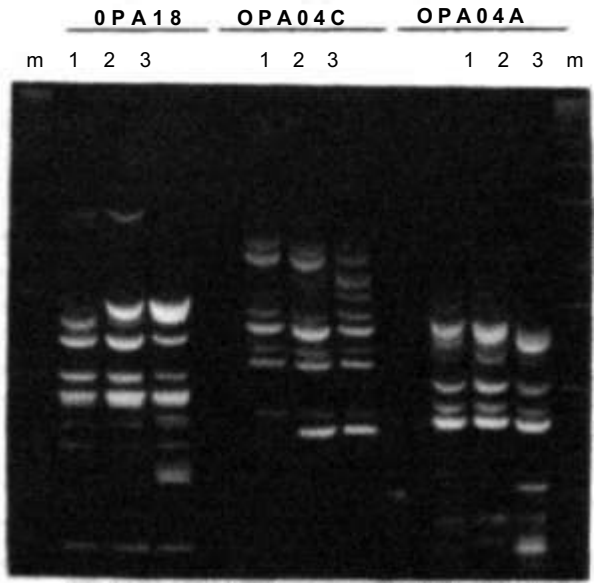


Figure 6. Changes in RAPD banding patterns obtained with three primers (OPA18, OPC04C and OPA04A) over three successive generations of asexual zoospores obtained from an initially heterogenous oosporic isolate of the pearl millet downy mildew pathogen, *Sclerospora graminicola.*

Conclusions

The results obtained in this study indicate that RAPD-PCR detects variation within and among populations of the pearl millet downy mildew pathogen 5. *graminicola.* Under stringent PCR conditions, 11-mers will provide good fingerprints for single pathogen genotypes of known virulence phenotype used for screening pearl millet mapping populations, allowing monitoring of pathogen isolate uniformity across screens.

References

Jones ES, Liu CJ, Gale MD, Hash CT and Witcombe JR. 1995. Mapping quantitative trait loci for downy mildew resistance in pearl millet. Theoretical and Applied Genetics 91:448-456.

Singh SD. 1995. Downy mildew of pearl millet. Plant Disease 79:545-550.

Williams JGK, Kubelik AR, Livak KJ, Rafalski JA and Tingey SV. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. Nucleic Acids Research 18:6531-6535.

Genetics and Breeding

Genetics and Cytology of a Minimized Sorghum Mutant from Somatic Cell Culture

Zhongyou Pei*, Ruidong Huang and Hongtu Ma
(College of Agronomy, Shenyang Agricultural University, Shenyang, 110161, PR China)
*Corresponding author

A genetically stabilized sorghum dwarf mutant was obtained through tissue culture of scutella cells from tall sorghum pure-line S401-1. The genetics and cytology of this dwarf mutant were studied.

A 3:1 ratio of tall vs. short plants was observed in the F_2 generation of the cross dwarf mutant x S401-1, fitting the expected Mendelian ratio if short plant height is controlled by recessive alleles at a single locus (Fig. 1). Similarly, a 9:3:3:1 ratio was observed for tall plants with broad leaves:tall plants with narrow leaves:short plants with broad leaves:short plants with narrow leaves, fitting the expected Mendelian ratio for inheritance controlled by two independently segregating genes. Goodness of fit of the observed segregation patterns to the expected Mendelian ratios were evaluated with a x^2 test, and all were non-significant (Table 1). The reduced leaf width and plant height of the dwarf mutant line are thus controlled by two independently segregating nuclear genes. One of these two loci controls plant height itself, and homozygosity for the recessive allele at this locus results in short plants. The second locus controls the size of plant organs, and perhaps a pleiotropic effect on plant height and homozygosity for the recessive allele at this locus results in reduced plant size. Homozygosity for the recessive alleles at both of these two loci is responsible for the dwarf phenotype of the mutant line.

Possible reasons for the dwarf phenotype of the mutant plants were assessed cytologically. Results indicated that the cause of dwarfening is hindrance of plant cell elongation, not a reduction in cell number.

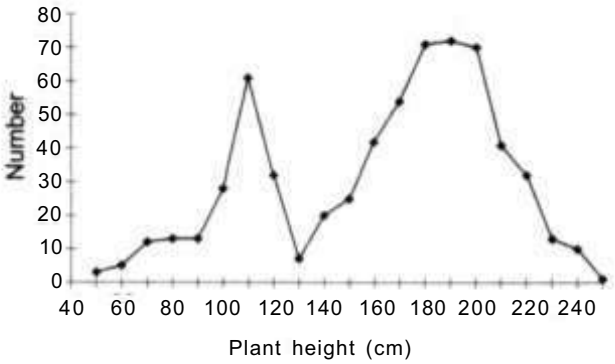


Figure 1. Frequency distribution of plant height in the F_2 generation of Ms/401-1.

Table 1. Chi-square test of leaf width and plant height segregation patterns in the F_2 of Ms/401-1, and mean plant heights of the four phenotypic classes.

	Phenotypic classes						
Plant height Leaf width	Tall Broad	Tall Narrow	Short Broad	Short Narrow	Total	X^2	*P*
Observed	149	49	60	21	279	1.371	>0.5
Expected (9:3:3:1)	168.81	54.94	54.94	18.31	279		
Plant height (cm)	191.5	175.7	114.0	99.1			

Moisture Stress and Potential Sorghum Yield

WG Wenzel* and PJ Van Rooyen (Agricultural Research Council, Grain Crops Institute, Potchefstroom 2520, South Africa)

*Corresponding author: wenzel@igg2.agric.za

Sorghum *[Sorghum bicolor* (L.) Moench] is known for its drought resistance and adaptation to the semi-arid zones of the world. In South Africa and elsewhere, sorghum is grown in some of the poorest and most drought-prone regions. Due to low yields, smallholder sorghum farmers are net grain buyers in most years (Rohrbach 1998). Since the 1990s new, high yield potential sorghum varieties and hybrids have been introduced in Zimbabwe, but no increase in average yields was observed (Rohrbach 2000).

In South Africa, yield increases were observed due to the introduction of sorghum hybrids during the 1970s, but commercial farmer average yields remained stagnant during the 1980s and 1990s (Fig. 1). The stagnancy prevailed although many South African and international seed companies continuously introduced new hybrids. The question now arises whether common causes are responsible for the Zimbabwean and South African scenarios. High potential cultivars may not be suitable for low-rainfall, low-input farming systems or low potential areas in general.

More than 50% of the South African commercial sorghum is grown in the northern Free State region. The rainfall for February, measured at the Viloenslaagte weather station (located within the major sorghum production area in South Africa), explained 65% of the national sorghum yield variation, and the rainfall for November to March,

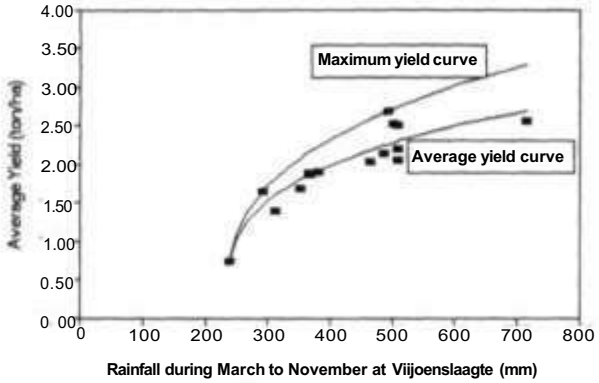


Figure 2. Relationship between national average sorghum grain yield in South Africa during the 1983/84 to 1993/94 seasons and within-season (November to March) rainfall observed at Viloenslaagte within the major sorghum production area in South Africa.

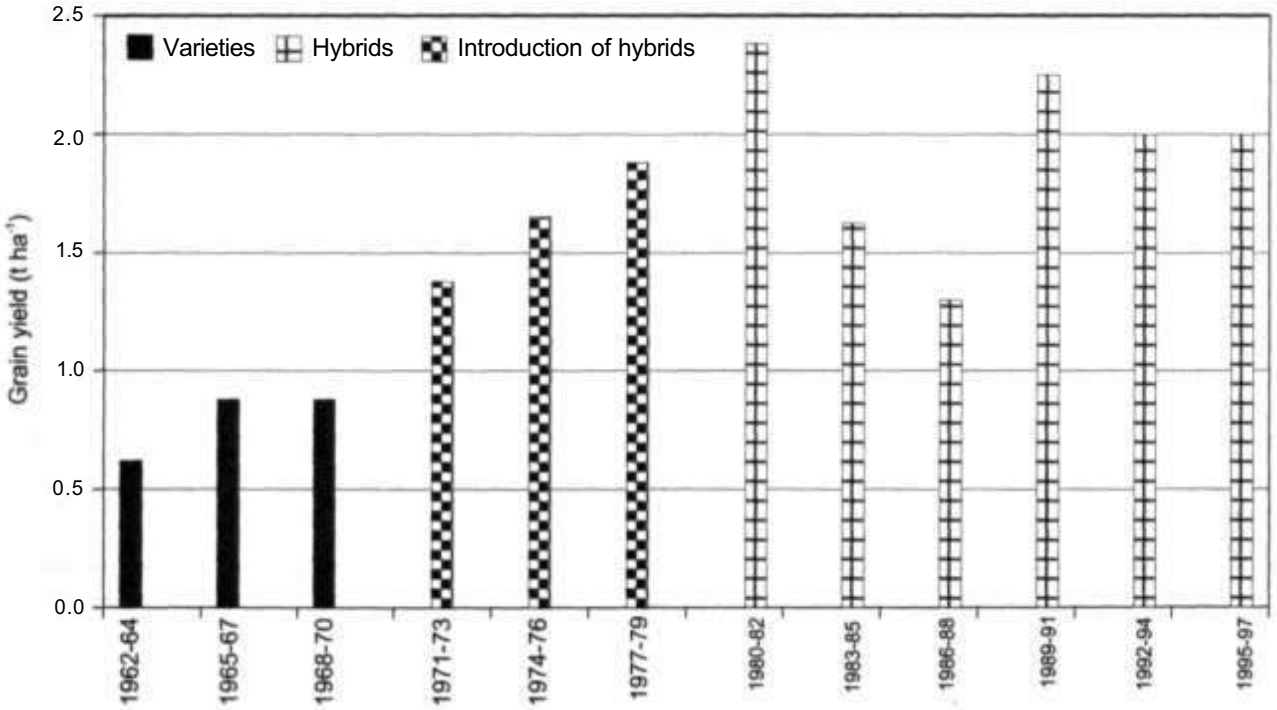


Figure 1. Changes in sorghum grain yields in South Africa from 1962 to 1997 expressed as means of three-year periods.

explained 74%. Hence, there can be no doubt that moisture is the most important determinant of average sorghum yields and that February is the most critical month. Most sorghums are in the flowering and seed development stages at that time.

By using the upper boundary line, the line representing the best performance under the prevailing conditions (Fig. 2), the following conclusions can be drawn. Firstly, the highest extrapolated average sorghum yield is estimated to be below 4 t ha^{-1} under near-optimum conditions (800 mm rain). It can be assumed that a less drought-resistant crop (a crop with higher yield potential), such as maize, would do better under these conditions. Secondly, the magnitude of the deficiency in yield can be assessed. Causal factors such as poor rainfall distribution can be quantified. Thirdly, the total commercial harvest (TH) can be predicted from the total acreage planted and rainfall records until the end of March, or for the month of February only by the equation:

TH = ((0.02 x $rainfall^{0.754}$) x acreage planted), if total within season rainfall is considered (r^2 = 0.74) or TH = ((0.732 x $rainfall^{0.248}$) x acreage planted), if total February rainfall is used (r^2 = 0.65).

An early estimate of the season's total harvest may be of value to the sorghum market.

Since high yield potential cultivars are expected to have low drought resistance, such cultivars may not be the best options for areas with low potential yields. The discrepancy usually found between on-station yield potentials and on-farm yields indicates that cultivars selected under optimal conditions may not be adapted under low-input conditions. Moisture stress is the most important factor limiting potential yields. In order to increase average sorghum yields in South Africa, drought resistance may be an attribute of greater importance than yield potential. Wenzel et al. (1999) have suggested a selection index that includes selection for intermediate drought resistance followed by selection for yield potential. Selection for maintenance of green leaf area was suggested by Borrell et al. (2000).

References

Borrell AK, Hammer GL and Henzell RG. 2000. Does maintaining green leaf area in sorghum improve yield under drought? II. Dry matter production and yield. Crop Science 40:1037-1048.

Rohrbach DD. 1998. Socioeconomics in SMIP: research highlights, impacts, and implications. International Sorghum and Millets Newsletter 39:41-53.

Rohrbach DD. 2000. Future of sorghum and millets in the region. *In* Workshop: SADC Regional Needs and Strategies for Sorghum and Millets Crops Improvement, 16th-18th October 2000, Matopos, Bulawayo, Zimbabwe (in press).

Wenzel WG, Ayisi K and Donaldson G. 1999. Selection for drought resistance in grain sorghum (*Sorghum bicolor* (L.) Moench). Journal of Applied Botany 73:118-121.

Impact of FYM and Fertilizer Nitrogen on Yield and Soil Properties of Sorghum Grown on Vertisol

Syed Ismail[1,*], PB Adsul[2], GG Shinde[1] and AS Deshmukh' (1. Sorghum Research Station; 2. Department of Soil Science, Marathwada Agricultural University, Parbhani 431 402, Maharashtra, India)

*Corresponding author: syedismail@123india.com

Introduction

Crop production under intensive cultivation without replenishment of requisite amounts of nutrients leads to negative soil nutrient balances. Further increases in food production must be attend by judicious use of production factors and efficient use of all major sources of plant nutrients in an integrated manner to maximize economic yields and at the same time improve soil health. Use of FYM (farm yard manure) and compost for crop production is an age-old practice in India. Importance or usefulness of organic manures along with chemical fertilizers in soil sustainability has been recently emphasized by Katyal (2000). Besides improving physical, chemical and biological properties of soil, organic matter application also affects levels of micronutrients that are gaining considerable importance in present day agriculture. The present work is an attempt to study the impact of FYM and nitrogen fertilizer (urea) on various soil properties and yield of sorghum [*Sorghum bicolor* (L.) Moench].

Materials and Methods

A field experiment was conducted on a Vertisol (Typic Haplustert) at Sorghum Research Station, Parbhani, in the postrainy season on a fixed site in split-plot design during 1997/98 to 2000/2001 with two levels of FYM (0 and 5 t ha^{-1}), four levels of nitrogen (80, 120, 160 and 200 kg ha^{-1}) and two sorghum genotypes (SPV 1359 and SPV 504). The 16 treatment combinations were replicated thrice. The initial experimental soil was clay in texture (54% clay), moderately alkaline in reaction (pH 8.2), and normal in salt content (EC 0.90 dS m^{-1}). It contained 5.7 g kg^{-1} organic carbon and 220 kg ha^{-1} N, 10.1 kg ha^{-1} P_2O_5 and 332 kg ha^{-1} K_2O. DTPA-extractable Fe, Zn, Mn and Cu in the soil were recorded as 4.58,0.87,13.15 and 2.30

mg kg^{-1} respectively. Each postrainy season organic manure (FYM) was incorporated in the soil before sowing of the crop and the graded doses of N and recommended doses of other fertilizers (40:40 P_2O_5 and K_2O kg ha^{-1}) were applied through straight sources at the time of sowing. Initially as a bulk, and after completion of three seasons, the soil samples were collected from each experimental plot, processed and analysed by standard procedures.

Results and Discussion

The results related to grain, fodder yield of sorghum and various soil properties (Table 1) indicate that grain and

Table 1. Grain and fodder yield (t ha^{-1}) of sorghum and physico-chemical properties of soil as influenced by various treatments.

Treatment	Grain yield (t ha^{-1})	Fodder yield (t ha^{-1})	pH	EC (dS m^{-1})	Organic C (g kg^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
FYM application								
No FYM	4.12	6.11	8.08	0.89	4.9	258	12.1	334
FYM @ 5 t ha^{-1}	4.58	7.08	7.98	0.89	6.0	329	16.3	364
SE(±)	0.05	0.11	0.09	0.003	0.08	1.13	0.09	0.46
CD at 5%	0.16	0.36	NS	NS	0.27	3.49	0.30	1.42
N levels								
80 kg ha^{-1}	4.24	6.36	8.04	0.90	5.2	265	12.3	344
120 kg ha^{-1}	4.50	6.44	8.02	0.89	5.6	283	13.4	345
160 kg ha^{-1}	4.46	7.13	8.04	0.89	5.5	300	14.5	351
200 kg ha^{-1}	4.19	6.44	8.01	0.88	5.6	326	16.7	356
SE(±)	0.76	0.16	0.12	0.004	0.12	1.60	0.14	0.65
CD at 5%	0.22	0.50	NS	0.012	NS	4.93	0.43	2.01
Genotypes								
SPV 1359	4.88	7.23	8.03	0.91	5.3	296	14.8	357
SPV 504 (Swati)	3.81	5.96	8.03	0.86	5.6	291	13.6	342
SE(±)	0.07	0.09	0.09	0.003	0.08	1.18	0.09	0.57
CD at 5%	0.18	0.27	NS	0.010	0.26	3.52	0.27	1.71

NS: Not significant.

Table 2. DTPA-extractable soil micronutrient (mg kg^{-1}) and microbial population (x 10^4) as influenced by various treatments.

Treatment	Fe	Zn	Mn	Cu	Bacteria	Fungi	Actinomycetes
FYM application							
No FYM	4.7	0.8	14.4	2.3	122	13.1	110
FYM @ 5 t ha^{-1}	5.0	1.2	19.0	2.5	127	14.1	119
SE(±)	0.02	0.02	0.02	0.02	0.26	0.06	0.06
CD at 5%	0.08	0.07	2.06	0.06	0.80	0.18	0.20
N levels							
80 kg ha^{-1}	4.7	1.0	15.3	2.3	122	13.5	112
120 kg ha^{-1}	4.7	1.0	15.8	2.3	121	13.5	116
160 kg ha^{-1}	5.0	1.1	17.2	2.4	126	13.6	113
200 kg ha^{-1}	5.0	1.1	18.4	2.4	126	13.8	116
SE(±)	0.04	0.03	0.02	0.02	0.36	0.08	0.09
CD at 5%	0.12	0.01	0.08	0.09	1.13	NS	0.28
Genotypes							
SPV 1359	4.9	1.1	16.9	2.4	124	14.0	117
SPV 504 (Swati)	4.8	1.0	16.5	2.3	124	13.2	112
SE(±)	0.03	0.02	0.01	0.02	0.51	0.06	0.06
CD at 5%	0.09	NS	0.05	NS	NS	0.18	0.20

NS: Not significant.

fodder yield were significantly increased with the application of FYM, as well as graded doses of nitrogen, over the control with maximum grain yields obtained following application of nitrogen at 120 kg ha^{-1} and maximum fodder yields following application of nitrogen at 160 kg ha^{-1}. Genotypic variations were also observed, showing significantly higher biological yields from SPV 1359 than from SPV 504 (Swati). Soil contents of organic carbon, N, P_2O_5, K_2O as well as DTPA-extractable micronutrients (Table 2) were increased significantly with application of FYM and with increasing levels of nitrogen. Genotypes also influenced these properties. Further, soil microbial populations (bacteria, fungi and actinomycetes) also increased significantly with FYM and fertilizer nitrogen but the increases were more prominent in FYM-treated plots as compared to the control and plots receiving only mineral fertilizers. This increase in the yield and improvement in the soil properties with application of FYM might be a result of build up in organic carbon, solubilization of different organic nitrogenous compounds into simple and available form, acidifying action of FYM on native/applied phosphorus at the time of decomposition making more phosphorus available, and reduction of potassium fixation (Syed Ismail 1998). Further, FYM forms organic ligands with micronutrients that decreases their susceptibility to adsorption or fixation and makes more micronutrients available (Mann et al. 1978). Similarly improvement in soil properties and increases in yield with fertilizer nitrogen up to a specific dose might be due to impact of balanced fertilization as reviewed by Katyal et al. (1997). Moreover, the positive relationship between organic matter addition and microbial population has been earlier established (Malewar et al. 1999).

References

Katyal JC, Sharma KL, Srinivas K and Reddy MN. 1997. Balanced fertilizer use in semi-arid soils. Fertilizer News 42(4):59-69.

Katyal JC. 2000. Organic matter maintenance. Journal of Indian Society of Soil Science 48(4):704-716.

Malewar GU, Hasnabade AR and Syed Ismail. 1999. CO_2 evolution and microbial population in soil as influenced by organic and NPK fertilizers under sorghum-wheat system. Journal of Maharashtra Agricultural Universities 24(2): 121-124.

Mann MS, Takkar PN, Bansal RL and Randhawa NS. 1978. Micronutrient status of soil and yield of maize and wheat as influenced by micronutrient and FYM application. Journal of Indian Society of Soil Science 26(2):208-214.

Syed Ismail, Malewar GU, Rege VS and Yelvikar NV. 1998. Influence of FYM and gypsum on soil properties and yield of groundnut grown in Vertisols. Agropedology 8:73-75.

Yield Maximization of Irrigated *Rabi* Sorghum

GG Shinde*, PM Deshpande, MH Lomte. AS Deshmukh and BN Algave (Sorghum Research Station, Marathwada Agricultural University, Parbhani 431 402, Maharashtra, India)

*Corresponding author

Introduction

In Mahaharashtra, India, *rabi* (postrainy season) sorghum [*Sorghum bicolor* (L.) Moench] is cultivated on an area of 3.4 m ha, mostly under rainfed conditions. Grain yields average 600-700 kg ha^{-1}. In recent years its cultivation has been extended to irrigated conditions and 25-30% of the *rabi* sorghum area is now under canal or well irrigation. Productivity under these more favorable conditions averages 2.5 to 3.0 t ha^{-1} for grain yield and 5 to 6 t ha^{-1} for fodder yield. High yielding varieties and hybrids coupled with use of organic and inorganic manures under irrigated conditions can substantially increase the productivity of *rabi* sorghum (Khade et al. 1989). With a view to assess the response of *rabi* sorghum genotypes to farm yard maure (FYM) application and higher nitrogen levels under irrigation, the present yield maximization study was undertaken for three years at the Sorghum Research Station, Marthwada Agricultural University, Parbhani, Maharashtra.

Materials and Methods

An experiment on *rabi* season sorghum productivity under irrigated conditions was conducted in a split-plot design with three replications on a deep Vertisol for three years, 1998/99, 1999/2000 and 2000/01, at the Sorghum Research Station at Marathwada Agricultural University, Parbhani. The treatments were comprised of two levels of FYM (no application, and application of FYM at 5 t ha^{-1}) as main plots, four levels of fertilizer nitrogen (80, 120, 160 and 200 kg N ha^{-1}) as subplots, and two genotypes (CSV 216R and SPV 504) as sub-subplots. The gross and net plot sizes were 3.6 m x 5.0 m and 2.7 m x 4.0 m, respectively. The Vertisol soil of the experimental plot was medium deep, clayey in texture and slightly alkaline in reaction. It contained about 5.20 g organic carbon kg^{-1} of soil, and 260 kg N, 12.3 kg P and 345 kg available K ha^{-1}. The crop was sown in the first week of October and harvested in the last week of February in each year. Four irrigations were scheduled at 20-25 day intervals. Other cultural operations and plant protection measures were undertaken as per recommendations. Soil samples were collected at the beginning of the experiment and at the

Table 1. Grain and fodder yield (kg ha^{-1}) as influenced by genotype and fertilization treatments, Parbahni, Maharashtra, India, postrainy seasons 1998/99 through 2000/01.

Treatments	1998/99		1999/2000		2000/01		Pooled		Cost of production (Rs ha^{-1})	Net monetary returns[1] (Rs ha^{-1})	Incremental benefit (Rs ha^{-1})	Benefit:cost ratio
	Grain	Fodder	Grain	Fodder	Grain	Fodder	Grain	Fodder				
FYM application (F)												
No FYM	4046	9129	4124	6115	4055	5748	4074	6990	13384	18836	–	1.40
FYM @ 5.0 t ha^{-1}	4314	9629	4581	7080	4648	5990	4527	7564	14135	21441	2605	1.51
SE ±	52	134	53	119	53	98	65	63		416		
CD at 5%	159	406	161	360	157	NS[2]	183	175		1152		
Nitrogen levels (N)												
80 (kg ha^{-1})	3796	8444	4248	6366	3842	5100	3963	6629	13160	17948	–	1.36
120 (kg ha^{-1})	4198	9370	4506	6443	4157	5601	4268	7138	13560	19992	2044	1.47
160 (kg ha^{-1})	4333	9759	4468	7137	4564	6064	4481	7648	13960	21390	1398	1.53
200 (kg ha^{-1})	4407	9953	4190	6443	4833	6703	4481	7694	14360	21225	–165	1.47
SE ±	74	190	76	168	54	98	94	221		589		
CD at 5%	226	577	239	509	158	298	259	612		1634		
Genotypes (G)												
CSV 216R (Yeshoda)	4009	10055	4888	7234	4805	6681	4564	7990	13760	22636	4995	1.64
SPV 504 (Swati)	4351	8703	3817	5961	3898	5057	4027	6574	13760	17641	–	1.28
SE ±	124	26	70	90	59	116	65	63		416		
CD at 5%	374	79	187	270	177	342	183	175		1152		
Interactions												
F×N												
SE ±	106	269	106	238	108	101	92	136		833		
CD at 5%	NS	NS	323	NS	NS	NS	NS	NS		NS		
F×G												
SE ±	176	54	88	128	111	231	74	89		589		
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS		NS		
N×G												
SE ±	249	317	125	180	83	157	144	181		833		
CD at 5%	NS	NS	375	NS	NS	NS	NS	NS		NS		
F×N×G												
SE ±	353	449	177	255	166	324	132	181		1179		
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS		NS		
CV (%)	11.64	7.80	7.05	6.71	6.68	9.7	3.85	5.39				
Grand mean	4181	9380	4353	6597	4352	5859	4296	7277		20139		

1. Prices: grain = Rs. 5.50 kg^{-1}; fodder = Rs. 1.40 kg^{-1}. 2. NS = not significant.

end of the third year and analyzed for organic carbon, N, P, K and micronutrients.

Results and Discussion

A summary of grain and fodder yields for three years along with pooled analysis and net monetary returns is given in Table 1.

FYM levels

Grain yield. The application of FYM at 5.0t ha^{-1} produced significantly higher grain yield than no application of FYM during all three years of this study as well as in the pooled analysis. This clearly indicated that FYM application at the rate of 5.0 t ha^{-1} is beneficial for increasing grain yield of irrigated *rabi* sorghum. Goudreddy et al. (1989) observed similar results.

Fodder yield. The FYM application treatment recorded significantly higher fodder yield than no application of FYM during two of three years in this study and in the pooled analysis. The exception was 2000/01, when fodder yields of these two treatments were at par with each other.

Nitrogen levels

Grain yield. The effect of nitrogen on grain yield was evident in all three years as well as in the pooled analysis but the trend was inconsistent. During 1998/99 and 1999/2000 grain yield increased significantly up to 120 kg N but decreased thereafter. However, in 2000/01 each higher nitrogen level recorded significantly superior yield to lower nitrogen level. In pooled analysis 120 kg N recorded significantly higher grain yield than 80 kg N but was at par with 160 and 200 kg N, indicating that *rabi* sorghum responds favorably to N fertilization rates up to 120 kg N under irrigated conditions. Goudreddy et al. (1989) also observed that grain yield of *rabi* sorghum increased with N fertilization rates up to 120 kg N.

Fodder yield. During 1998/99 and 2000/01 plots receiving application of 120 kg N recorded significantly higher fodder yields than those receiving 80 kg N. However, in 1999/2000 and in the pooled analysis the 80 and 120 kg N treatments were at par for fodder yield. Further, the pooled analysis indicated that the 120, 160 and 200 kg N fertilization treatments were statistically at par for fodder yield in agreement with observations of Raj and Patel (1988).

Genotype

Grain and fodder yield. CSV 216R (Yeshoda) was significantly superior in producing grain and fodder yield than SPV 504 (Swati) during two of three years as well as in the pooled analysis. The exception was in 1998/99, wherein Swati (SPV 504) performed better than CSV 216R. Thus CSV 216R proved its superiority over SPV 504 in respect of grain and fodder yield under irrigated conditions.

Interaction effects

Significant interaction effects between FYM, fertilizer nitrogen, and genotype treatments were not observed except in 1999/2000 when the interaction of FYM x nitrogen for grain yield was significant; the FYM + 80 kg N treatment combination recorded significantly higher grain yield than all other treatment combinations except FYM + 120 kg N and FYM + 160 kg N.

Net monetary returns

FYM. The pooled data of net monetary returns (Rs ha^{-1}) revealed that FYM application at 5.0t ha^{-1} gave significantly higher net monetary returns (Rs 22,331 ha^{-1}) than no application of FYM. The incremental benefit due to FYM application was Rs 2605 ha^{-1} indicating that FYM application of 5.0 t ha^{-1} increased net monetary returns from cultivation of irrigated *rabi* sorghum.

Nitrogen. Application of fertilizer nitrogen at 120 kg ha^{-1} gave significantly higher monetary returns (Rs 19,992 ha^{-1}) than 80 kg N ha^{-1}. However, monetary returns from the 120 kg N rate were at par with the 160 and 200 kg N application rates. The incremental benefit due to application of 120 kg N rather than 80 kg N was Rs 2044 ha^{-1}, and that due to application of 160 kg N rather than 120 kg N was Rs 1398 ha^{-1}, indicating that economic returns from irrigated *rabi* sorghum can be maximized with the application of 160 kg N ha^{-1}.

Genotypes. The genotype CSV 216R (Yeshoda) gave significantly higher net monetary returns of Rs 22,636 ha^{-1} and an incremental benefit of Rs 4995 ha^{-1} compared to SPV 504.

Soil properties

Compared to initial soil status at the start of this experiment, all soil properties were improved by application of FYM.

Among the soil properties observed, content of organic carbon, nitrogen, P_2O_5, K_2O and micronutrients (Fe, Zn, and Cu) increased significantly with application of FYM. All of these soil properties except organic carbon also increased significantly with increasing levels of nitrogen. Soil pH was not influenced significantly by FYM application and nitrogen levels. Electrical conductivity decreased significantly with increasing in nitrogen levels up to 200 kg N ha^{-1}.

Conclusions

On the basis of pooled analysis of grain and fodder yield as well as net monetary returns, it is concluded that:

- On deep medium black soil, the *rabi* sorghum genotype CSV 216R (Yeshoda) can give maximum grain and fodder yield under irrigated conditions.
- FYM application at the rate of 5.0t ha^{-1} is beneficial to irrigated *rabi* sorghum, maximizing grain and fodder yields as well as net monetary returns.
- Nitrogen application to irrigated *rabi* sorghum at the rate of 120 kg ha^{-1} can maximize grain and fodder yields and net monetary returns.
- Soil properties like organic carbon, nitrogen, phosphorus, potash, and micronutrient (Fe, Zn, and Cu) contents can be improved with application of FYM and nitrogen.

References

Goudreddy BS, Patil VS, Reddy GD and Cittapur BM. 1989. Response of *rabi* sorghum to nitrogen, FYM and azotobacter under irrigated condition. Journal of the Maharashtra Agricultural University 14(3):266-268.

Khade VN, Patil SP, Khanvilkar SA and Chavan LS. 1989. Response of grain sorghum to irrigation and fertilizer regimes on medium black soils of Kokan. Journal of the Maharashtra Agricultural University 14(2): 173-174.

Raj MK and Patel BK. 1988. Influence of N on quality of forage sorghum hybrid. Gujarat Agricultural University Research Journal 14(I):61-63.

Winter Season Adaptation Features in Sorghum

JE Jahagirdar[1,*] and ST Borikar[2](I. Ph.D. student and 2. Senior Sorghum Breeder, Sorghum Research Station, Marathwada Agricultural University, Parbhani 431 402, Maharashtra, India)
*Corresponding author

Introduction

Winter sorghum [*Sorghum bicolor* (L.) Moench] in Maharashtra, India, has maintained stability in area during the last three decades as the crop is equally valued for its grain and fodder. Winter sorghum grain prices are about two-fold higher than that of rainy season sorghum grain. The last 30 years have witnessed a 30% rise in winter sorghum productivity at the national level (Nerkar 1998) from 475 kg ha^{-1} to 616 kg ha^{-1}. The productivity increases in Maharashtra and Karnataka during this period are 29% and 28%, respectively.

Winter sorghum hybrids will have a tangible impact only when their male-sterile (A-) and R-lines have the required seasonal adaptability. A close look at available sorghum parental lines shows that most are still rainy season lines with very few winter-adapted ones. CSH 13R has significant yield superiority over M 35-1 but is highly vulnerable to shoot fly [*Atherigona soccata* (Rondani)] and low temperature, and has inferior grain quality. In CSH 15R traits required for winter adaptation are better than those of CSH 13R, though not equal to M 35-1. Hence, the present study involving new sorghum male-sterile lines and restorers was planned.

Materials and Methods

The experimental materials consisting of 11 male-sterile lines (9 rainy season: PMS 1A, PMS 2A, PMS 3A, PMS 4A, PMS 5A, PMS 6A, PMS 8A, PMS 19A; and 2 winter season: 104A and 116A) and 11 testers (6 rainy season: KR 112, KR 189, KR 190, KR 191, KR 192,and PVK 801; and 5 winter season: RS 585, RS 615, RS 29, SPV 492 and SPV 727) and their 121 F_1 hybrids along with control entries CSH 13R and CSH 15R were evaluated in a randomized block design with two replications in winter 1998/99 at the Sorghum Research Station, Parbhani. Each genotype was represented by a single-row (5 m) plot, with 45 and 15 cm inter- and intra-row spacings, respectively. Seed setting (%) in selfed panicles was recorded on five randomly selected plants to assess combined pollen fertility restoration and stigma recepability under low temperature conditions. Other observations included grain

Table 1. Main features of promising heterotic sorghum hybrids for winter season, Parbhani, Maharashtra, India, 1998/99.

Hybrid pedigree	Grain yield/ plant (g)	Grain size	Grain shape	Grain color	Grain luster	Agronomic acceptability	Shoot fly deadhearts (%)	Seed setting (%)
PMS 8A × RS 29	83.0	Medium	Sublenticular	White-chalky	Non-lustrous	Low*	39.1	79.2
116A × RS 585	66.7	Medium-bold	Spherical	Creamy	Lustrous	High*	38.9	7.9
PMS 7A × SPV 727	63.0	Medium-bold	Spherical	Creamy	Lustrous	High**	30.3	3.0
PMS 19A × SPV 727	62.7	Medium-bold	Spherical	White-pearly	Lustrous	High**	22.6	71.7
PMS 19A × SPV 492	61.9	Medium-bold	Spherical	Creamy	Lustrous	High**	21.5	70.6
PMS 19A × RS 29	61.5	Medium-bold	Sublenticular	White-chalky	Non-lustrous	Moderate**	14.0	59.8
116A × SPV 727	61.0	Medium-bold	Spherical	White-pearly	Lustrous	Moderate**	33.6	0.0
104A × SPV 492	60.1	Bold	Spherical	White-pearly	Lustrous	High**	26.7	22.7
116A × KR 191	58.5	Medium-bold	Spherical	Creamy	Lustrous	Moderate**	27.8	3.8
PMS 8A × SPV 492	58.2	Medium	Sublenticular	White-pearly	Lustrous	Moderate*	39.8	30.7
CSH 15R (control)	42.5	Medium	Spherical	White-pearly	Lustrous	High	38.9	52.0

* compared with CSH 15R; ** compared with CSH 15R and M 35-1.

yield per plant, grain size, grain shape, grain color, grain luster and agronomic acceptability.

An additional set of genotypes was also sown during early winter along with susceptible and resistant controls to assess their shoot fly reactions.

Results and Discussion

In the present study, out of 121 hybrids, 10 hybrids were promising for grain yield (Table 1). Hybrids based on new shoot fly resistant rainy season adapted male-sterile line PMS 19 A with winter-adapted male parents SPV 727, SPV 492 and RS 29 were promising for grain yield and pest resistance with low percentages of shoot fly deadhearts. The study indicated that hybrids based on shoot fly resistant male-sterile lines (104A, 116A and PMS 19A) and restorers (RS 585, RS 615, SPV 492 and SPV 727) can be utilized in winter season. These findings are in agreement with those of Kaul and Rana (1996). Biradar and Borikar (1985) also reported less shoot fly deadhearts in resistant parents and progenies involving both resistant parents.

Hybrid PMS 8A x RS 29, though top ranking for grain yield, had low acceptability due to its non-lustrous and white-chalky grains. Hybrids PMS 19A x SPV 727, 116 A x SPV 727, 104A x SPV 492 and PMS 8A x SPV 492 were promising and had medium-bold, lustrous, white pearly grains with high agronomic acceptability and better threshability. Chavan and Nerkar (1978) also reported that rainy season x winter hybrids may give combinations of economic value that could be stable over both seasons. Rana and Kaul (1996) also reported that total biomass productivity and bold lustrous grain are favored by farmers to meet household and market needs.

Low temperature is the second most important abiotic stress after drought for winter sorghum adaptation. When the crop is subjected to non-freezing temperatures below 10-15°C chilling injury can occur. The common symptoms of chilling injury include poor establishment, chlorosis of young seedlings, restricted growth and development and, in the case of certain cereals, spikelet sterility and reduced grain yield (Peacock 1982). Fertility restoration is a major limitation for manifestation of heterosis in winter sorghum (Kaul and Rana 1996).

During the present study nightly minimum temperatures were below 10°C from meteorological week 49 to 3 (3 December 1997 to 21 January 1998). Out of 10 promising hybrids, satisfactory seed setting under bagged conditions was observed only in hybrids PMS 8A x RS 29, PMS 19A x SPV 727 and PMS 19A x SPV 492. Seed setting in control hybrid CSH 15R was poor (52.1%). The present study indicated that the lowest seed setting occurred in hybrids involving two winter-adapted parents, perhaps due to a

low frequency of pollen fertility restoration genes in such materials. This situation indicates the need of increasing genetic diversity in parents and identification of heterotic (rainy x winter) crosses suitable for winter season where cold waves often coincide with reproductive growth of the crop.

References

Biradar SG and Borikar ST. 1985. Genetic analysis of shoot-fly resistance in relation to growth stages in sorghum. Zeitschrift fur Pflanzenzuchtung 9:173-178.

Chavan PD and Nerkar YS. 1978. Combining ability studies in *rainy season* and *winter* sorghum (5. *bicolor* (L.) Moench). Madras Agricultural Journal 65(11):730-735.

Kaul S and Rana BS. 1996. Emerging trend in post-rainy (*winter*) sorghum breeding. Page 147 *in* 2nd International Crop Science Congress, 17-24 Nov 1996, New Delhi, India.

Nerkar YS. 1998. Winter sorghum improvement for food and fodder security - opportunities and strategies. A special lecture delivered at the XXIXth Workshop of All India Coordinated Sorghum Improvement Project, 23-25 April 1998, University of Agricultural Sciences, Dharwad, Karnataka, India.

Peacock JM. 1982. Response and tolerance of sorghum to temperature stress. Pages 151-154 *in* Sorghum in the Eighties. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Rana BS and Kaul S. 1996. Exploitation of heterosis to enhance the sorghum productivity in India. Page 227 *in* 2nd International Crop Science Congress, 17-24 Nov 1996, New Delhi, India.

Studies on the Adverse Effects of Low Night Temperatures on *Rabi* Sorghum

GG Shinde*, PM Deshpande, MH Lomte and AS Deshmukh (Sorghum Research Station, Marathwada Agricultural University, Parbhani 431 402, Maharashtra, India)

*Corresponding author

Introduction

Rabi (postrainy season) sorghum [*Sorghum bicolor* (L.) Moench] is a very important crop in Maharashtra, where it is grown on an area of 3.4 m ha, mostly on residual soil moisture under rainfed conditions. Average grain yields are 600-700 kg ha^{-1} and are mostly governed by factors such as sowing time, soil moisture availability, soil fertility and plant population. Low night temperature during flowering has an adverse affect on seed setting and ultimately on grain yield (Brooking 1976, Rao et al. 1984). With a view to study the effect of low night temperature on seed setting and grain yield, an experiment was conducted with three sowing dates and four sorghum genotypes in which the crop was subjected to a range of temperatures during the flowering period.

Materials and Methods

A split-plot experiment with three sowing dates (early = 24 Sep, 39th meteorological week; normal = 9 Oct, 41st meteorological week; and late = 24 Oct, 43rd meteorological week) as main plot treatments and four sorghum genotypes (CSH 13R, CSH 15R, M 35-1 and SPV 504) as subplot treatments was conducted under rainfed conditions during the *rabi* seasons of 1998/99 and 1999/2000 at the Sorghum Research Station, Marathwada Agricultural University, Parbhani. Harvesting was completed on 29 Jan, 10 Feb and 22 Feb in both years in the early, normal and late sowing date treatments, respectively. Data were recorded on grain and fodder yield, seed setting, plant count, plant height, grain yield per plant, and 1000-grain weight. Correlation and multiple regression analysis were used to determine the effect of average night temperatures during the flowering period on seed setting and grain yield.

Results and Discussion

Interaction effects of sowing date x genotype, and sowing date x genotype x year were non-significant for grain and fodder yield in the pooled analysis across the two years of mis study.

Effect of sowing dates. Pooled analysis indicated that the normal 9 Oct sowing date gave the highest grain yield (2050 kg ha^{-1}), which was significantly superior to mat obtained from me 24 Sep or 24 Oct sowing dates (Table 1). This higher grain yield was obtained due to sufficient moisture for germination and crop establishment, which resulted in better vegetative growth and higher plant stand at harvest compared to the late sowing date. Seed setting percentage was also normal in the crop harvested from me 9 Oct sowings. In the pooled analysis fodder yield did not vary significantly across me sowing dates.

Response of genotypes. Across years, CSH 15R gave the highest grain yield (2000 kg ha^{-1}), which was at par with SPV 504 and M 35-1, and significandy superior to CSH 13R (Table 1). Single-plant grain yield and 1000-grain mass were also higher for CSH 15R than the other genotypes tested. Differences in fodder yield due to genotypes were significant only in 1998/99, but absent in 1999/2000 and in the pooled analysis. In 1998/99, CSH 15R recorded

Table 1. Grain and fodder yield of postrainy (*rabi*) season sorghum as influenced by sowing date and genotype, Parbhani, Maharashtra, India, 1998/99 and 1999/2000.

Treatment	Grain yield (kg ha^{-1})			Fodder yield (t ha^{-1})			Two-year means		
	1998/1999	1999/2000	Pooled	1998/1999	1999/2000	Pooled	Final plant count per plot	Grain yield per plant (g)	1000-grain mass (g)
Sowing dates (D)									
24 Sep	1852	1669	1765	4.17	5.67	4.92	70	27.7	31.2
9 Oct	2056	2032	2050	4.78	5.94	5.36	68	26.3	30.9
24 Oct	1331	2024	1678	3.07	5.36	4.22	53	29.4	28.2
SE(±)	40	70	86	0.12	0.10	0.12			
CD (5%)	119	209	238	0.35	0.21	NS			
Genotypes (G)									
CSH 13R	1350	1760	1556	3.56	5.92	4.38	62	26.3	24.3
CSH 15R	2000	1996	2000	4.41	5.61	5.01	65	27.7	31.1
M 35-1	1907	1846	1880	4.46	5.81	5.14	66	29.0	32.7
SPV 504	1746	2031	1889	3.57	5.30	4.44	62	28.2	32.3
SE(±)	45	81	99	0.20	0.20	0.14			
CD (5%)	134	NS	295	0.61	NS	NS			
Interaction (D x G)									
SE(±)	78	141	166	0.35	0.34	0.24			
CD (5%)	231	417	NS	NS	1.02	NS			
Grand mean	1748	1908	1830	4.00	5.66	4.83	64	27.8	30.1

NS = not significant.

4.46 t ha^{-1} fodder yield, which was on par with M 35-1 (4.41 t ha^{-1}) and significantly superior to the remaining two genotypes. These results indicate that CSH 15R and M 35-1 can give good grain and fodder yield under rainfed conditions.

Effect of low night temperature. Lower seed set (77%) of hybrids CSH 13R and CSH 15R indicated that these were more sensitive to low night temperature than open-pollinated varieties M 35-1 and SPV 0504 (95-98% seed set). Correlations of low night temperature and seed set with grain yield per plant were significant. Results from multiple regression analysis showed 41% of observed variation in grain yield per plant could be attributed to these two variables, with the partial regression coefficient for seed setting significant at $P = 0.05$, and that for low temperature significant at $P = 0.10$.

Conclusions

Optimum yields of *rabi* sorghum genotypes CSH 15R, M35-1 and SPV 504 can be obtained under rainfed conditions by sowing on medium to deep black soils in assured rainfall areas during the 41st meteorological week (8-14 October).

References

Brooking IR. 1976. Male sterility in *Sorghum bicolor* (L.) Moench induced by low night temperature. I. Timing of the stage of sensitivity. Australian Journal of Plant Physiology 3:589-596.

Rao NGP, Tripathi DP and Rana BS. 1984. Genetic anaylsis of cytoplasmic systems in sorghum. Indian Journal of Genetics and Plant Breeding 44:480-496.

Germination Behavior of Four Sorghum Genotypes at Supra-optimal Temperatures and Limited Moisture Conditions in Response to Seed Soaking Treatments

Mohamad A Kader[1,*] and S Jutzi[2] (1. Consultica Worldwide, PO Box 3089, Tamarama NSW 2026, Australia; 2. Animal Health Division, FAO, Rome, Italy)
*Corresponding author: m.kader@mbox.com.au

Two experiments were conducted to investigate the effect of hydration-dehydration cycles on seeds of four sorghum [*Sorghum bicolor* (L.) Moench] genotypes, both before and after pre-sowing seed treatments, based on earlier work (Al-Mudaris and Jutzi 1997).

In the first experiment sorghum ICSV 745 seeds were either untreated (dry control) or soaked in water (24 hours at 6°C) and dried once (one cycle) or twice (two cycles, i.e., soak, dry, soak, dry). After treatment, seeds were stored for 2 weeks at 20°C, and thereafter treated again by soaking in either water or a 25-g NaCl L^{-1} water solution.

In the second experiment sorghum varieties ICSV 1, ICSV 112, ICSV 745 and M 35 1 were tested. Seeds were either soaked in water or in one of four growth regulator/ salt mixtures (GA_3, kinetin, NaCl or KNO_3), dried and stored for 5 months at 20°C. Seed lots were subsequently taken out of storage and either rehydrated by soaking in water for 6 hours at 6°C or sown dry. Germination was monitored under 0, -7.7, -10 or -12.5 bar drought levels achieved by using PEG 10,000 (polyethylene glycol). Seed treatments were conducted at 6°C in the dark to disallow pre-mature germination during treatment. Germination tests under the drought levels above were conducted at a temperature of 40/25°C (12h/12h day/ night) to reflect both drought and heat stress.

Final germination percentage, mean germination time and germination index were measured. Results revealed that one cycle of hydration-dehydration of the seeds gave the highest germination percentages in comparison to non-hydrated or two-cycle-hydrated seeds. Soaking seeds in water was superior to a 25-g L^{-1} NaCl soak. A mixture of NaCl and KNO_3 gave higher germination percentages than other growth regulator/salt combinations, with M 35 -1 giving the highest positive response. The potential for pre-sowing hydration-dehydration treatments in improving germination under drought and heat stress is worthy of further investigation.

Reference

Al-Mudaris M and Jutzi S. 199.7 Germination of *Sorghum bicolor* L. (Moench) under heat and drought stress as affected by NaCl seed priming. Book of Abstracts, International Conference on Sustainable Agriculture for Food, Energy and Industry, Braunschweig, Germany. p. 304.

Supra-optimal Temperature Stress and the Heat Treatment of Sorghum Seed

Mohamad A Kader (Consultica Worldwide, PO Box 3089, Tamarama NSW 2026, Australia)
m.kader@mbox.com.au

Recent interest in presowing seed treatments to improve field emergence under stress has generated considerable advances in treatments. Priming with sodium chloride (NaCl) has been used in *Sorghum bicolor* (L.) Moench and has been shown to advance germination under drought but not under heat stress (Al-Mudaris and Jutzi 1998). The principle of acclimatizing seeds or whole plants to stress is also well documented (Amzallag et al. 1990) and has been applied to NaCl treatments in sorghum (Al-Mudaris and Jutzi 1998). Therefore, the possibility of acclimatizing seeds to heat stress by pre-exposure to high temperatures seems to be feasible. The objective of this investigation was to test the influence of seed treatments and pre-stress heat exposure timing on germination of *S. bicolor* seeds of genotype SPV 462 under heat stress.

Materials and Methods

Three NaCl-based seed-priming treatments were used.

1. Soaking seed in solution containing 2 g L^{-1} NaCl (osmotic potential -1.5 bar) for 3 days (d) in the dark
2. Soaking seed in solution containing 4 g L^{-1} NaCl (osmotic potential -3.2 bar) for 3 d in the dark
3. Soaking seed in solution containing 6 g L^{-1} NaCl (osmotic potential -4.3 bar) for 3 d in the dark
4. Dry, untreated control.

Heat treatments were applied on the 1st, 2nd, 3rd d of soaking by exposing seeds (within solutions) to a temperature of 41°C for 2 hours (h) only. For the remainder of the experimental period seeds were held in solution at 25°C. Seeds continuously exposed to 25°C during the whole 3-d

period were used as control. Dry, untreated seeds were exposed to the same temperatures as NaCl-soaked seeds. After treatment, the seeds were surface dried and plated for germination on filter paper moistened with distilled water (0 bar). Day/night temperatures of 41/19°C (12 h/ 12 h) were used in germination cabinets which were not lighted (24 h dark). Observations of seed germination were made at 24-h intervals for 10 d. After 10 d, seedling plumules and radicles were excised, dried, and weighed to determine the mean dry weight of plumules (DWP) and radicles (DWR). By dividing DWP by DWR a plumule : radicle ratio (PRR) was obtained. From daily germination scores, the final germination percentage, mean germination time, and germination index were calculated. Analysis of variance was used to test for priming treatment and heat effects, and for their interaction on arsine-transformed germination percentages. Duncan's Multiple Range Test was used to separate means.

Results and Discussion

The higher the NaCl concentration used, the greater were the dry weights of plumules and radicles recorded. Heat treatment of seeds on the 3rd d of soaking yielded higher germination percentages than those of the control seeds, while treating them on the 2nd d resulted in faster germination. Both the 2nd and 3rd d heat treatments produced superior germination indices and higher PRR ratios. Results revealed a faster germination pattern in all three NaCl treatments than in the control. The final germination percentage was not influenced by heat treatments, but mean germination time decreased progressively when seeds were treated on the 2nd or 3rd d of soaking. Seeds exposed to 41 °C (2 h) on the 2nd or 3rd d of soaking did not 'sense' stress when they were transferred to a 12-h d^{-1} regime of 41 °C. They can be considered acclimatized to this stress and thus had less need to produce larger radicles. This resulted in higher PRR ratios in these treatments.

It is suggested that heat acclimatization of sorghum seeds by priming treatments can improve subsequent germination and growth under supra-optimal temperature conditions.

References

Amzallag G, Lerner H and Poljakoff-Mayber A. 1990. Induction of increased salt tolerance in *Sorghum bicolor* by NaCl pretreatment. Journal of Experimental Botany 41:29-34.

Al-Mudaris M and Jutzi S. 1998. The influence of genotype, priming material, temperature and osmotic potential of priming solution on imbibition and subsequent germination of sorghum and pearl millet seeds during and after treatment. Journal of Agriculture in the Tropics and Subtropics 100:147-157.

Varying Temperature Regimes Affect Osmotically Primed Sorghum Seeds and Seedlings

Mohamad A Kader (Consultica Worldwide, PO Box 3089, Tamarama NSW 2026, Australia)
m.kader@mbox.com.au

Soil surface temperatures vary between day and night and a number of factors influence seedling emergence. These include: absolute temperature, average temperature, and the magnitude of the difference between absolute maximum and minimum temperatures during the day. This paper reports the effects of both absolute temperature and the difference between maximum and minimum day and night temperatures on the germination of primed seeds of sorghum [*Sorghum bicolor* (*L.*) *Moench*] cultivar CSV 15.

Materials and Methods

Sorghum seed was primed by various treatments:

T_1 = Seeds soaked in sodium chloride solution containing 2 g L^{-1} NaCl fosmotic potential (ψ_s) = -1.5 bar, electrical conductivity (EC)= 3.8 mS cm^{-1}] for 2 days (d).

T_2 = Seeds soaked in 4 g L^{-1} NaCl solution (ψ_s)=-3.2 bar, EC= 7.3 mS cm^{-1}) for 2 d.

T_3 = Seeds soaked in 6 g L^{-1} NaCl solution (ψ_s)= -4.3 bar, EC= 9.3 mS cm^{-1}) for 2 d.

Dry (unsoaked) and wet (soaked in plain water for 2 d) controls were also tested.

Seeds from all treatment combinations were germinated in a polyethylene glycol (PEG 10,000) solution generating an osmotic potential of -3.0 bar to simulate a moderately moist/dry soil.

Germination parameters and dry weights of roots and shoots were measured for seeds germinated under the following four temperature regimes:

R_1 = Seeds germinated at a constant 30°C (Control)

R_2 = Seeds germinated at a 35/25°C (12 h/12 h) day/ night temperature (mean 30°C)

R_3 = Seeds germinated at 40/20°C (12 h/12 h) day/night temperature (mean 30°C)

R_4 = Seeds germinated at 41 /19°C (12 h/12 h) day/night temperature (mean 30°C)

Results and Discussion

The R_1 and R_2 regimes resulted in the highest final germination percentages and the highest germination

index values of all treatments. The fastest germination occurred in R_2 and the slowest in R_4. The dry weights of roots and shoots were significantly affected by the germination temperature regime, with R_2 yielding the highest dry weights.

T_1 was effective in increasing germination rate across the range of temperature regimes studied. Increase in priming solution concentration and germination temperatures caused decreases in the mean germination time up to a optimum threshold, and increases thereafter. T_1 seed priming enhanced the curvilinear response to temperature. The data from the present study emphasize that absolute temperature levels have more significant effects on sorghum germination than the average daily temperature in both primed and unprimed seeds.

The relationship between the rate of germination to temperature is not a Q_{10} one as for a simple chemical reaction. Instead, above a minimum temperature below which no germination occurs, over a considerable range this relationship is linear or almost so. Beyond the optimum range, in which most of a seed population will germinate, an increasing proportion of individuals respond to lower or higher temperatures by not germinating. Seed priming and heat treatments can alter this reaction.

Pathology

Prevalence of Sorghum Diseases in Karnataka and Maharashtra States, India, during 2001 Rainy Season

AH Rajasab[1] and RA Frederiksen[2] (1. Gulbarga University, Karnataka, India; 2. Professor Emeritus, Department of Plant Pathology and Microbiology, Texas A&M University, College Station, TX 77843, USA)

Survey Team and Route

Professor AH Rajasab of Gulbarga University, (India) with the assistance of US Grains Council representatives AP Sachhdev and Amit Sachhdev in India, organized a 20-day, 4800 km field survey through the sorghum (*Sorghum bicolor* (L.) Moench.) growing regions of Karnataka and Maharashtra. RA Frederiksen (Professor Emeritus, Texas A&M University, USA) was invited to accompany the survey that was made from 26 Aug to 14 Sep 2001. Some 174 fields of both forage and grain sorghums including hybrids and traditional cultivars in the states of Karnataka, and Maharashtra, and one field in Andhra Pradesh were evaluated for prevalence and severity of diseases, insect and mite pests, and *Striga* spp. (Tables 1-3).

The route began from Hyderabad, Andhra Pradesh, proceeded directly to Gulbarga, Karnataka and then continued south through Karnataka with overnight breaks in Raichur, Hospet, Chitradurga, and Hassan. From Hassan, an eastern route was taken northwards through Karnataka to Shimoga. A visit was made to the sorghum research team at the University of Agriculture, Dharwad before continuing via Hubli finally to Bijapur. The survey then proceeded north into Maharashtra, from Solapur to Osmanabad, and finally to Aurangabad. After extensive surveys in these areas, the group returned to Hyberabad via Jalna, Parbhani, and Nanded, visiting the Department of Plant Pathology at Parbhani and the Maharashtra Hybrid Seed Company (MAHYCO) at Jalna.

Specimens and detailed notes on the crops and their condition were taken in each of the 174 fields surveyed. Diseases were evaluated visually based on experience, and with reference to the *Compendium of Sorghum Diseases* (Frederiksen and Odvody 2000).

Results

Many of the common diseases of sorghum were present in varying degrees of prevalence and severity. Unfortunately, laboratory follow-up of suspected new or unusual diseases, particularly virus-like diseases was not possible. Generally the same diseases were found in both states with minor differences. Such common diseases as anthracnose [*Colletotrichum graminicola* (Cesti.) Wilson], leaf blight [*Exserohilum turcicum* (Pass.) Leonard and Suggs.], maize stripe mosaic, and sooty stripe [*Ramulispora sorghi* (Ell. & Ev.) L.S. Olive & Lefebvre] ranked almost equally and were the most common in both states. The number of different virus-like diseases was greater in Maharashtra than in Karnataka. For example, maize stripe mosaic was very prevalent in Maharashtra and less so in Karnataka (Table 1).

Damaging pests were observed in many fields (Table 3). These included sugarcane aphid *[Melanaphis sacchari* (Zehntner)], mite damage caused by *Oligonychus indicus* (Banks), shoot fly *[Atherigona soccata* (Rondani)], stem borer [*Chilopartellus* (Swinhoe)], head worms [*Helicoverpa armigera* (Hiibner)], corn leaf aphids *[Rhopalosiphum maidis* (Fitch.)] and head bugs (*Eurystylus oldi* Poppius).

Table 1. Relative incidence and severity of diseases in sorghum fields in Karnataka (89 Fields visited) and Maharashtra (85 fields visited) during rainy season 2001.

	Karnataka			Maharashtra		
Common disease name	Number of fields with the disease	Highest disease incidence	Highest disease severity[1]	Number of fields with the disease	Highest disease incidence	Highest disease severity[1]
Anthracnose	17	100	3	31	100	3
Maize stripe mosaic	15	20	3	49	75	4
Leaf blight	15	100	4	43	100	3
Sooty stripe	11	25	3	11	50	2
Striga asiatica	11	25	2	10	50	2
Rust	10	15	2	26	100	1
Sorghum downy mildew	7	5	4	3	30	4
Zonate leaf spot	6	25	2	10	100	2
Target leaf spot	4	75	1	10	100	2
Bacterial leaf spot	5	1	1	3	1	1
Gray leaf spot	4	25	2	S	50	2
Long smut	3	5	2	2	1	1
Grain mold	3	25	1	-[5]	-	-
Pokkah boeng [Gibberella *fujikuroi* var. *subglutinans* Edwards]	2	1	1	11	1	4
True small seed	2	10	1	-	-	-
Acrcmonium will	1	1	2	2	5	2
Maize mosaic	3	1	2	10	30	1
Undescribed virus-like disease[2]	1	1	4	2	10	4
Maize dwarf mosaic-like disease[3]	1	1	1	1	1	1
Loose smut	1	1	4	6	5	4
Head smut	1	1	4	1	1	4
Ergot	1	100	4			
Oval leaf spot	1	2	2	8	100	2
Rough leaf spot	1	5	1	7	100	2
Covered kernel smut	1	2	1	9	5	2
Downy mildew (Crazy top)	-	-	-	1	1	4
Mottle symptoms[4]	-		-	5	4	4

1. Severity is based on a 1-4 scale, where 1 represents no apparent damage. 2 very little damage, 3 generally present and may represent economic loss on individual plants. and 4 severely damage individual plants.
2. A different virus symptom, leaves have small green islands in a more or less mosaic pattern.
3. Symptoms similar to mild maize dwarf mosaic—a potyvirus common in sugarcane. Both this disease and the one described in footnote 2 occurred near sugarcane fields.
4. These are virus-like mottle symptoms (affected plants are reduced in size by half).
5. - = Absence of disease/pest.

Discussion

Among the more common diseases found were anthracnose, maize stripe (a plant hopper-transmitted virus disease) bacterial leaf blight, at least 2 or 3 unidentified virus-like diseases, all four sorghum smuts [long (*Tolyposporium ehrenbergii* (Kuhn) Patouillard), head (*Sporisorium reilianum* (Kuhn) Langdon and Fullerton), covered kernel (grain) (*Sporisorium sorghi* (Ehrenberg) Link), loose kernel (*Sphacelotheca cruenta* (Kiihn) Potter)], as were sorghum downy mildew [*Peronosclerospora sorghi* (Weston and Uppal) C G Shaw, oval leaf spot (*Ramulispora sorghicola* Harris), rough leaf spot (*Ascochyta sorghina* Sacc), acremonium wilt (*Acremonium strictum* W. Gams), ergot (*Claviceps africana* Frederickson, Mantle & de Milliano), and grain mold (caused by species of *Fusarium,*

Table 2. Relative incidence and severity of diseases and pests on varieties (96 fields visited) and hybrids (78 fields visited) of sorghum in Karnataka and Maharashtra during rainy season, 2001.

	Traditional varieties			Hybrids		
Disease/pathogen or pest	Number of fields with the disease	Highest disease incidence	Highest disease severity[1]	Number of fields with the disease	Highest disease incidence	Highest disease severity[1]
Leaf blight	45	50	2	13	10	2
Anthracnose	43	100	3	5	50	3
Maize stripe virus	40	10	2	21	75	4
Rust	30	100	1	6	5	2
Target leaf spot	14	100	1	-[4]	-	-
Zonate leaf spot	11	100	2	5	75	2
Striga asiatica	10	20	3	11	50	2
Covered kernel smut	9	5	4	1	5	1
Sorghum downy mildew	8	100	2	2	5	1
Maize mosaic virus	8	5	3	5	30	4
Sooty stripe	8	15	3	14	75	3
Gray leaf spot	7	100	2	2	25	3
Pokkah boeng	7	1	1	6	1	4
Loose smut	6	5	4	1	1	4
Oval leaf spot	6	100	1	3	15	1
Long smut	4	10	2	1	5	1
Rough leaf spot	4	5	1	5	100	2
Acremonium wilt	3	5	1	-	-	-
Bacterial leaf spot	3	1	1	5	5	1
Grain mold	2	25	1	1	1	1
Head smut	2	1	4	-	-	-
True small seed	-	-	-	2	10	1
Downy mildew (Crazy top)	1	1	4	-	-	-
Ergot	1	100	4	-	-	-
Undescribed virus-like disease[2]	1	2	1	-	-	-
Mottle symptoms[3]	1	10	4	5	15	1
Potyvirus	2	1	1	1	1	1
Mite	17	100	4	3	10	2
Shoot fly	17	30	2	46	50	4
Stem borer	14	10	1	17	20	1
Aphids	6	100	1	32	100	4
Bird damage	1	10	1	11	25	2
Midrib insect	1	25	2	-	-	-
Head worm	-	-	-	1	25	2
Head bug	-	-	-	1	10	

1. Severity is based on a 1-4 scale, where 1 represents no apparent damage, 2 very little damage, 3 generally present and may represent economic loss on individual plants, and 4 severely damage individual plants.
2. A different virus symptom, plants have small green islands in a more or less mosaic pattern.
3. These are virus-like mottle symptoms (affected plants are reduced in size by half).
4. - = Absence of disease/pest.

Table 3. Pest problems observed in sorghum fields of Karnataka (89 fields visited) and Maharashtra (85 fields visited) during rainy season 2001.

	Karnataka			Maharashtra		
Pest	Number of fields with the pest	Highest incidence (%)	Highest pest severity[1]	Number of fields with the pest	Highest incidence (%)	Highest pest severity[1]
Shoot fly	28	100	4	35	30	4
Sugarcane aphid	25	50	4	10	100	2
Stem borer	24	15	4	7	15	2
Birds	10	10	2	2	10	2
Mites	4	10	4	16	100	4
Head worm	-[2]	-	-	1	25	2
Head bug	-	-	-	1	10	2
Others	1	25	1	-	-	-

1. Severity is based on a 1-4 scale, where 1 represents little or no damage and 4 indicates severe economic impact.
2. - = Absence of pest.

Curvularia, and *Phoma).* Other diseases observed included leaf blight, gray leaf spot (*Cercospora sorghi* Ell. & Ev.), target leaf spot *[Bipolaris sorghicola* (Lefebvre & Sherwin) Shoem], zonate leaf spot (*Gloeocercospora sorghi* D. Bain & Edg.) and rust *(Puccinia purpurea* Cooke).

Charcoal rot [*Macrophominaphaseolina* (Tassi.) G. Goid.], a common disease of the postrainy season (*rabi*), was not present, even though the crops suffered from severe drought at many locations in both states. Bacterial streak disease caused by *Xanthomonas campestris* pv. *holcicola* (Elliott) Dye was not observed during the survey. Further, in the present disease survey, Milo disease caused by *Periconia circinata* (Mangin) Sacc, the root parasite *Striga hermonthica* (Del.) Benth. and red-flowered *Striga asiatica* (L.) Kuntze were not observed.

A comparison between hybrids and traditional cultivars is important (Table 2). Leaf blight, anthracnose, maize stripe virus and rust were more prevalent on traditional cultivars, whereas on hybrids maize stripe virus, sooty stripe, and leaf blight were more prevalent. For the most part, hybrids tended to have less disease and be less damaged by diseases than the traditional cultivars, except for those affected by maize stripe mosaic. The crop yields and appearance of hybrids were superior to those of traditional cultivars.

In most fields pest problems, particularly those caused by aphids, shoot fly, stem borers, and mites seemed much more economically important than disease problems.

Concerns about Introduction of New Pathogens or Disease Problems

Analysis of the disease situation suggests that most of the diseases common in the USA are already present in India. In the past there has been concern about the introduction of *Periconia circinata;* however this pathogen, that was known to cause Milo disease, has not been observed in sorghum production fields in the US for over half a century. Milo disease is directly related to the growing of old, susceptible 'milo' varieties. These susceptible varieties were replaced by resistant varieties in the USA in the 1940's, and all currently grown hybrids possess immunity to the disease. Sorghum grain produced in the USA for feed purposes comes from Milo disease immune cultivars. The pathogen cannot be isolated from those immune plants, it is only soilborne and it is not a grain contaminant. India is not known to grow any Milo disease susceptible varieties.

There are several other sorghum diseases, like the common bacterial diseases, bacterial stripe and streak, that are present in the US but are of no economic importance. During the survey a bacterial stripe disease was observed, suggesting that the pathogen is present but the disease probably occurs at extremely low levels. There may be some confusion between the common names of bacterial stripe and bacterial blight. Bacterial blight was observed in sorghum fields in Karnataka near sugarcane *Saccharum* spp. fields. This bacterial disease is known to occur in other warm humid environments but is not known to cause economic losses. Consequently, it is even less likely that the pathogen *Pseudomonas andropogonis* (E.F. Smith) Stapp, that is very rare in India, would cause losses in Indian sorghum.

Bacterial leaf streak disease that was not observed during the present survey, is caused by *Xanthomonas campestris* pv. *holcicola* (Elliot) Dye. The disease is known throughout the world in cooler environments such as those at higher elevations, or those in more temperate regions. When the disease occurs, it is expressed in inbred lines and to a lesser extent in hybrids. In no instance has it

caused economic losses in any of the areas where it commonly occurs.

During the survey several virus-like diseases of sorghum were observed that could not be diagnosed by their field symptoms. These diseases were relatively minor compared to maize stripe and maize mosaic, which may be the most damaging diseases of sorghum in India. There are several known viruses and virus-like organisms present on sorghum in India. These include members of the potyviridae, often referred to as 'sugarcane mosaic viruses'; and both maize stripe virus from the tenuivirus group and maize mosaic virus, a member of the rhabdoviridae. These virus diseases were found in both states. At least two other distinctly different virus-like symptoms in sorghum were also observed, the more prevalent being a mottle-like symptom. The growth and development of affected plants was reduced. The other virus-like disease had 'green island' symptoms and was noted commonly in southern Maharashtra.

The white-flowered form of the root parasite *Striga asiatica* is very prevalent in sorghum fields in India, but not the red-flowered form. *Striga hermonthica* that is common in countries in Africa, is not present in the United States, nor has it been reported in India.

During this survey the team visited faculty and students working on sorghum diseases in Gulbarga, Dharwad, and Parbhani Universities, the National Research Centre for Sorghum (NRCS) and International Crops Research Institute for Semi Arid Tropics (ICRISAT). SS Navi, a Research Officer from ICRISAT, accompanied the team for 3 days in Maharashtra. The team visited a feed milling unit (Yarana Feeds) where they expressed their concern about grain mold in stored sorghum grain. The team also visited MAHYCO at Jalna.

Acknowledgments. The authors thank the US Grains Council for financial assistance. They also thank SS Navi, Research Officer, ICRISAT, Patancheru for his help in computing the raw data. AH Rajasab thanks Gulbarga University, Gulbarga for sanctioning him leave to undertake the survey.

Reference

Frederiksen RA and Odvody GN. 2000. Compendium of Sorghum Diseases. 2nd Ed. APS Press, Minnesota, 78 pp.

Experimental Parasitism on Sorghum of *Claviceps sorghi* recently 'Re-discovered' in India

PG Mantle (Department of Environmental Science and Technology, Imperial College of Science, Technology and Medicine, London SW7 2AZ, UK)
p.mantle@imperial.ac.uk

Introduction

The ergot pathogen on sorghum *[Sorghum bicolor* (L.) Moench], indigenous to the Indian sub-continent during most of the 20th century, seems to have been *Claviceps sorghi,* which was the *Claviceps* species first described concerning sorghum ergot disease (McRae 1917, Kulkarni et al. 1976). In the 1980s, with the prospect that ergot disease would be problematic in A-lines as hybrid sorghum seed production became more popular, the early stage of the disease was studied using this pathogen (Frederickson and Mantle 1988). Also, broader aspects of its biology and parasitism were set out against which to describe the African pathogen of sorghum as a distinct species, *C. africana* (Frederickson et al. 1991). Subsequently, all axenic cultures and living preserved material of C. *sorghi* were lost and it became increasingly unclear as to whether it still had an ecological niche in India, in spite of the more aggressive pathogen C. *africana* having already become well established there (Bogo and Mantle 1999).

Very recently, RAPD patterns (S. Pazoutova and A. Bogo, Institute of Microbiology, Prague) of many isolates of Indian sorghum ergot pathogen (R. Bandyopadhyay, ICRISAT) have differentiated the majority of isolates, which are C. *africana,* from two that fit the data of Pazoutova et al. (2000) for *C. sorghi.* Similarly, the pathogen isolated in Prague from ergotized sorghum sourced by N. Johnson (Gulbarga University) was shown to be C. *sorghi.* To complement these molecular findings, the pathogenic characteristics of one isolate from ICRISAT (coded NAP 7) and the Gulbarga isolate have been studied in England, several thousand miles from any other possible sorghum ergot pathogen.

Experimental

Cultures on a sucrose/asparagine agar (Mantle 1973) at 25°C generally grew slowly as richly-sporulating yeast-like colonies from which aqueous inoculum was readily prepared for spraying, in August 2001, gaping florets on sorghum inflorescences. Plants of sorghum male-sterile line ATx623 (WL Rooney, College Station, Texas) were grown in a greenhouse in Surrey to flower at 150 cm

height with prominent exserted stigmas. There was no overhead watering.

The sorghum florets were uniformly green but, a few days after application of the cultured inoculum, floral parts often became 'stained' a terracotta color. This appeared to be a host reaction.

Some adjacent inflorescences were also left uninoculated to assess any natural spread of disease; such secondary infections occurred very rarely, attributable simply to insect or secondary spore transmission. The latter may have been minimized by protection from wind and rain in the greenhouse environment.

First honeydew emerged 8-10 days and 11 days after inoculating with culture-derived inoculum of the ICRISAT and Gulbarga isolates, respectively. Honeydew exuded without sphacelia in floral cavities having first forced the glumes apart. In disease caused by *C. africana* the distal aspect of sphacelia is often apparent before exudate is seen. The first exudate from florets, seen in the morning, was crystal clear, watery and sweet. Further liquid flow carried spores, which often sedimented in the honeydew droplets in high humidity. Notably, no prominent superficial whitening of droplets occurred, as is a strong feature in *C. africana* when macrospores produce a palisade of secondary sporulation above the exudate surface (Frederickson et al. 1989). However, many honeydew droplets did have a type of whiteness that results from light reflection from the spores suspended in the honeydew. This should not be confused with the bright whiteness of secondary sporulation of *C. africana* where light reflects from secondary spore surfaces directly in contact with air.

Microscopically, the surface of honeydew droplets of the ICRISAT isolate, 1-2 days old and drying somewhat in the mid-day sun, consisted mainly of ungerminated spores of variable size. Microspores were rare; the honeydew spores may therefore be generally regarded as 'macrospores' only because they conform generally to the macrospores described for the anamorph *Sphacelia sorghi* (McRae 1917). There was no evidence of any secondary sporulation. Rarely a few germinating spores were seen, but all bore a terminal germ tube of variable length, different from the straight laterally positioned tapering sterigma characteristic of a germinating *C. africana* macrospore producing a secondary spore. Older honeydew on inflorescences also bore no secondary spores.

In the relatively humid environment of a greenhouse copious volumes of honeydew exuded, dripping on leaves and soil. A few days later, microscopic examination of white patches on these surfaces and on adjacent other vegetation revealed extensive secondary sporulation, providing potentially airborne inoculum. This was in striking contrast to the behavior of the pathogen's macrospores on inflorescences.

Fresh honeydew of each isolate was diluted in water, spread over the surface of the sucrose/asparagine agar and incubated at 25°C. Within two days there was extensive germination that was almost exclusively in the form of secondary sporulation, long sterigmata pointing up from the agar surface and each bearing a characteristic pear-shaped spore.

Inoculations of sorghum were also made using fresh honeydew. First honeydew from florets inoculated with either isolate appeared after 7 days. These experiments were insufficiently replicated to sustain a firm conclusion about superior pathogenicity of parasitically-produced inoculum, but it would not be surprising if this was so.

Subcultures of the ICRISAT isolate made on sucrose/asparagine agar over several months remained morphologically similar, dominated by proliferation of spores. However the Gulbarga isolate allowed selection by subculture of growth forms different from the free-sporing type (typical for C. *sorghi),* for example one with a somewhat folded mycelial mat with slight pink soluble pigmentation and another with a thick white hyphal mat. Inoculum of these two forms was also applied to inflorescences. From the former, very few infections became apparent 11 days after inoculation, in spite of fairly extensive spore content of the inoculum. The latter white variant, producing no spores, did not give rise to any ergot disease. This variation deserves further study.

Discussion

The early parasitic characteristics of these two recent isolates of C. *sorghi* matched closely those last experienced in England 13 years ago, namely the relatively long period between inoculation and appearance of first honeydew symptoms, the absence of secondary sporulation on ergotized inflorescences, the cryptic young sphacelium at the first sign of honeydew, and the subsequent extrusion of an ergot body (Frederickson et al. 1991).

Preparation of the present report to meet copy deadline for ISMN 2002 precluded reporting other than biological aspects of the present study. However, it will be interesting to analyse the oligosaccharide composition of the present honeydews to see whether the contrasting qualitative differences between *C. sorghi* and *C. africana* (Bogo 2000) are confirmed. Also, analysis should confirm caffeine as the significant 'ergot-alkaloid' of this *Claviceps* species (Bogo and Mantle 2000). In any case the present biological study complements the genomic data of RAPD pattern to recognise *C. sorghi.*

Whereas some characteristics may only be of mycological interest, others may have profound practical epidemiological implication. A relevant striking feature of *C. sorghi* is its apparent failure to perform secondary sporulation on an

ergotized sorghum inflorescence, while readily doing so in the laboratory on an agar medium and on honeydew dripped on to leaves and soil. Notably, the first laboratory study of this phenomenon in *C. sorghi* (Manzarpour 1985) showed temperature-dependence expressed as exclusive secondary sporulation at 25°C, exclusive hyphal germination at 37°C and a mixture at 30°C. Microscopic examination of honeydew from a sorghum inflorescence may therefore alone enable diagnosis of the pathogen species.

For a *C. sorghi* macrospore to produce a secondary spore on a sorghum stigma would be futile, and it does not happen (Frederickson and Mantle 1988). However, to fail to do this as a means of airborne dissemination from an ergotized inflorescence is strategically inferior to the behavior exploited by *C. africana.* However, C. *sorghi* has the advantage of apparently being much better, or exclusively fitter, at generating ascospore inoculum. In any case, it has survived competition with *C. africana* in India. This can be explained by sources of secondary spore inoculum from leaf and soil surfaces. Different behavior of *C. sorghi* macrospores on ergotized inflorescences, virgin stigmas and plant and soil surfaces may relate to uptake and metabolism of contaminating honeydew saccharides by plant surfaces and soil microorganisms, and positive signalling from stigmatic hair cells.

Rediscovery of the distinctive *C. sorghi* opens interesting opportunities for thoughtful fundamental studies that could bear significantly on management of hybrid sorghum production to minimize the impact of ergot disease(s). Phytosanitary controls may also need to be applied to this pathogen.

Some people have wondered whether the brief description of *C. sorghi* by Kulkarni et al. (1976) refers also unwittingly to *C. africana* so that this species may have been in the Indian sub-continent much longer than it appears. Both 'small and hard' and 'long and soft' sclerotial bodies are mentioned, the product of two different sorghum variety hosts. However, the possible misinterpretation could only have applied to the small type, which was the only form from which the teleomorph arose and which is distinct from *C. africana.* It may be of historical interest that the Nigerian ergot sclerotia (later *C. africana)* obtained by the present author in 1967 as the basis for many further studies was from the Combine Kafir-60 A-line. The very different *C. sorghi* material (used to provide illustration of *C. sorghi* [Frederickson et al. 1991], and some still archived) from Akola, India in 1983 was from the same sorghum A-line. The teleomorph only arose from the proximal hard portion of the long ergots or from the small hard ones that remained after the long distal sphacelial region had broken off. There seems therefore no clear evidence of *C. africana* being common in India much before the 1990s.

Switch from proliferation of soft sphacelial tissue to hard compact sclerotial tissue is a vital transformation during parasitism to provide the substrate for later development of the teleomorph on fallen ergots in the field. Little is known about this process in sorghum pathogens but *C. sorghi,* with its capacity sometimes to produce long thin ergots and a delayed transition to a sclerotial type of parasitic growth, is a suitable subject for such study. Different sorghum varieties, as the parasite's nutrition provider, may have an important influence on the initiation of sclerotial growth.

Clearly this neglected ergot species deserves further study on its own, and both in comparison and in competition with the other two sorghum pathogens, C. *africana* and C. *sorghicola.* Also, for its place in biodiversity it must now be preserved.

References

Bogo A. 2000. Biochemical physiopathology of some ergot fungi and other honeydew-producing plant parasites. PhD thesis, University of London, UK.

Bogo A, and Mantle PG. 1999. *Claviceps africana* discovered in India. Plant Disease 83:79.

Bogo A, and Mantle PG. 2000. Caffeine: also a fungal metabolite. Phytochemistry 54:937-939.

Frederickson DE and Mantle PG. 1988. The path of infection of sorghum by *Claviceps sorghi.* Physiological and Molecular Plant Pathology 33:221-234.

Frederickson DE, Mantle PG and De Milliano WAJ. 1989. Secondary conidiation of *Sphacelia sorghi* on sorghum: a novel factor in the epidemiology of ergot disease. Mycological Research 94:497-502.

Frederickson DE, Mantle PG and De Milliano WAJ. 1991. *Claviceps africana* sp. nov.; the distinctive ergot pathogen of sorghum in Africa. Mycological Research 95:1101-1107.

Kulkarni BGP, Seshadri VS and Hegde RK. 1976. The perfect stage of *Sphacelia sorghi* McRae. Mysore Journal of Agricultural Science 10:286-289.

McRae W. 1917. Notes on some South Indian fungi. Madras Agriculture Yearbook 108-111.

Mantle PG. 1973. Production of ergot alkaloids *in vitro* by *Sphacelia sorghi.* Journal of General Microbiology 75:275-281.

Manzarpour A. 1985. Aspects of metabolism and physiology in *Claviceps.* Thesis. Diploma of Imperial College.

Pazoutova S, Bandyopadhyay R, Frederickson DE, Mantle PG and Frederiksen RA. 2000. Relations among sorghum ergot isolates from the Americas, Africa, India, and Australia. Plant Disease 84:437-442.

Inheritance of Resistance to *Sporisorium sorghi* in Grain Sorghum

HS Nzioki[1], LE Claflin[2], PJ Bramel[3] and BA Ramundo[2]
(1. Kenya Agricultural Research Institute, National Dryland Farming Centre. Katumani, PO Box 240, Machakos, Kenya; 2. Department of Plant Pathology, Kansas State University, Manhattan 66506-5502, Kansas. USA; 3. ICRISAT, PO Box 776, Bulawayo, Zimbabwe)

Introduction

Covered kernel smut, caused by *Sporisorium sorghi* (Ehrenberg ex Link [=*Sphacelotheca sorghi* (Link) G. P. Clinton) is an important disease of sorghum *(Sorghum bicolor* (L.) Moench). Grain losses may exceed those caused by other sorghum diseases (Casady 1961, Frowd 1980) particularly in lesser-developed countries where seed treatments are expensive, unavailable, or rarely used (Frowd 1980). Previous studies have shown that resistance to covered kernel smut exists in several sorghum genotypes and that cultivars resistant to various races of *S. sorghi* (Melchers et al. 1932) are also resistant to loose smut (*Sphacelotheca cruenta* [Kuhn] Potter) and head smut (*Sporisorium reiliana* [Kuhn] Langdon and Fullerton) (Reed 1923, Melchers et al. 1933, Casady et al. 1962, Frowd 1980). Most studies have shown that resistance to covered kernel smut is controlled by single genes (Casady 1961, Marcy 1937a,b, Reed 1928, Swanson and Parker 1931). Whether resistance or susceptibility is dominant depends on the parent used as the source of resistance (Reed 1928).

Reed (1928) concluded that susceptibility was dominant in crosses between reportedly resistant Feterita and susceptible varieties, and that resistance was dominant in crosses between resistant Standard While Milo and Blackhull Kafir. Swanson and Parker (1931) inoculated 284 F_3 lines of Red Amber x Feterita with race 1 of *S. sorghi* and reported a 3:1 segregation of smutted to healthy lines, indicating a single recessive gene as the mode of inheritance.

The reaction of various sorghum accessions to *S. sorghi, S. cruenta,* and *S. reiliana* was tested. Spur Feterita was reported (Reed 1923, Reed and Melchers 1925) to be highly resistant to covered kernel, loose and head smut diseases of sorghum. Five physiological races of *S. sorghi* were determined through the use of differential sorghum varieties (Melchers et al. 1932) and one selection from Spur Feterita (K.B. 2540) was immune to all races. Resistance to race 1 of *S. sorghi* was attributed to a single pair of genes with resistance being dominant to susceptibility. The 'blasting' reaction of sorghum to *S. sorghi* race 1 was eliminated by a single pair of genes considered to be epistatic to the gene for resistance (Casady 1963). The blasting reaction occurred only under environmental conditions highly favorable for heavy infection by race 1 of *S. sorghi.*

Casady (1961) corroborated the reports (Marcy 1937a,b) of resistance to *S. sorghi* race 1, except for finding resistance to be incompletely dominant. Resistance to *S. sorghi* races 2 and 3 was controlled by 2 separate gene pairs with incompletely dominant resistance in both cases. *Ss 1, Ss 2,* and *Ss3* were suggested as symbols to denote the genes for resistance to races 1, 2, and 3, respectively. The genes were linked. In studying the progeny of Spur Feterita x Pink Kafir, Casady et al. (1962) found that Spur Feterita carried both the gene *(Ssl)* for resistance and the gene for blasting to race 1. Blasting was expressed only in the presence of the recessive allele (*ssl*). Therefore the gene for blasting was not phenotypically expressed in Spur Feterita or K.B. 2450.

During the late 1950s and early 1960s, agronomically acceptable sorghum lines resistant to covered kernel smut were developed by Kansas State University and the United States Department of Agriculture (USDA) with a series of backcrosses using Spur Feterita as the source of resistance (Casady et al. 1962). These lines did not possess the same high level of resistance as Spur Feterita, and low levels of infection were observed under favorable environmental conditions.

Since the late 1960s, breeding work on covered kernel smut has not been reported. The All Disease and Insect Nursery (ADIN) from Texas A&M University was screened for genetic variability to *S. sorghi* for over 10 years at Kansas State University and B35-6, SC 414, and Sureno were identified as immune to *S. sorghi* under field conditions (Claflin and Ramundo 1996). The objective of this research was to investigate the inheritance of resistance to *S. sorghi* in B35-6, SC 414 and Sureno.

Materials and Methods

Seeds of true breeding lines and crosses used in this study were supplied by PJ Bramel (1CRISAT) and DT Rosenow (Texas A&M University, Lubbock). Immune accessions were B35-6 (IS 12555 derivative), SC414 (IS 2508 derivative), and Sureno ((SC423 x CS 3541) x E 35-1), recently released germplasm possessing acceptable agronomic characteristics. In all crosses, the susceptible parent was BTx623 (BTx3197 x SC 170-6). Crosses were made between resistant and susceptible accessions to determine inheritance. Crosses between resistant accessions were used to determine if they possessed the same genes. Crosses between resistant lines were SC 414 x Sureno, SC 414 x B35-6, and Sureno x B35-6. Crosses between resistant and susceptible lines were B35-6 x BTx623, SC 414 x BTx623, and Sureno x BTx623.

Greenhouse experiments. F_1 seed was sown and advanced by selfing to produce the F_2 generations. To produce the F_3 generation of crosses between resistant and susceptible parential lines, F_2 populations were grown and selfed in the greenhouse in 1995. The F_3 seed was harvested in May 1995 and stored in paper bags until sown in the field in June.

Eight seeds of each line were sown in pots (28 x 46 cm) containing a sterile soil mix consisting of Baccto potting soil (Michigan Peat Co., Houston, TX 77098)-sand-perlite (2:1:1). Plants were supplied with fertilizer (20-30-20; Schultz Company, St. Louis, MO 63043) according to Schultz Co. recommendations. To study inheritance of resistance, F_2 seed of all crosses were grown in pots in the greenhouse during the winter of 1995. The F_2 seed of the crosses between resistant and susceptible parents were divided into two equal portions and sown in different greenhouses (1 and 2). Potted plants in greenhouse 1 were placed on the cement floor and those in greenhouse 2 were placed on benches. Both greenhouses were maintained at 27°C day, 21°C night, with a 12 h photoperiod. Plants were thinned at the 3-4 leaf stage of growth and numbers of plants per pot varied from 3 to 5 depending on the pot size.

Field experiments. F_3 lines were machine sown in 3-m rows spaced 76 cm apart at the Rocky Ford Experimental Farm, Kansas State University, Manhattan, Kansas, in June, 1995. Ammonium nitrate fertilizer (34:0:0) was applied presowing at 94.2 kg ha^{-1}. Weeds were controlled by applying Ramrod/Atrazine (Propachlor, (2-chloro-N-isopropylacetanilide, 48%); Atrazine, [2-chloro-4-(ethylamino)-6-(isopropylamino-s-tirazine, 15.5%]} pre-emergence at 12.6 L ha^{-1} followed by hand weeding as needed. B35-6 x BTx623 provided 33 F_3 lines, Sureno x BTx623 provided 38 F_3 lines, and 41 F_3 lines were obtained from SC414 x BTx623.

Table 1. Number and percentage of covered kernel smutted plants in the F_1, F_2, and parental varieties.

Generation	Total plants	Smutted plants	Diseased (%)
Field sowing			
B35-6	329	0	0.0
BTx623	349	x	2.3
SC414	298	0	0.0
Sureno	455	0	0.0
Greenhouse			
B35-6	79	0	0.0
BTx623	71	54	76.1
SC414	80	0	0.0
Surefio	85	0	0.0
F_1			
B35-6 x Surefio	19	0	0.0
Surefio x BTx623	18	4	22.2
F_2			
B35-6 x Surefio	135	0	0.0
Surefio x SC414	122	32	26.2
B35-6 x SC414	47	2	4.3
SC414 x BTx623	147	31	21.1
Surefio x BTx623	165	56	33.9

Seed sterilization. Seeds were immersed in a mixture of formalin and water (1:300 v/v) for 1 h. Seeds were then washed in running tap water for 30 min, air-dried for 24 h and stored in paper envelopes (Dhingra and Sinclair 1985).

Inoculum preparation. Inoculum consisted of a mixture of *S. sorghi* teliospores from infected panicles of sorghum cultivars collected from the covered kernel smut nursery at the Rocky Ford Experiment Farm, Manhattan, Kansas. Smutted panicles were threshed by hand in plastic bags. The smut mass was sieved through 100 and 400 mesh screens to eliminate debris. Teliospores were stored at 4°C prior to use.

Seeds infested with teliospores. Dry teliospores (0.6% w/w) were added to F_3 seeds in paper envelopes. The envelopes were thoroughly shaken to ensure uniform distribution of spores on the seed coat. Infested seeds were sown under field conditions within 2 h of treatment.

Partial vacuum infestion. F_1 and F_2 seeds were mixed with teliospores (0.2% w/w), and a sufficient amount of water to wet the seed was added. The mixture was then placed under partial vacuum (180-200 mm Hg) for 1 h, and the vacuum was released at 15 min intervals. Seeds were dried at room temperature, and the procedure was repeated the following day. After the second application had dried, teliospores (0.2% by weight) were added to the F_1 and F_2 seeds in paper envelopes, shaken vigorously (Selvaraj 1980) and sown in the greenhouse within 2 h.

Disease incidence. Disease incidence (%) was determined by dividing the sum of smutted plants after all plants had reached physiological maturity by the total number of plants. Data were analyzed by Chi-square tests (Gomez and Gomez 1984).

Results

Smut reaction of parents. Resistant parents remained immune to *S. sorghi* under both field and greenhouse conditions (Table 1). The incidence (76%) of smutted panicles of BTx623 grown under greenhouse conditions was substantially higher than that in BTx623 plants grown in the field (2.3%).

The reactions of F_1 progenies of the crosses B35-6 x Sureno and Surefio x BTx623 suggest incomplete

dominance of resistance. The resistance of B35-6 is either dominant or it has the same gene(s) for resistance as Sureno (B35-6 x Sureno, Table 1). Reaction of other F_1 progenies to covered kernel smut could not be determined due to the limited number of seeds.

Smut reaction of R x R F_2 progenies. There was variability in smut reactions among crosses of resistant (R) by resistant (R) germplasm (Table 1). F_2 progenies of B35-6 x Sureno were free from smut and only 2 plants out of a total of 47 plants in the F_2 progenies of SC 414 x B 35-6 were smutted. Although unanticipated, 26% of the F_2 progenies of Sureno x SC 414 were smutted.

Smut reaction of R x S F_2 progenies. Covered kernel smut incidence varied among crosses of resistant (R) and susceptible (S) parents, depending on the greenhouse in which each cross was grown. Greenhouse 1 was located on a north exposure in the complex and temperature gradients were more severe in the winter than those in greenhouse 2, which was located on the south exposure. Both greenhouses contained the same heating and cooling equipment and were constructed in the same year, but pots in greenhouse 2 were placed on raised benches while those in greenhouse 1 were placed on the floor-which may have resulted in lower soil temperatures and lower light intensities for the plants grown in greenhouse 1. Plants in greenhouse 2 matured earlier than those in greenhouse 1, with a maturity difference of 2-4 weeks, although the time of sowing was identical in both greenhouses. Because of genotype x environmental interaction, a test for independence was performed. Contingency Chi-square values of 0.28, P = 0.70-0.50 for the cross SC414 x BTx623, and 0.022, P = 0.90-0.70 for Sureno x BTx623, indicated no significant differences in disease reaction between greenhouses. Therefore, the Chi-square test was calculated using the pooled data from both greenhouses.

Reaction of F_3 lines to smut. Conditions for smut infection were not conducive under field conditions as shown by the low incidence (2.3%) of infection in the susceptible parent (Table 1). F3 lines of the crosses exhibited a numerically higher incidence of covered kernel smut than the susceptible parent (BTx623, Table 1), with a mean covered kernel smut incidence of 6.2% in 38 F_3 lines of Sureno x BTx623, 3.8% in 41 F_3 lines of SC414 x BTx623, and 3.7% in 33 F_3 lines of B35-6 x BTx623 (data not shown).

The smutted F_3 lines were merely classed as susceptible, because it was impossible to separate segregating and homozygous susceptible lines. Therefore, a 1:3 ratio for homozygous resistant to segregating and homozygous susceptible classes was assumed, and the Chi-square values were calculated on this basis. The Chi-square and probability values indicated a close fit for the 1:3 ratio of the F_3 families of SC414 x BTx623 and Sureno x BTx623 (Table 2). These results are in good agreement with those of the greenhouse screens of F_2 families of each respective F_3 family, thus confirming the operation of a single dominant gene conferring resistance. These results are similar to those obtained by others (Casady 1961, Marcy 1937a, b, Swanson and Parker 1931).

Discussion

F_1 progenies of Sureno x BTx623 showed an incomplete dominance of resistance. Similar results were reported (Casady 1961) in F_1 plants of Combine Kafir 60 (S) x Spur Feterita (R) and Pink Kafir (S) x Spur Feterita (R). There was a very limited amount of F_1 seed from the other resistant x susceptible crosses and therefore no conclusion could be reached about the reactions of their progenies to *S. sorghi*.

A 3:1 ratio of resistant to susceptible plants was obtained in the F_2 population of SC414 x BTx623 (Table 1). The calculated Chi-square value of 1, P = 0.50-0.10 suggests the segregation of a single gene pair under the prevailing environmental conditions with the isolate of 5. *sorghi* used in this experiment. A poor fit of the 3:1 ratio of resistant to susceptible plants was obtained in the F_2 population of Sureno x BTx623 (Table 1), suggestsing incomplete dominance. Higher smut incidence in the F_1 progeny of Sureno x BTx623 was a further indication of the incomplete dominance of resistance from Sureno.

Table 2. Segregation for covered kernel smut among F_3 sorghum lines from three crosses grown under field conditions, Manhattan, KS, USA, 1995.

Cross	(N)[1]	(S)[2]	Expected ratio	X^2	P
B35-6 x BTx623	19	14	1:3	15.36	<0.001
SC414 x BTx623	12	29	1:3	0.20	0.5-0.3
Sureno x BTx623	11	27	1:3	0.14	0.7-0.5

1. N = Non-segregating.
2. S = Segregating or susceptible.

Data from the F_2 plants of B35-6 x SC414, B35-6 x Sureno, and Sureno x SC414 (Table 1) reveals that the lack of segregation in Sureno and B35-6 is attributable to 1) a number of lines that possess the same gene for resistance, 2) a number of different alleles at the same locus, or 3) that the parental lines have two tightly linked loci and are different from that in the line SC414. Therefore, in breeding sorghum for resistance to *S. sorghi,* it is immaterial whether Sureno or B35-6 is used as the resistant parent, although given data from this experiment, a breeder might choose to use B35-6, especially if producing F_1 hybrids. Because of pathogen variation, it is very useful to identify other sources of resistance such as that found in SC414. However, the two resistance genes from SC414 and B35-6/Surcno can be pyramided into one line or hybrid. It still remains to be determined whether the genes controlling resistance in B35-6 and SC414 occur in dominant or recessive form although the F_2 data in R x S crosses suggests that resistance is dominant.

Differences in covered kernel smut incidence in the susceptible parent (BTx623) in both greenhouse and field experiments were attributable to environmental differences as inoculation protocols utilized in this research are not significantly different (Nzioki et al. 2000). Disease escapes occur and the results are in agreement with long-term evaluations of the All Disease and Insect Nursery (Claflin and Ramundo 1996) where susceptible accessions seldom exhibit >50% smutted panicles.

The simple mode of inheritance to *S. sorghi* suggests that resistance can be easily transferred to susceptible sorghum cultivars with desirable agronomic characteristics. Due to the diversity of grain sorghum germplasm and possible occurrence of physiologic races of *S. sorghi* in less developed countries, additional research should be of high priority, particularly since such a program would be cost effective and productive in incorporating resistance genes in either development of new cultivars or in existing germplasm.

Acknowledgments. We thank Dr DT Rosenow from Texas A&M University (Lubbock, TX) for the All Disease and Insect Nursery sorghum seed used in this research. Mr H S Nzioki's fellowship was provided by the University of Missouri/Kenya Agricultural Research Institute/USAID project 615-0229. This research was supported by the Sorghum/Millet Collaborative Research Program (INTSORMIL) AID/DAN-1254-G-00-1022-00; and the Kansas Agricultural Experiment Station, Kansas State University, Manhattan. The Schultz Company, St. Louis, Missouri, provided fertilizer for this research.

References

Casady AJ. 1961. Inheritance of resistance to races 1,2, and 3 of *Sphacelotheca sorghi* in sorghum. Crop Science 1:63-68.

Casady AJ, Heyne EG and Hansing ED. 1962. Breeding sorghum for smut resistance. Crop Science 2:519-522.

Casady AJ. 1963. Inheritance of the blasting reaction of sorghum to physiologic race 1 of *Spacelotheca sorghi* in sorghum. Crop Science 3:535-538.

Claflin LE and Ramundo BA. 1996. Evaluation of all disease and insect sorghum germplasm for susceptibility to covered kernel smut. Phytopathology 86: S63 (Abstr).

Dhingra OD and Sinclair JB. 1985. Basic plant pathology methods. CRC Press, Inc. Boca Raton, Florida.

Frowd JA. 1980. A world review of sorghum smut. Pages 331-344 *in* Sorghum diseases, a world review: proceedings of the International Workshop on Sorghum Diseases, 11-15 Dec 1978, International Crops Research Insitute for the Semi-Arid Tropics (ICRISAT), India. Patancheru 502 324, Andhra Pradesh. India: ICRISAT.

Gomez AK and Gomez AA. 1984. Statistical Procedures for Agricultural Research. 2nd edition. Chichester, UK: John Wiley and Sons, pp 458-477.

Marcy E. 1937a. Inheritance of resistance to loose and covered kernel smuts of sorghum. (I). Dwarf yellow milo hybrids. Bulletin of the Torrey Botanical Club 64:209-228.

Marcy E. 1937b. Inheritance of resistance to loose and covered kernel smuts of sorghum. (II). Feterita hybrids. Bulletin of the Torrey Botanical Club 64:245-267.

Melchers LE, Ficke CH and Johnston CO. 1932. A study of physiologic forms of kernel smut (*Sphacelotheca sorghi*) of sorghum. Journal of Agricultural Research 44:1-11.

Melchers LE, Ficke CH and Johnston CO. 1933. Physiologic specialization of *Sphacelotheca cruenta* (Kuhn) Potter. Journal of Agricultural Research 47:339-342.

Nzioki HS, Claflin LE and Ramundo BA. 2000. Evaluation of screening protocols to determine genetic variability of grain sorghum germplasm to *Sporisorium sorghi* under field and greenhouse conditions. Journal of Pest Management 46:91-95.

Reed GM. 1923. Varietal resistance and susceptibility of sorghum to *Sphacelotheca sorghi* (Link) Clinton and *Sphacelotheca cruenta* (Kuhn) Putter. Mycologia 15:132-143.

Reed GM. 1928. The inheritance of resistance in sorghum to covered kernel smut. Reports on Research for 1927. Plant Pathology. Brooklyn Botanical Gardens Record 17:47-48.

Reed GM and Melchers LE. 1925. Sorghum smuts and varietal resistance in sorghum. USDA Departmental Bulletin 1284.

Selvaraj JC. 1980. Sorghum smuts. Pages 351-365 *in* Sorghum diseases, a world review: proceedings of the International Workshop on Sorghum Diseases, 11-15 Dec 1978, International Crops Research Insitute for the Semi-Arid Tropics (ICRISAT), India. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

Swanson AF and Parker JH. 1931. Inheritance of smut resistance and juiciness in stalk. Heredity 22:51-56.

Entomology

Efficiency of a Pheromone-baited Trap for the Sorghum Stem Borer, *Busseola fusca*

D Dakouo[1,*] and A Ratnadass[2,3] (1. INERA, Station de Farako-ba, BP 910, Bobo-Dioulasso, Burkina Faso; 2. ICRISAT-CIRAD, BP320, Bamako, Mali. 3. CIRAD-CA, Programme CALIM, TA73/09,34398 Montpellier Cedex 5, France)

*Corresponding author: ddakouo@fasonet.bf

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the main cereal crop in Burkina Faso with mean annual cultivated area and grain production of 1.3 million ha and 0.943 million tons, respectively (FAO 1999). The crop is subject to various abiotic and biotic constraints. Among the latter, insect pests are of major importance. They mainly belong to two groups: lepidopterous stem borers *[Busseola fusca* (Fuller), *Sesamia calamistis* (Hampson), *Coniesta ignefusalis* (Hampson), *Eldana saccharinal* (Walker) and *Chilo diffusilineus* (de Joannis)] and panicle-feeding insects | sorghum midge (*Stenodiplosis sorghicola* Coquillett) and head bugs (particulary *Eurystylus oldi* Poppius)] (Dakouo and Lankoande 1992). Yield losses due to stem borers range from 16 to 32% under research station conditions in the absence of protection measures (Dakouo and Lankoande 1992). Earlier studies carried out by Dakouo and Ratnadass (1997) revealed that *B. fusca* was the dominant species at Farako-ba research station, near Bobo-Dioulasso in the southwestern part of Burkina Faso. Dakouo and Ratnadass (1997) developed for *B. fusca* a monitoring method based on a pheromone-baited trap, which was found effective on research station. The trapping system was subsequently tested in farmers' fields during two consecutive wet seasons in 1998 and 1999 to monitor the distribution and importance of the pest both on research station and in farmers' fields. The present paper reports the main results obtained.

Materials and Methods

Pheromone trap materials. The trap design was chosen according to previous studies (Youm and Beevor 1995; Dakouo and Ratnadass 1997). It consisted of an aluminium tray (35.5-cm diameter) filled to a depth of 2 cm with water to which a few drops of liquid detergent had been added. The tray was supported 0.5 m above ground level. A shade consisting of a second aluminium tray (26.5-cm diameter) was suspended 5 cm above the larger tray from a horizontal wooden support; both trays were secured with wires. A polythene vial dispenser containing the synthetic pheromone blend of *B. fusca* (commercially available from AgriSense-BCS, UK) was suspended from the underside of the shade on small wire.

Experimental design and trapping method. There were seven trapping sites during the two years. Six sites were located in farmers' sorghum fields at Darsalamy, Sisalia, Samangan, Bankeledaga, Sakaby, and Tondogosso, all within a radius of 5 to 25 km from the site located on the Farako-ba research station.

Moth catches were sorted, removed, and recorded daily at the research station, and three times a week in farmer's fields (in the latter sites by the farmers who had been trained prior to the experiment). Pheromone traps operated from May to December corresponding to the wet season. Pheromone dispensers were replaced every month.

Results and Discussion

Catches were observed from the 26* to the 48* conventional weeks with two distinct peaks of moth flights in both years (Fig. 1). The first peak was observed between the 29th and the 35th conventional weeks. The second peak, which was larger, occurred during the 42nd week in 1998, and the 41st week in 1999. No moths were trapped after the 48th conventional week during either year. The number of moths caught per location ranged from 341 to 817 in 1998 and from 195 to 541 in 1999 (Table 1). The total number of moths caught all locations was 4108 in 1998 and 2389 in 1999 (Table 1).

The results confirmed the efficiency of the pheromone-baited trap in monitoring adult population of *B. fusca* both on-station and in farmers' fields. These promising

Table 1. Average and total number of male *Busseola fusca* moths caught in pheromone-baited traps as function of conventional weeks and years, Burkina Faso, 1998-99.

	Locations							Total number of moths caught per year
Year	Farako-ba	Darsamalamy	Sisalia	Samangan	Banakeledaga	Sakaby	Tondogosso	
1998	605	629	817	571	341	509	636	4108
1999	455	541	389	363	195	246	200	2389

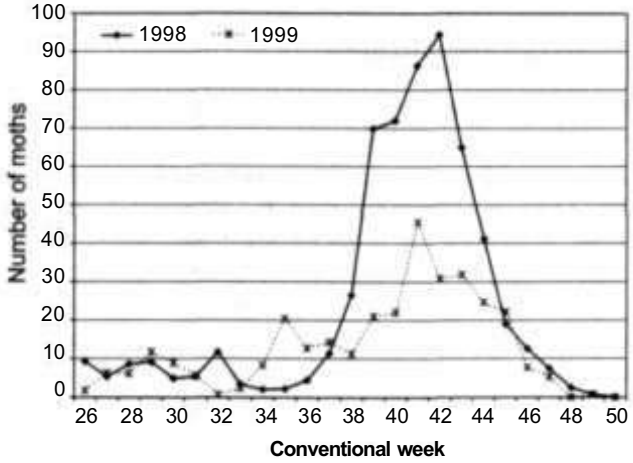


Figure 1. Males of *Busseola fusca* caught in pheromone-baited traps as a function of weeks and years, Burkina Faso, 1998 and 1999.

results could be used in the development of an IPM strategy for the control of stem borers by a better timing of insecticide application. Alternatively, there is prospect for use of *B. fusca* pheromone in mating disruption as promising results were reported by Critchley et al. (1997) from Kenya. Further investigations are needed.

Acknowledgment. This study was supported by the European Union funded project INCO-DC-18-CT96-0106. The authors thank Zongo Adama, Sanou Jean and Sanou Boureima for technical assistance in handling the trapping experiment.

References

Critchley BR, Hall DR, Farman DI, McVeight IJ, Mulaa MAOA and Kalama P. 1997. Monitoring and mating disruption of the maize stalk borer, *Busseola fusca,* in Kenya with pheromones. Crop Protection 16:541-548.

Dakouo D and Lankoande A. 1992. Les lepidopteres foreurs des tiges du sorgho: fluctuations saisonnieres, importance 6conomique et perspectives de lutte integree. Sahel PV Info 42:16-22.

Dakouo D and Ratnadass A. 1997. Bioecology of sorghum stem borers in West Africa and prospects for integrated pest management. Page 43 *in* Insects in African Economy and Environment: Proceedings of the Joint Congress of the Entomological Society of Southern Africa (11th Congress) and the African Association of Insect Scientists (12th Congress) (Roberston HG, ed.). 30 Jun-4 Jul 1997, Stellenbosch, South Africa.

Food and Agriculture Organization of the United Nations (FAO). 1999. Trimestrial Bulletin of Statistics, Vol. 121/2. Rome, Italy: FAO.

Harris KM and Nwanze KF. 1992. *Busseola fusca* (Fuller), the African maize stalk borer: a handbook of information. Information Bulletin no.33, Patancheru, India: ICRISAT, and Wallingford, UK: CAB International. 92 pp.

Youm O and Beevor PS. 1995. Field evaluation of the pheromone-baited traps for *Coniesta ignefusalis* (Lepidoptera: Pyralidae) in Niger. Journal of Economic Entomology 88:65-69.

Effects of Systemic Seed Treatment Insecticides Imidacloprid and Thiamethoxam on Sorghum Hybrids

ED Brown[1], J Trybom[2], WA Colette[1], RC Thomason[1] and BB Pendleton[1,*] (1. Division of Agriculture, West Texas A&M University, Canyon, TX 79016, USA; 2. Pioneer Hi-Bred International, Inc., Sorghum Research Station, Plainview, TX 79072, USA)
*Corresponding author: bpendleton@mail.wtamu.ed

Introduction

Greenbug [Schizaphis *graminum* (Rondani)] has been a major insect pest of sorghum [*Sorghum bicolor* (L.) Moench] since 1968 (Harvey and Hackerott 1969). Greenbugs kill seedlings and reduce yield of more mature plants (Cronholm et al. 1998). Management tactics include the use of foliar insecticides and plant resistance. However, greenbugs have developed new biotypes and resistance to insecticides. In addition, environmental and health concerns regarding certain pesticides have eliminated or restricted their use. Recent focus has been on use of systemic, seed-applied insecticides such as Cruiser (thiamethoxam, 50.0% a.i.) and Gaucho (imidacloprid, 40.7% a.i.). Objectives of this research were to assess effects of Cruiser and Gaucho on damage caused by greenbug, sorghum germination, emergence, and yield.

Materials and Methods

Experiments were conducted at Pioneer Hi-Bred International and at the Stokes commercial farm 8 km away near Plainview, Texas. Soil was Pullman clay loam. The sorghum was grown with limited irrigation. Reduced tillage, manual labor, and herbicides were used to control weeds. Seed was sown on 5 May 2000 to yield 173,000 plants per hectare at the Stokes farm. Seed was sown at Pioneer Hi-Bred International on 7 June 2000 to yield 215,000 plants per hectare. Randomized split plots with sorghum hybrids as the main blocks and seed treatments

Table 1. Comparison of seed treatments on greenbug abundance and sorghum germination, emergence, and yield, Plain view. Texas, USA, 2000.

Seed treatment[1]	Greenbug damage score[2]	Germination (%)		Emergence (% of seeds sown)	Yield (kg ha^{-1})
		Warm	Cold		
Concep III (control)	5.4 a	94.6 a	93.9 a	70.9 ab	3620 a
Cruiser	2.2 b	92.9 a	92.1 a	75.9 a	3810 a
Cruiser + Concep III	2.1 b	90.4 b	90.7 a	72.1 ab	4000 a
Gaucho	1.9 b	87.3 c	92.5 a	74.0 ab	3920 a
Gaucho + Concep III	2.0 b	88.8 bc	91.8 a	62.9 c	3860 a
Gaucho + Concep III + Magna britener	2.7 b	87.2 c	90.8 a	68.5 b	4050 a

Data presented are treatment means across all hybrids and both locations.

Means followed by the same letter in a column are not significantly different (Duncan's Studentized Range (HSD) Test at $P = 0.05$).

1. Concep III = fluxofenim, 74.3% a.i., Cruiser = thiamethoxam, 50.0% a.i., Gaucho = imidacloprid, 40.7% a.i., Magna britener = mica + titanium oxide, 21.0% a.i.
2. Greenbug damage score
   1 = No aphids in plot; 2 = Less than 50 aphids on 50% of plants; 3 = 50-100 aphids on 50% of plants, with red mosaic patterns beginning mosaic patterns caused by aphids; 4 = 100+ aphids on 50% of plants, with 20% of plants showing red mosaic patterns caused by aphids; 5 = 200+ aphids on 50% or more of plants and 50% of plants with red; 6 = Death of 1 functional leaf on 20% of plants; treatment recommended at this point; 7= Death of 1 functional leaf on 50% of plants; 8 = Death of 2 or more leaves on 20% of plants; 9 = Plant death.

as the split plots were used with 4 replications per site. Pioneer hybrids 8212Y, 85Y34, 85Y22, and 8313 were used. All seeds were treated with the fungicides Allegiance (metalaxyl, 27.0% a.i.) and Captan (captan, 37.4% a.i.), and the insecticide Redlan (chlorpyrifos-methyl, 43.2% a.i.). Insecticides Cruiser and Gaucho, herbicide antidote Concep III (fluxofenim, 74.3% a.i.), and seed lubricant Magna britener (mica + titanium oxide, 21.0% a.i.) were applied to the seeds in 6 combinations.

Vacuum plate seed counters and incubation chambers were used to assess the effect of the seed treatments on germination under cool or warm conditions. Seeds were germinated at a constant 15.6EC for 10 days or at 20EC for 8 hours and 30EC for 16 hours for 7 days. A seed was considered germinated if the seedling had a root and shoot length of >6 mm. Numbers of plants that emerged in the field were counted at the 2-3 true-leaf stage of growth. Greenbug damage to sorghum was evaluated at 40, 50, and 60 days after sowing.

Results and Discussion

Effects of seed treatments on greenbug abundance and growth of sorghum hybrids are presented in Table 1. Greenbugs were more than twice as abundant on non-treated as on treated sorghum. Greenbug abundance gradually increased during the season but remained low.

Significant differences were observed in percentages of treated seeds that germinated under warm conditions. Most seeds, 94.6%, germinated when treated only with Concep III. Significantly more seeds germinated when treated with Cruiser than with Gaucho. But germination of seeds treated with Cruiser + Concep III was not significantly different than germination of seeds treated with Gaucho + Concep III. Fewest seeds, 87.2%, germinated when treated with Magna britener. The seed treatments resulted in no significant differences in germination at cool temperatures.

The seed treatments caused significant differences in percentages of plants that emerged. Emergence was least, 62.9%, when seeds were treated with Gaucho + Concep III, significantly less than seeds treated with either treatment of Cruiser or with Gaucho only. Sorghum treated with Concep III only or Cruiser germinated well but did not emerge better than that treated with other chemicals.

There were no significant differences in yield among sorghums treated with the different chemicals. Sorghum treated with Gaucho + Concep III + Magna britener yielded most and the control treatment (Concep III only) yielded least.

References

Cronholm G, Knutson A, Parker R, Teetes G and Pendleton B. 1998. Managing insect and mite pests of Texas sorghum. Texas Agricultural Extension Service Bulletin B-1220.

Harvey TL and Hackerott HL. 1969. Recognition of a greenbug biotype injurious to sorghum. Journal of Economic Entomology 62:776-779.

Quantitative Trait Loci for Head Bug Resistance in Sorghum

M Deu[1], A Ratnadass[1,2,*], MA Hamada[2], M Diabate[2], JL Noyer[3], S Togola-Fane[2] and J Chantereau[1]
(1. CIRAD-CA, Programme CALIM, TA 73/09. 34398 Montpellier Cedex 5, France; 2. ICRISAT-CIRAD, BP 320, Bamako, Mali; 3. C1RAD-AMIS, Programme BIOTROP, TA 40/03,34398 Montpellier Cedex 5, France)
*Corresponding author: alain.ramadass@cirad.fr

Introduction

The mirid panicle-feeding bug (= head bug) *Eurystylus oldi* Poppius has recently become a key pest of sorghum *[Sorghum bicolor* (L.) Moench] in the savanna areas of the West and Central Africa (WCA) region, where this cereal is the most important food crop. Diallel analyses showed that additive gene effects could be very important in the inheritance of resistance to this pest, and suggested high heritability (Ratnadass et al. in press). A QTL mapping project aimed at completing these earlier inheritance studies was undertaken by CIRAD in Mali and France. This report presents its preliminary results.

Materials and Methods

A F_2 progeny derived from a cross between head-bug resistant sorghum cultivar Malisor 84-7 and head-bug susceptible S 34, was selected for mapping studies. The mapping population consisted of 217 plants. The F_2 phenotypic evaluation trial was sown at the Samanko research station of the ICRISAT-CIRAD Joint Sorghum Program, Mali, during the 1997 rainy season, in a plot consisting of ten 6-m rows, with an inter-row spacing of 0.75 m. In order to avoid selection, it was sown in continuous lines, and thinned two weeks after sowing, so as to have an inter-plant spacing of 0.20 m, with one plant per hill. The F_2 plot was bordered with one row of each of the parents on each side.

The head-cage technique used in earlier inheritance studies (Ratnadass et al. in press) was slightly modified so as to allow the artificial infestation of the upper part of the panicle with 10 head bug pairs, the protected bottom part serving as a control for parameters measured at grain maturity, namely thousand kernel weight (TKW) and germination rate (GER); head-bug damage was assessed visually on a 1-9 scale (where 1 = all grains fully developed with only a few head bug feeding punctures, and 9 = most grains undeveloped and barely visible outside the glumes due to head bug feeding and oviposition) (Ratnadass et al. in press) on the infested part of the panicle (NOTF2). The following criteria were used to account for head-bug damage:

- %TKW: relative difference in TKW between the protected and the infested parts of the panicle [100 x $(TKW_p - TKW_1)/ TKW_p$] calculated over the plants on which the parameter could be measured on several replications of 1000 grains, namely 136 plants out of 217.
- DGER: difference in germination rate between the protected and the infested parts of the panicle [$GER_p - GER_1$].

Seeds of the protected (and self-pollinated) bottom part of each of the 217 plants were sown in the greenhouse and the DNA was extracted from a bulk of five F_3 seedlings, representing each F_2 plant.

During the 1999 cropping season, seeds of F_4 plants derived from the remnant seeds of the protected (and self-pollinated) bottom part of 110 F_2 panicles of the 1997 trial, representing the F_3 families, were sown at Samanko in a randomized complete block design trial with two replications and one 5-m row per plot, with one row of each of the two parents every 10 rows. At grain maturity, panicles of the F_5 plants representing F_3 families were scored for head bug damage under natural infestation, using the 1-9 scale (NOTF3).

For building the sorghum genetic map, 345 RFLP probes, selected according to their localization on our reference map (Dufour et al. 1997, Boivin et al. 1999, Ventelon et al. 2001), were screened in combination with six restriction enzymes *(Bam*HI*, Dra*I*, Eco*RI*, Eco*RV*, Hind*III and *Sst*I*)* for their ability to reveal polymorphism. Probes were obtained from various sources: rice (RZ prefix), oat (CDO prefix) and barley probes (BCD prefix) from Cornell University; rice probes (R and C prefixes) from the Rice Genomic Project; maize probes (UMC prefix from the University of Missouri, BNL prefix from the Brookhaven National Laboratory, CSU from California State University); pearl millet probes (PSM prefix) from the John Innes Centre; sugarcane probes (SSIR prefix) from CIRAD and sorghum probes (SbRPG prefix) produced in collaboration with RUSTICA PROGRAIN GENETIQUE and CIRAD. Forty-nine microsatellite markers developed by Brown et al. (1996) and Taramino et al. (1997) were also screened (m prefix on the map). The computer software Mapmaker 3.0 (Lander et al. 1987) was used for map construction. A LOD threshold of 5.0 and a maximum distance of 50 centiMorgans (cM) were used to establish linkage groups. Markers were ordered by multipoint analyses. Genetic distances were

estimated with the Haldane mapping faction. Linkage groups (LGs) were named on the basis of their homology with the LGs of our reference map.

QTLs were detected using the PlabQTL software package (Utz and Melchinger 1995). The analysis was performed using composite interval mapping (C1M) with a LOD value of 2.0, and the marker the closest to the QTL was used as a co-factor. A QTL was declared significant when the LOD value was above 3.0. This threshold was determined by the permutation method implemented in the QTL Cartographer software (Basten et al. 1997) with a global type-I error of 5%. A QTL was declared putative when the LOD value was between 2.0 and 3.0.

Results and Discussion

Among the 345 RFLP probes tested, 81 could reveal polymorphism between the two parents. In addition, 14 microsatellite markers gave usable amplification products. The genetic map based on the Malisor 84-7 x S 34 cross includes 92 distributed over 13 LGs, covering a total distance of 1160 cM. Three markers remained independent. Composition and order of markers in this map are globally consistent with those of the most recent composite map (which includes 416 RFLP loci distributed over 11 linkage groups, covering a genetic distance of 1495 cM: Ventelon et al. 2001; and unpublished data). However, genome coverage remains low in some regions, particularly for LGs A, B and J (Fig. 1).

Three significant and seven putative QTLs were detected (Table 1). The significant QTLs, which explained an important part of the phenotypic variation (R^2), were placed on the genetic map (Fig. 1). Concerning reduction in TKW, one QTL that accounted for 13% of the phenotypic variation was detected in the interval between markers SbRPG943 and RZ630 on LG C2. For this QTL, resistance is conditioned by me Malisor 84-7 allele and is dominant. A QTL for TKW was also found in the same region of LG C by Rami et al. (1998).

Two QTLs were detected for visual damage score under natural head bug infestation (NOTF3). These were on LG D, in the interval between markers RZ476 and SbRPG872, and on LG E, between markers SbRPG667 and CDO580. They explained 16 and 26% of the phenotypic variation for this trait, respectively. Resistance from the QTL on LG D is conditioned by me S 34 allele, whereas resistance from the QTL on LG E is provided by the Malisor 84-7 allele; in both cases, resistance is recessive. No significant QTLs were detected for NOTF2 and DGER but co-localization of two putative QTLs for these traits was observed in the interval between markers BNL 5.37 and SbRPG749 on LG G2 and in both cases, resistance is conditioned by the S 34 allele.

These results are partly in line with the recessive nature of head bug resistance suggested by earlier results based on visual damage assessment on the one hand, and me existence of resistance genes in me susceptible parent, suggested by transgressive segregations, on the other hand. Since mere was no correlation between NOTF2 and

Table 1. Genetic characteristics of significant and putative QTLs detected for the traits measured under natural and artificial infestation of sorghum progenies with head bugs.

	Cofactors	N	LG	Markers interval	Position	LOD	R^2	a	d	Direction
F_2 (natural infestation)										
NOTF2	*BNL5.37*	*1*	*G2*	*BNL5.37-SbRPG749*	*16.5*	2.9	*6.5*	*-0.44*	*0.64*	*PB*
%TKW	RZ630, BNL5.37	1	C2	SbRPG943-RZ630	132	4.19	13.2	10.31	-7.31	PA
DGER	*BNL5.37. RZ123. UMC29*	*2*	*G2*	*BNL5.37-SbRPG749*	*18.5*	*2.15*	*4.9*	*-6.62*	*6.28*	*PB*
			I	UMC29-SbRPG931	14	2.45	5.4	7.13	6.02	PA
F, (artificial infestation)										
NOTF3	SbRPG826. RZ476, CDO580,	6	*C2*	*CDO20-C223*	*16*	2.08	*10.4*	*-0.09*	*0.19*	*PB*
	UMC 139		*C2*	*RZ630-SbRPG826*	*144*	*2.5*	*11.9*	*-0.19*	*0.15*	*PB*
			D	RZ476-SbRPG872	36	3.65	16.2	-0.09	0.30	PB
			E	SbRPG667-CDO580	5.9	5.91	26.1	0.24	0.20	PA
			E	*RZ244b-SbRPG852*	*55.9*	*2.49*	*11.5*	*-0.19*	*0.13*	*PB*
			F	mAGB03-UMC139	76	2.44	11.2	0.13	0.18	PA

Italic lines indicate that the QTL was detected at a non significant level (LOD<3)
N: number of QTLs detected for each trait
LG: linkage group
Position: cumulative distance in cM from the first marker of the LG to the position of me LOD peak
R^2: percentage of me phenotypic variation explained by the QTL
a and d: additive and dominance effects as estimated by the program
Direction: origin of the allele contributing to the resistance: Parent A (Malisor 84-7) or Parent B (S 34)

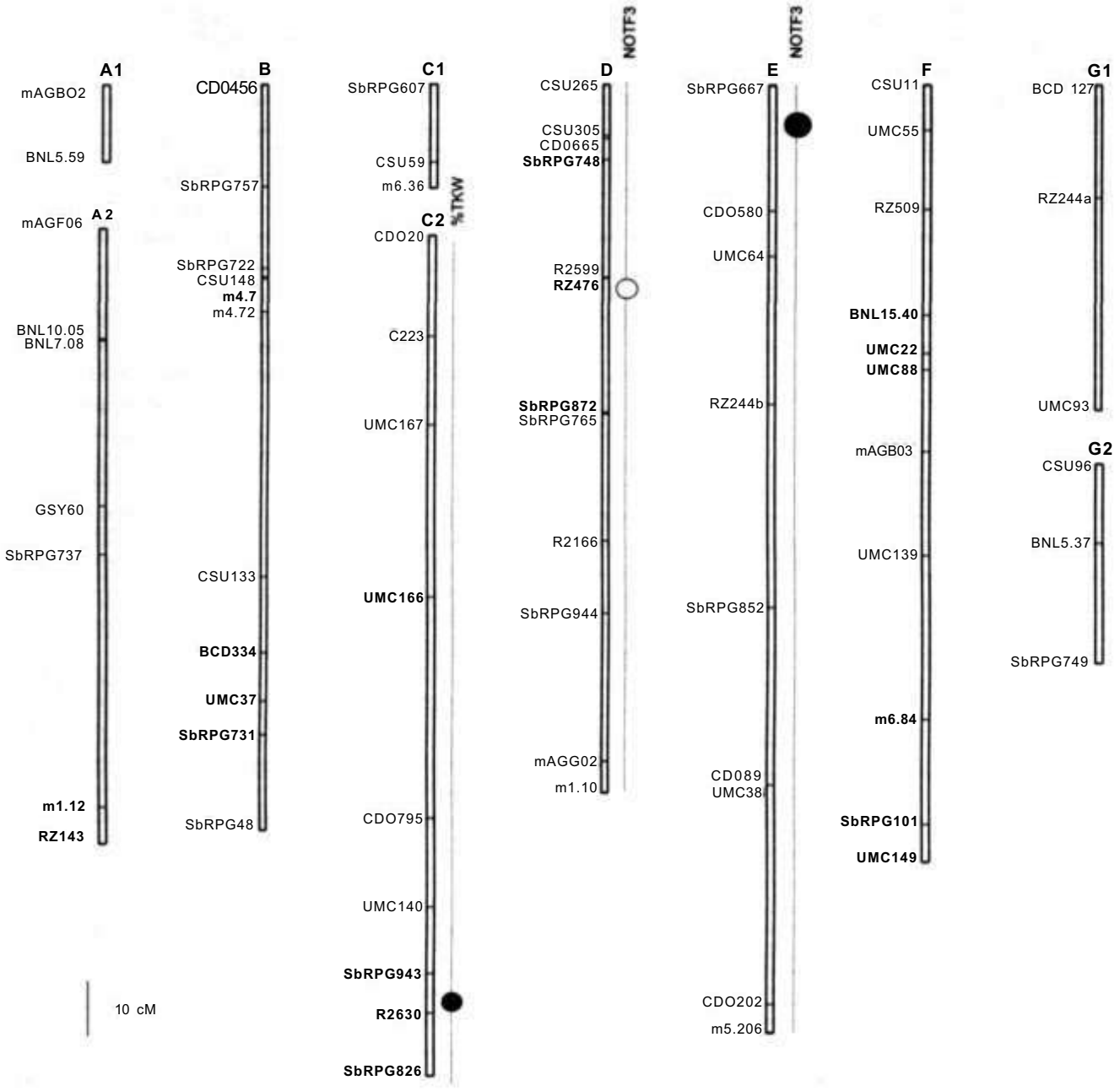


Figure 1. Genetic map and localization of significant QTLs for head-bug resistance in sorghum.
Each QTL detected at LOD score >3.0 is represented by circle located on its LOD peak (white circle resistance conditioned by the allele of the susceptible parent S 34; grey circle resistance conditioned by the allele of the resistant parent Malisor 84-7).

N0TF3, they also suggest the possible existence of different mechanisms of resistance under natural infestation on the one hand (namely under multiple-choice conditions and possibility of no coincidence between pest population peak and plant susceptible stage), and under artificial infestation on the other hand (under no-choice conditions, and no possibility of "escape", time- or space-wise).

Much remains to be done before application of marker-assisted selection for head-bug resistance can be envisaged. As a first step, a new phenotyping of families derived from this cross should be considered, with multilocational testing. However, the number of progenies that are still available for this testing (less than a hundred) might not suffice, and it could be relevant to start all over with a cross with parents more distant genetically so as to have more polymorphic markers, a more saturated map, and higher probability for QTL detection. Based on the pattern of segregation for head-bug resistance observed for some parameters in the F_2 progeny (e.g., TKW), the artificial infestation technique could be refined by reducing head-bug pressure on the infested part of the panicle. Other parameters usually highly correlated with damage score and considered as translating sorghum grain reaction to head bug attacks, could also be evaluated (e.g., percent flotation in a sodium nitrate solution).

Acknowledgments. This research was supported by a grant from the European Commission-INCO-DC Program (Contract #18-CT96-0106).

References

Hasten CJ, Weir BS and Zeng ZB. 1997. QTL cartographer: a reference manual and tutorial for QTL mapping. Raleigh, NC, USA: North Carolina State University, Department of Statistics.

Boivin K, Deu M, Rami JF, Trouche G and Hamon P. 1999. Towards a saturated sorghum map using RFLP and AFLP markers. Theoretical and Applied Genetics 98:320-328.

Brown SM, Hopkins MS, Mitchell SE, Senior ML, Wang TV, Duncan RR, Gonzalez-Candelas F and Kresovich S. 1996. Multiple methods for the identification of polymorphic simple sequence repeats (SSRs) in sorghum (*Sorghum bicolor* (L.) Moench). Theoretical and Applied Genetics 93:190-198.

Dufour P, Deu M, Grivet L, D'Hont A, Paulet F, Bouet A, Lanaud C, Glaszmann JC and Hamon P. 1997. Construction of a composite sorghum genotype map and comparison with sugarcane, a related complex polyploid. Theoretical and Applied Genetics 94:409-418.

Lander ES, Green P, Abrahamson J, Barlow A, Daly MJ, Lincoln SE and Newburg L. 1987. MAPMAKER, an interactive computer package for constructing primary genetic linkage maps of experimental and natural populations. Genomics 1:174-181.

Rami JF, Dufour P, Trouche G, Fliedel G, Mestres C, Davrieux F, Blanchard P and Hamon P. 1998. Quantitative trait loci for grain quality, productivity, morphological and agronomical triats in sorghum (*Sorghum bicolor* L. Moench). Theoretical and Applied Genetics 97:605-616.

Ratnadass A, Chantereau J, Coulibaly MF and Cilas C. (in press). Inheritance of resistance to the panicle-feeding pests *Eurystylus oldi* and the sorghum midge *Stenodiplosis sorghicola* in sorghum. Euphytica.

Taramino G, Tarchini R, Ferrario S, Lee M and Pe ME. 1997. Characterization of simple sequences repeats (SSRs) in *Sorghum bicolor.* Theoretical and Applied Genetics 95:66-72.

Utz HF and Melchinger A. 1995. PLABQTL A computer program to map QTL. Stuttgart, Germany: Institute of Plant Breeding, Seed Science, and Population Genetics, University of Hohenheim. ftp://ftpuni-hohenheimde/anonymou/pub/plabqu7

Ventelon M, Deu M, Garsmeur O, Doligez A, Ghesquiere A, Lorieux M, Rami JF, Glaszmann JC and Grivet L. 2001. A direct comparison between the genetic maps of sorghum and rice. Theoretical and Applied Genetics 102:379-386.

Utilization

False Positives for Tannin Sorghum in Non-tannin Sorghum Using the Bleach Test

J Awika, CM McDonough, LW Rooney* and RD Waniska (Graduate Assistant, Research Scientist and Professors, respectively. Cereal Quality Lab, Texas A&M University, College Station, TX 77843. USA)
*Corresponding author: lrooney@tamu.edu

Introduction

Sorghum containing condensed tannins has dominant B_1B_2 genes that produce a thick, pigmented testa layer in the kernel upon maturation (Blakely et al. 1979, Earp and Rooney 1986). This layer varies in thickness, intensity and color. The presence of this pigmented layer indicates that the kernel contains condensed tannins that reduce the feed efficiency of livestock rations. These "bird proof sorghums are readily consumed by birds and other livestock when provided in feed rations; however, more ration is required to produce the same amount of daily gain. Thus feed efficiency is reduced significantly. The decrease in feed efficiency depends on the livestock species, the method of feeding and other factors.

The best method of determining condensed tannins in sorghum is the vanillin-HCl method when the blanks are subtracted to eliminate background non-tannin materials. However, it requires significant time and is not readily applied in routine grading of sorghum. Efforts by the National Sorghum Grain Producers Association have nearly eliminated tannin sorghum production in the United States. However, a bleach test is used to look for tannin sorghums during grading (Waniska et al. 1992).

The Clorox® bleach test is used by the United States Department of Agriculture's Federal Grain Inspection Service-Grain Inspection, Packers and Stockyard Administration (USDA-FGIS-GIPSA) (USDA 1987) to test samples during grading for the presence of tannin sorghum, since the color of red and tannin sorghums are similar, especially when sorghum is weathered. This test uses Clorox bleach and KOH to remove the pericarp and turn the pigmented testa layer dark black. It is relatively simple, quick, inexpensive and usually provides an accurate indication of the relative percentage of tannin sorghum kernels during grading and assigning class. The test should always be run along with standard check samples of tannin and non-tannin sorghums to confirm that the test is working properly since the Clorox loses it strength over time.

Under certain circumstances, sorghums without a pigmented testa will turn dark or black after bleaching, which can lead to erroneous conclusions that a sorghum contains tannins. The false positives occur when sorghum is extensively weathered or molded in the field prior to harvest. The anthocyanin pigments from the glumes and pericarp migrate deep into the endosperm and can form a colored layer that can be confused with a pigmented testa. In addition, the kernel produces anthocyanins and other pigments in response to insect bites and infection by molds prior to and after maturation. These non-tannin pigments stain the outer layers so intensely that a dark color remains on the kernel after bleaching. These kernels are sometimes classed as tannin sorghums by inspectors who do not have much experience with grading of sorghum or never see the relation of grain weathering and stained kernels after bleaching.

The FGIS-GIPSA procedures clearly indicate that weathered sorghum kernels should not be counted as tannin sorghums. This is stated in their procedures as follows: "sorghum kernels injured due to mold, insect, and weather damage may exhibit dark spots similar to those depicted above and should not be confused with bleached tannin sorghum." Thus experienced grain inspectors know to look for stained sorghum kernels but relatively inexperienced inspectors may not be aware of this situation and that can cause erroneous and confusing marketing problems when off-colored, stained sorghum is called tannin sorghum.

We have observed this situation on many occasions during the past. It can cause sorghum to be improperly classed as mixed sorghum, which is unfortunate since there is no evidence to suggest that these pigments decrease feeding value. This can be clarified by using the vanillin-HCl method to quantitatively analyze for condensed tannins by removing the absorbance of the blank, which eliminates the inherent background material (Price et al. 1978).

The objective of this presentation is to document what these kernels look like before and after bleaching compared to non-tannin and tannin sorghums.

Materials and Methods

Commercial sorghum samples that had been graded as containing more than 3% tannin sorghum, thus becoming mixed sorghum, were obtained from an elevator and swine feeding operation. The samples included a red and a white pericarp sorghum. Both had purple plant color and glumes.

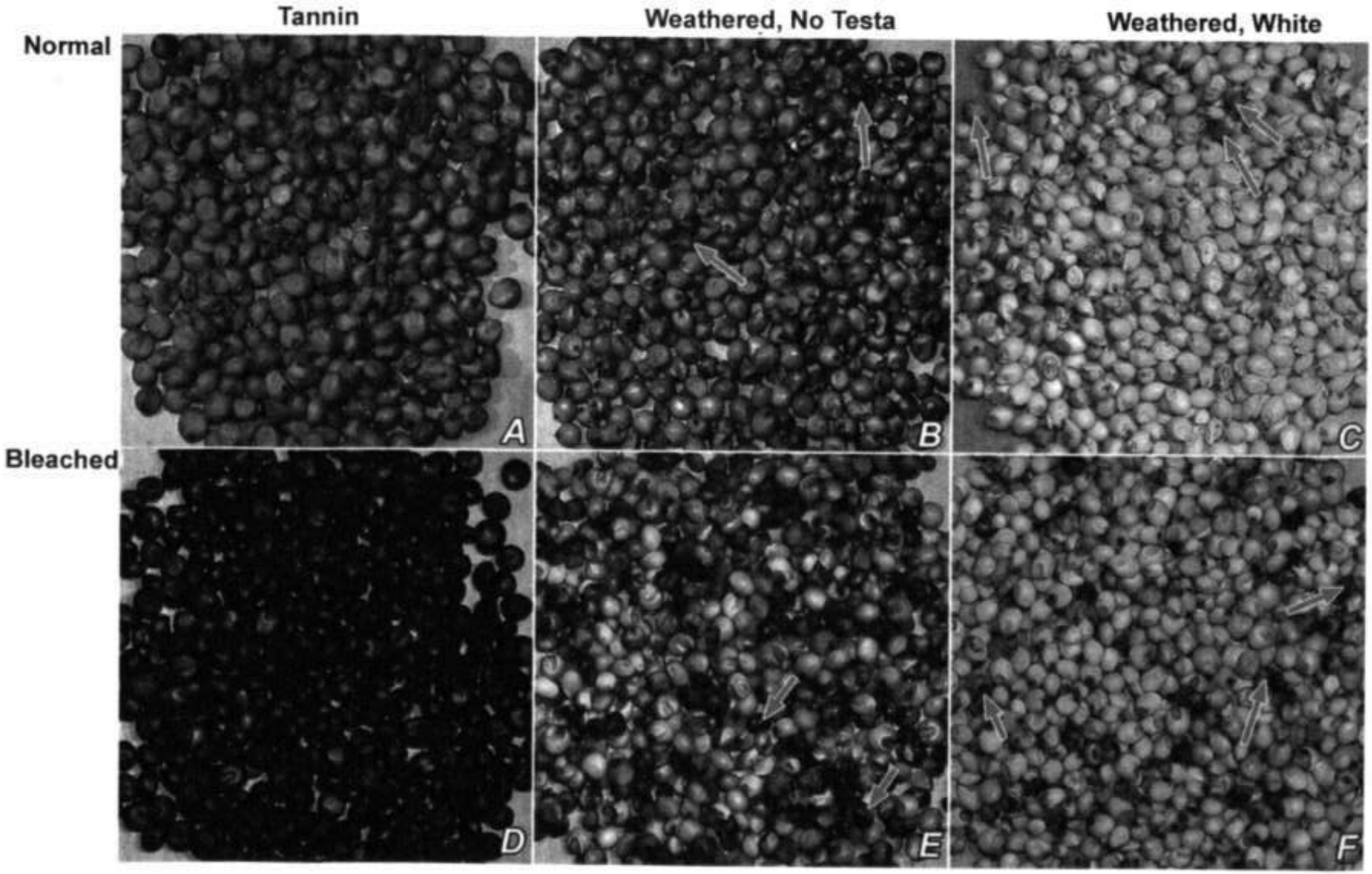


Figure 1. Photos of sorghum (A, B, C) and bleached sorghum (D, E, F). The tannin sorghum contains a pigmented testa that stains black upon bleaching with Clorox. The weathered red and white grains, both without a testa, had some kernels that appeared dark and off colored. The arrows in the figures point to stained kernels of sorghum (Fig. 1B, C) and to the bleached stained kernels (Fig. 1E, F).

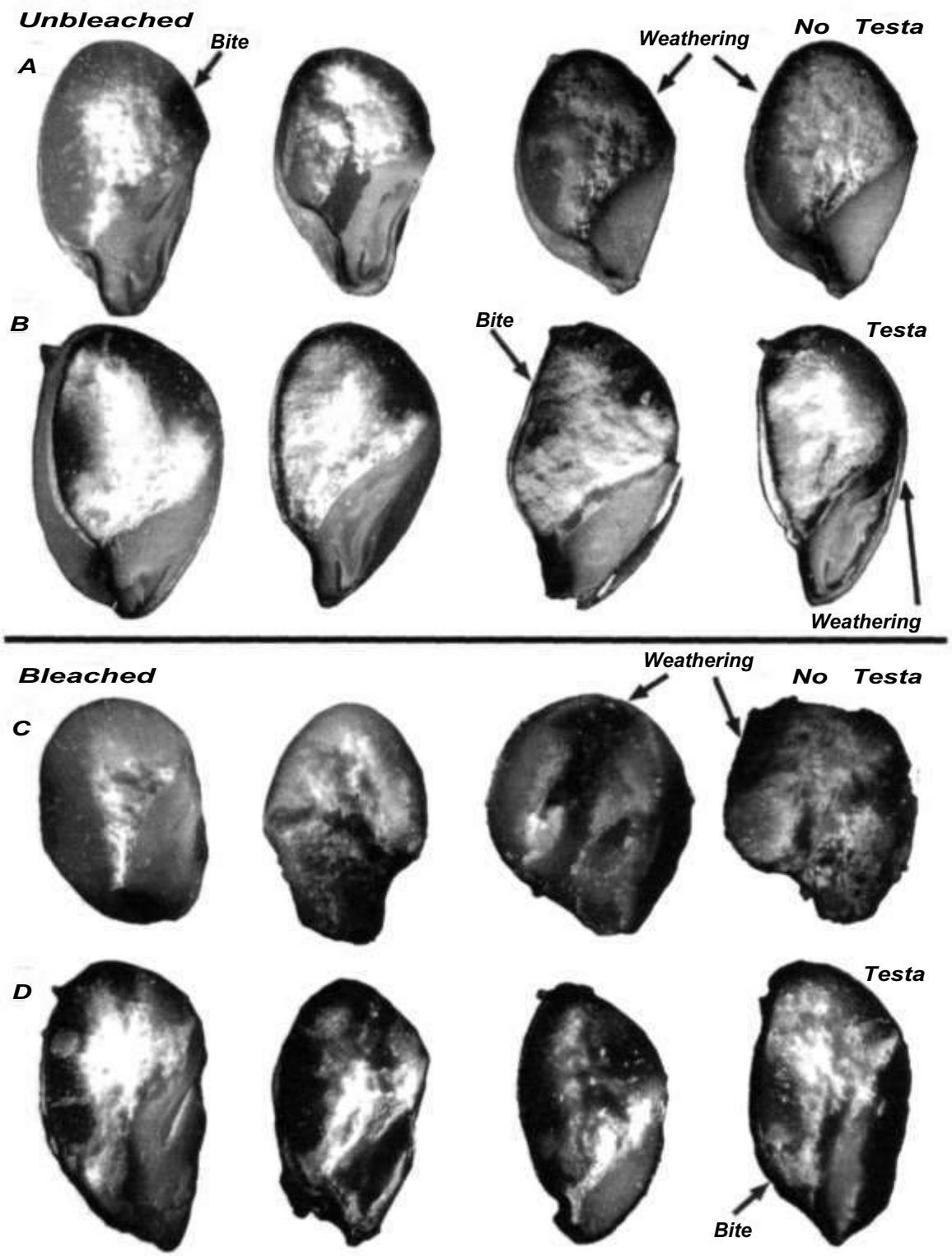


Figure 2. A, B. Unbleached half kernels of non-tannin (A) and tannin (B) sorghum showing the effect of weathering on appearance and apparent pigmented layers under the pericarp. The arrows indicate where damage has occurred. C, D. Bleached half kernels of non-tannin (C) and tannin (D) sorghums. Arrows indicate weathering and damage. The non-tannin kernels are hard to distinguish from those with tannins because of the pigments leached into the kernel that give the appearance of a pigmented testa.

Bleach test. Standard procedures according to FGIS-GIPSA were used and standard sorghum and tannin sorghums were included as checks during all bleaching procedures. All analyses were repeated at least three times with excellent precision.

Photos were taken of longitudinal kernels selected to represent the dark weathered kernels and the normal appearing kernels from each sample.

Condensed tannins were determined by the vanillin-HCl method of Price et al. (1978) with the blanks subtracted to eliminate non-tannin positives (Hahn and Rooney 1984). Catechin was used as a standard. The modified Folin-Ciocalteu method of Kaluza et al. (1980) was used to determine phenols; absorbance was measured at 600 nm, and gallic acid was used as a standard.

Microscopy. Kernels that appeared dark were selected and sectioned by hand and viewed with a Zeiss light microscope to determine if a pigmented testa was present. Half kernels of a normal and a weathered kernel that was representative of the false-positive grains were viewed with a JEOL scanning electron microscope.

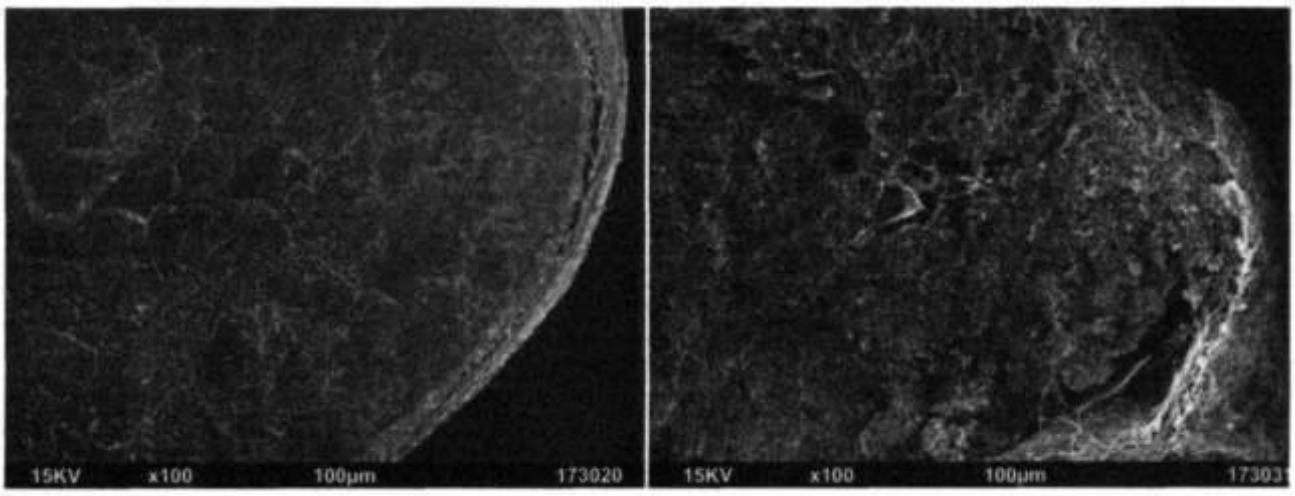
Results and Discussion

Hand sectioning of the suspected false positive samples indicated that no testa was present (not shown). Photos of standard sorghum samples and the commercial samples that produced false positives are presented (Fig. 1A-C) along with longitudinal sections of the same kernels (Fig. 2A, B). The pigments have diffused from the purple glumes, from the red pericarp and in some cases are the result of insect bites or damage (Fig. 2A, B arrows). The severely weathered, insect damaged or molded kernels in the bleached samples (Fig. 1E, F) appear dark but the

Table 1. Tannins[1] (catechin) and phenols in sorghum samples.

Sample analysis	Brown ATx623 x SC103	White weathered	White non-weathered	Red weathered	Red non-weathered
Tannins					
Blank	0.051	0.150	0.013	0.225	0.072
Abs.- Blank	0.180	-0.004	0.001	0.006	0.002
mg/100mg	2.3	-0.02	0.01	0.07	0.03
St. dev.	0.11	0.08	0.00	0.06	0.02
Phenols					
mg/100mg	1.26	0.38	0.28	0.22	0.11
St. dev.	0.05	0.01	0.03	0.02	0.02

1. (absorbance of sample - blank) at 500 nm; results are means of triplicates.



A. Normal Kernel **B. Weathered or Bitten**

Figure 3. Scanning electron microscopy photos of A) non-weathered and B) weathered sorghum kernels.

intensity of the darkness is significantly less than those with a pigmented testa (Fig. 1D). The bleached white damaged kernels are in general less dark than the damaged kernels from the red sorghum. After bleaching the sorghum samples, the interior damage to the weathered grains became more apparent in the longitudinal views and internal staining was visible on the outer surface (Fig. 2C, arrows indicate damage). Aside from the dark testa layer, the tannin sorghums underwent very little damage and the entire outer appearance was black (Fig. 2D, Fig. 1D).

When a sorghum kernel undergoes weathering or suffers an insect bite, the resulting damage to the endosperm can be seen in the SEM photos (Fig. 3A, B). The seed responds to damage by producing enzymes that degrade the starch in the endosperm (Fig. 3B), as well as releasing anthocyanins into the damaged areas. This is why the heavily weathered kernels in Fig. 2A and B usually have a more floury, less defined endosperm structure where the pigments are released.

The damaged commercial white and red sorghums have only trace levels of catechins, which indicates that they did not contain condensed tannins (Table 1). The weathered samples had significantly higher vanillin-HCl blank readings than non-weathered sorghums, indicating they had higher levels of background pigmentation. The total phenol analysis confirmed that the weathered kernels had significantly higher levels of phenols. Hence, the false positives from the bleach test (Fig. 1) were mainly due to pigments that leached deep inside the endosperm and could not be removed by the bleaching procedure. Caution is thus required when interpreting bleach test data alone. Appropriate standards should be incorporated when suspected false positives are noticed. Analysis via the vanillin-HCl method can be used to confirm that the sample does not contain tannin sorghums. The kernels can also be dissected and visually evaluated for the presence of a testa layer, which can be difficult without sufficient experience.

Fortunately the problem of false positive tannin sorghums does not occur routinely and causes only limited problems. However, when it happens, improper classification is significant. With vigilance and a working knowledge of the methods available, these situations can be minimized.

References

Blakely ME, Rooney LW, Sullins RD and Miller FR. 1979. Microscopy of the pericarp and the testa of different genotypes of sorghum. Crop Science 19:837-842.

Earp CF and Rooney LW. 1986. Fluorescence characterization of sorghum caryopsis. Food Microstructure 5:257-264.

Hahn DH, Rooney LW and Earp CF. 1984. Tannins and phenols of sorghum. Cereal Foods World 29:776-779.

Kaluza WZ, McGrath RM, Roberts TC and Schroder HH. 1980. Separation of phenolics of *Sorghum bicolor* (L.) Moench grain. Journal of Agricultural and Food Chemistry 28:1191-1196.

Price ML, Van Scoyoc S and Butler LG. 1978. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. Journal of Agricultural and Food Chemistry 26:1214-1218.

Waniska RD, Hugo LF and Rooney LW. 1992. Practical methods to determine the presence of tannins in sorghum. Journal Applied Poultry Research 1:122-128.

USDA. 1987. The official United States Standards for grain. Federal Grain Inspection Service, Inspection Division, U.S. Department of Agriculture, Washington, DC

Genetics and Breeding

Effects of Drying Time and Method on Viability of Stored Pollen of Pearl Millet

MD Sanogo[1] and WW Hanna[2] (1. Agronomy Research Station, Institut d'Economie Rurale, Cinzana, BP 264, Mali; 2. United States Department of Agriculture, Agricultural Research Service (USDA-ARS), PO Box 748, Coastal Plain Experiment Station, Tifton, GA 31793, USA)

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the 6th most important cereal crop in the world following wheat, rice, maize, barley, and sorghum (Jauhar 1981). It is grown on about 28 million ha worldwide, the largest areas being in India and the Sahel of West Africa where its nutritious grains are mainly used for human consumption. In other areas, eg, the United States, Australia, and South America, pearl millet is used for feed and fodder production. It is usually grown where it is too dry, the soil fertility is too low, and growing conditions are too harsh to grow most other grain crops. However, it responds positively to favorable fertility and moisture conditions (Hanna 1998).

For a plant breeder, it is essential to have accessions that represent the largest possible genetic diversity needed to accomplish the objectives of a breeding program. Before it was possible to store pearl millet pollen, hybrids could only be made among breeding lines with similar flowering behavior or by staggering sowings of breeding lines. Now, using stored pollen (Hanna 1990) crosses can be easily made among breeding lines regardless of flowering response and sowing date. Pollen storage is a valuable tool in plant breeding programs. Storage temperature and pollen moisture are two of the most critical factors affecting the viability of stored pollen (Stanley and Linkskens 1974). The objectives of this study were to determine the effects of drying time and technique on the viability of stored pearl millet pollen as estimated by seed set on cytoplasmic-nuclear male-sterile inflorescences.

Materials and Methods

Pollen was collected from field-grown SOSAT-C88, an improved pearl millet cultivar from West Africa, following general procedures previously described by Hanna(1990).

Pollen was dried in the following treatments (T):

T_1 = 1 h in glassine bags in a forced-air oven at 38°C.
T_2 = 2 h in glassine bags in a forced-air oven at 38°C.
T_3 = 2 h in glassine bag in a forced-air oven at 38°C followed by 1 h exposed in a thin layer on glass plates.
T_4 = Control, fresh pollen collected on the day of each application and not dried or stored.

This T_4 pollen was used on each pollination date to check for seed set differences that may be due to variation in female parent stigma receptivity.

Each treatment was replicated four times. After drying in the oven treatments T_1, T_2, and T_3 were screened through a 450-mm sieve to separate anthers from pollen. After each drying treatment pollen water content was determined from a 0.5 mL sample dried at 80°C for 18 h. The pollen was stored in small glass vials in a freezer at 5°C.

Pollen viability after storage was determined by taking pollen from each of the four replications' containers of each treatment, and pollinating four cytoplasmic-nuclear male-sterile (cms) inflorescences. The crosses were made 2, 4, and 6 weeks after storage. Pollen viability was determined by scoring percentage seed set 21 days after pollination. The mean values for each treatment are summarized in Table 1.

Results and Discussion

Pollen water contents of treatment after drying were T_1 4%, T_2 3.7%, and T_3 2%. There were no significant (P<0.05) differences in seed set from pollen stored for 2, 4, or 6 weeks. There were no differences in seed set among T_2, T_3, and T_4. However, pollen from T_1 set significantly less seed on a cms inflorescence than the other treatments. Apparently, drying pollen on a glass plate for 1 h in a convection oven after drying it glassine bags is not necessary. Drying pearl millet pollen for 2 h in glassine

Table 1. Effect of pollen drying techniques on seed set (to estimate viability of pearl millet pollen).

Pollen treatments	Seed set (%) after storage (weeks)		
	2	4	6
T_1	26	26	50
T_2	100	100	100
T_3	100	100	100
T_4	100	100	100
LSD			
Treatments (P<0.05)			20
Dates (P<0.05)			17

bags in a forced-air oven is sufficient to maintain the viability of stored pollen for at least 6 weeks. There was no treatment x date interaction.

According to studies by Hanna (1990) on the long-term conservation of pollen, two factors affect the viability of pollen: its moisture content at the time of storage, and temperature during storage. The moisture content of the pollen must be lower than 4% to maintain its viability. To obtain this moisture content, 2 h of drying at 38°C are sufficient. T_2 and T_3 contained <4% moisture at the time of storage and maintained the best viability in this experiment.

Acknowledgment. This research was conducted on INTSORMIL (Sorghum/Millet Collaborative Research Support Program) Project ARS-204 while the senior author was a visiting scientist at Tifton, Georgia, supported by the INTSORMIL.

References

Hanna WW. 1998. Pearl millet. Pages 332-343 in Hybrid Cultivar Development (Banga SS and Banga SK, eds.). New Delhi, India: Navosa Publishing House.

Hanna WW. 1990. Long-term storage of *Pennisetum glaucum* (L.) R. Br. pollen. Theoretical and Applied Genetics 79:605-608.

Jauhar PP. 1981. Cytogenetics and Breeding of Pearl Millet and Related Species. New York, USA: Alan R. Liss, Inc.

Stanley RG and Linkskens HF. 1974. Pollen: Biology. Biochemistry and Management. New York, USA: Springer-Verlag.

Genetic Diversity in Relation to Heterosis and Combining Ability in Pearl Millet

R Madhusudhana[1,*] and OP Govila[2] (1. National Research Centre for Sorghum, Rajendrangar, Hyderabad 500 030, Andhra Pradesh, India, 2. Division of Genetics. Indian Agricultural Research Institute (LARI), New Delhi 110 012, India)

*Corresponding author: madhusudhana@nrcsorghum.res.in

Heterosis is manifested as improved performance relative to its parents of the F_1 hybrid generated by crossing genetically diverse individuals. Breeders of F_1 hybrids have always been interested in choosing parents that would produce productive heterotic combinations without necessarily making all possible crosses among potential parents. Parents selected from genetically divergent groups are expected to be more heterotic. Multivariate analysis using Mahalanobis's D^2-statistic for the assessment of genetic divergence has an important bearing on selection of parents for use in conventional breeding (Bhatt 1970). The present study investigated the relationship between genetic divergence of parents and their hybrid performance among newly developed pearl millet *[Pennisetum glaucum* (L.) R. Br.] cytoplasmic male-sterile (CMS) lines and restorers.

Materials and Methods

Twenty-two parents (eleven newly developed CMS lines, three control CMS lines and eight restorers) (Table 1) and their 112 hybrids were grown in a randomized block design with three replications at the Division of Genetics, IARI, New Delhi during the 1995 rainy season. Each entry was represented in each replication by a single row of 3 m length. Observations were recorded for time to 50% flowering (d), plant height (cm), effective tillers per plant, panicle length (cm), panicle width (cm), grain set density (no./cm^{-2}), grain yield per plant (g) and 1000-grain mass (g). Trait means of the parental lines *per se* were analyzed using Mahalanobis's D^2-statistics and the parents were grouped according to the Tocher method (Rao 1952). Heterosis over mid-parent and over better parent were estimated as suggested by Hayes et al. (1955).

Results and Discussion

The 22 parents fell into seven distinct groups (Table 2) on the basis of genetic diversity for grain yield and grain yield component characters. Cluster I having eight genotypes

Table 1. Pearl millet hybrid parental lines used in this line x tester study.

Designation	Pedigree	Origin
CMS maintainer lines		
ICMB 91333	(843B x 81B)-25-1-11	ICRISAT, Patancheru
ICMB 91444	[843B x (Boudama-481 x Ankautess)-41-2+	ICRISAT, Patancheru
ICMB 92444	(843B x ICMPS-1500-7-4-1-6)-23-1-B-1-4	ICRISAT, Patancheru
ICMB 91777	[843B x (J 1623 x ¾Ex Bornu-96-I-10)-5-2	ICRISAT, Patancheru
ICMB 92777	[843B x (ICMP 500-4-4-3 x ICMPS 1800-3-1-2)-3-4-1-7-1-3	ICRISAT, Patancheru
ICMB 92888	[843B x ICMP 900-9-3-2-2)-41-2-6-2-2	ICRISAT, Patancheru
1023B	B x B mating involving 81B, 5141B, 841B and 843B	IARI, New Delhi
1049B	B x B mating involving 81B, 5141B, 841B and 843B	IARI, New Delhi
1109B	B x B mating involving 81B, 5141B, 841B and 843B	IARI, New Delhi
1139B	B x B mating involving 81B, 5141B, 841B and 843B	IARI, New Delhi
1161B	B x B mating involving 81B, 5141B, 841B and 843B	IARI, New Delhi
ICMB 841	Downy mildew resistant selection from seed lot no. 8015 of 5141B	ICRISAT and IARI
843B	Selection from KSU line BKM 2068	ICRISAT, Patancheru
5141B	An inbred of Indian origin from Baroda 4	IARI, New Delhi
Restorers		
J 104	Jamnagar selection	GAU, MRS Jamnagar
D 23	K 560-230-23	IARI, New Delhi
PPMI 301	-	IARI, New Delhi
M 46	Mutant from J 104	
PPMI 493	-	IARI, New Delhi
B 110	-	IARI, New Delhi
ICMP451	LCSN 72-1-2-1-1	ICRISAT, Patancheru
H 77/833-2	Selection from landrace of the driest region of Haryana	HAU, Hisar

was the largest followed by cluster II with six genotypes. Clusters III, IV and V had two genotypes each, and clusters VI and VII had one genotype each.

Cluster I consisted of six lines from the pearl millet improvement program at IARI, New Delhi and two lines from ICRISAT, indicating their close genetic relationship. In cluster II CMS lines 843A, ICMA 91333 and ICMA 92888 (from ICRISAT) were grouped with restorer J 104 (from Jamnagar, Gujarat) and its mutant M 46, and CMS line 1109A (both from IARI, New Delhi). Similarly ICMA 841 and MS 5141A were grouped together. It has been reported (Rai and Singh 1987; Singh et al. 1990) that the maintainer of ICMA 841 was developed from residual variability found in the maintainer of 5141A (Table 1). The pollinator line H 77/833-2, derived from a landrace selected from the driest areas of Haryana, and ICMA 91777, a male-sterile line developed at ICRISAT using improved African landrace Ex-Bornu, fell into single-genotype clusters. This indicates that they are genetically more divergent from rest of the materials studied.

The diversity observed among the parental lines (CMS lines and restorers) in performance *per se* was reflected in the performance *per se* and standard heterosis (%) of their hybrids relative to commercial control Pusa 23 (Table 3). Individual plant grain yield means of the hybrids ranged from 36.6 g (1023A x M 46; standard heterosis = -56.5%) to 143.9 g (1049A x D 23; standard heterosis = +71.4%).

Table 2. Pearl millet hybrid parents and their clusters.

Cluster	Number of lines	Hybrid parental lines
1	8	ICMA 92444, ICMA 92777, 1049A, 1023 A, 1139 A, 1161A, PPMI 301, B 110
II	6	843A, ICMA 91333, ICMA 92888, 1109A,J104, M 46
III	2	D 23, ICMP 451
IV	2	ICMA 841, 5141A
V	2	ICMA 91444, PPMI 493
VI	1	ICMA 91777
VII	1	H 77/833-2

Table 3. Variability in performance *per se* (parental lines and hybrids) and standard heterosis (hybrids only) relative to Pusa 23 (ICMA 841 ´ D 23) for a range of agronomic characters, rainy season 1995, New Delhi, India.

	Cytoplasmic male sterile lines			Restorer lines			Hybrids: absolute performance and standard heterosis		
Character	Minimum	Maximum	Genotypic variance	Minimum	Maximum	Genotypic variance	Minimum	Maximum	Genotypic variance
Time to 50% flowering (d)	47 (843A)	61* (ICMA 91777)	10.1	46 (H 77/833-2)	58* (PPMI 493)	16	41 [–21.5] (843A × H77/833-2)	60* [13.9] (ICMA 91777 × PPMI 493)	12.4
Plant height (cm)	106 (843A)	169* (1049A)	417	125 (M 46)	176* (D 23)	314	155 [–18.2] (ICMA 841 × M 46)	269* [41.4] (ICMA 91777 × PPMI 493)	254
Effective tillers per plant	1.9 (ICMA 92777)	3.2* (ICMA 92444)	0.2	1.8 (PPMI 301)	2.8* (H77/833-2)	0.1	1.6 [–50.0] (ICMA 92777 × PPMI 301)	5.0* [58.4] (1109A × ICMP 451)	0.32
Panicle length (cm)	16.6 (843A)	24.5* (ICMA 91444)	5.0	15.1 (M 46)	26.8* (PPMI 493)	14.0	19.0 [–27.0] (843A × J 104)	29.0 [12.8] (ICMA 91444 × ICMP 451)	5.06
Panicle width (cm)	1.5 (5141A)	2.6* (ICMA 91777)	0.1	1.7 (H 77/833-2)	2.5* (ICMP 451)	0.1	1.7 [–20.5] (ICMA 841 × H77/833-2)	2.9* [32.1] (ICMA 92888 × B 110)	0.05
Grain set density (grain no. cm^{-2})	18.1 (843A)	30.6* (5141A)	16.0	16.4 (D 23)	25.3* (H 77/833-2)	8.4	17.6 [17.3] (843A × ICMP 451)	42.1* [97.4] (5141A × H 77/833-2)	16.8
1000-grain mass (g)	5.8 (843A)	10.6* (ICMA 91444)	2.5	5.8 (B 110)	12.8* (D 23)	5.5	5.8 [–38.7] (5141A × H 77/833-2)	13.6* [42.8] (ICMA 92888 × ICMP 451)	2.32
Grain yield per plant (g)	27.3 (843A)	40.5* (1023A)	9.8	16.0 (B 110)	49.9* (ICMP 451)	182	36.6 [–56.5] (1023A × M 46)	144* [71.4] (1049A × D 23)	389

* Differences between minimum and maximum values are significant.
Values in square brackets indicate standard heterosis (%) over Pusa 23.

Table 4. Association of genetic diversity with heterosis in pearl millet.

	Heterosis over mid-parent	Heterosis over control (Pusa 23)	Superior crosses*
Total crosses	106	9	20
Intra-cluster	20(18%)	1 (10%)	1(5%)
Inter-cluster	86 (82%)	8 (90%)	19 (95%)

* (> 90 g per plant).

Observations for components of individual plant grain yield were similar. Of the 112 hybrids assessed, 106 showed mid-parental heterosis (Table 4). Out of these heterotic hybrids, 86 had parents from different clusters (ie, inter-cluster parentage) whereas only 20 were derived from parents from the same cluster. Of the 29 crosses showing significant and positive specific combining ability effects, 23 crosses (80%) had inter-cluster parentage.

Except for 1049A x B 110, the nine hybrids showing significant and positive standard heterosis (over Pusa 23) all involved two parents from different groups. Hybridization of genetically diverse parents belonging to clusters separated by high inter-cluster values is suggested for achieving desirable heterosis or for isolating productive recombinants (Kumar and Nadarajan 1994). In this respect, crossing between lines of clusters VI and VII, and III and VII might be productive for fixing transgressive segregants. Apart from high divergence, the performance of genotypes for characters such as yield, earliness, effective tillers, downy mildew resistance and combining ability should be given due consideration for final selection of parents. Keeping this in view, the genotypes, ICMA 91444, 1049A, 1161A, ICMA 841, ICMA 91777 among CMS lines and D 23, ICMP 451, PPMI493 and B 110 among restorers were identified as promising parents for breeding pearl millet hybrids.

These observations clearly indicate that, in general, crossing genetically diverse parents could give highly heterotic hybrids. In rice also, it has been observed that at present, the highest yielding hybrids involve crosses between the two cultivated subspecies of rice (*indica* and *japonica)* (Xiao et al. 1995). It is thus suggested that parents from diverse genetic groups should be selected for breeding hybrid cultivars in pearl millet.

References

Bhatt GM. 1970. Multivariate analysis approach to selection of parents for hybridization aiming at yield improvement in self-pollinated crops. Australian Journal of Agricultural Research 21:1-7.

Hayes HK, Immer FR and Smith DC. 1955. Methods in Plant Breeding. New York: McGraw Hill Book Co.

Kumar M and Nadarajan N. 1994. Genetic divergence studies in soybean *(Glycine max* L.). Indian Journal Genetics and Plant Breeding 54: 242-246.

Rai KN and Singh NB. 1987. Breeding pearl millet male-sterile lines. Pages 127-137 *in* Proceedings of the International Pearl Millet Workshop, 7-11 April 1986, ICRISAT Center, Patancheru, A.P., India. International Crops Research Institute for the Semi-Arid Tropics: Patancheru, A.P., India.

Rao CR. 1952. Advanced Statistical Methods in Biometrical Research. New York: John Wiley and Sons.

Singh SD, Rai KN and Andrews DJ. 1990. Registration of ICMA 841 and 1CMB 841 pearl millet parental lines with A1 cytoplasmic-genic male sterility system. Crop Science 30: 1378.

Xiao J, Li J, Yuan L and Tanksley SD. 1995. Dominance is the major genetic basis of heterosis in rice as revealed by QTL analysis using molecular markers. Genetics 140:745-754.

Genetic Analysis of Crosses among Pearl Millet Populations

Yagya Dutt* and CR Bainiwal (Department of Plant Breeding, CCS Haryana Agricultural University, Hisar 125 004, Haryana, India)
*Corresponding author

Introduction

The poor sink capacity of traditional pearl millet [*Pennisetum glaucum* (L.) R. Br.] cultivars with 15-20% harvest index is a basic problem of the species in itself, causing this crop to produce low grain yields. For development of high-yielding varieties and hybrids, sink capacity is the most important grain yield component. In pearl millet, therefore, study of different panicle characters need not be emphasized. Plant breeders are faced with the task of identifying parents that, when crossed, will express maximum heterosis.

A population cross diallel among a set of divergent populations should help to establish useful heterotic patterns. Heterosis effects and combining ability serve as a guide for choice of parents for intra- and inter-population improvement programs. Bainiwal and Yadav (1996) used the population cross diallel method to examine heterotic patterns of a set of pearl millet populations. In this experiment our objectives were

- to identify pearl millet base populations for intra- and inter-population improvement programs;
- to study the heterotic patterns among the populations and their crosses; and
- to partition heterosis into average heterosis, population heterosis and specific heterosis for various panicle traits.

Materials and Methods

Ten pearl millet populations from diverse origin [namely, HTP 88, HMP 9002, HMP 9102, ICMV 91450, HP 8601, RVPT 93(102) = CZ-IC 314, RVPT 93(115) = ICMP 93886, ICMV 95501, ICMV 95778 and ICMV 94774] were used in this study. These populations were crossed in all possible combinations, excluding reciprocals, during the 1995 rainy season. The 10 populations and their 45 population crosses were grown in a randomized block design with 6 replications during the 1996 rainy season. The experiment was conducted at CCS Haryana Agricultural University, Hisar, Haryana, India. Each population and cross was grown in plots of two rows of 4-m length. Plant-to-plant and row-to-row distances were maintained at 15 and 45 cm, respectively. All recommended cultural practices were followed before and after sowing. Observations were recorded on panicle length, panicle girth and panicle weight.

Analysis II of Gardner and Eberhart (1966) was used to estimate the genetic effects for which Singh (1978) has provided details of necessary calculations. Variety effect (v_i) is the difference between the mean performance *per se* of each parent and the mean of all parents. Heterosis effect (h) arises as a consequence of differences in gene frequencies in two populations and dominance of more favorable alleles. Further, the h_{ij} effect is partitioned into three components (h, h_i and s.). Average heterosis (h) contributed by a particular set of parents used in a set of diallel crosses is the difference between the mean of all crosses and the mean of all parents. Population heterosis (h_i) is the contribution to heterosis by population 'i' in its crosses, measured as a deviation from average heterosis. Specific heterosis (s_{ij}) effect measures the deviation between the observed performance of the specific cross and its expected performance based on v_j, h and h_j effects.

Table 1. Mean squares from the analysis of variance of a population cross diallel analysis II of Gardner and Eberhart (1966) for different panicle characters of pearl millet, based on a 10-parent diallel evaluated at Hisar, Haryana, India, during the 1996 rainy season.

Source	d.f.	Panicle length (cm)	Panicle girth (cm)	Panicle weight (kg)
Among diallel entries	54	4.7882**	0.4021**	0.0139**
Population (v_i) effect	9	17.8567**	1.6101**	0.0278**
Heterosis (h_{ij})	45	2.1745**	0.1605**	0.0111**
Average heterosis (h)	1	0.9822	0.4215**	0.0100
Population heterosis (h_i)	9	1.2352**	0.1428**	0.0067**
Specific heterosis (s_{ij})	35	2.4501**	0.1576**	0.0123**
Error	270	0.3824	0.0810	0.0033

** Significant at $P = 0.01$.

Results and Discussion

Singh and Paroda (1984) compared different methods of diallei analyis and suggested that the variety cross diallel of Gardner and Eberhart (1966) provides the maximum information on heterosis. Singh and Singh (1984) also concluuded that analysis II of Gardner and Eberhart provided information on heterosis. Thus, analysis II of Gardner and Eberhart (1966) is believed to be the best for the material studied. Both v_i and h_{ij} variances were significant for all observed traits, indicating the importance of non-additive gene effects in their expression. The sums of squares due to population heterosis (h_i) and specific heterosis (s_{ij}) were significant for all three panicle characters (Table 1). Among the partitioned components of heterosis, specific heterosis was found to play a major role in all three panicle characters.Populations ICMV 95501 and RVPT 93(102) had positive and significant population (v_i) effects (Table 2) for all three observed panicle traits except in case of RVPT 93(102) for panicle length. These populations had the highest panicle weights and were also involved in crosses giving high mean and specific heterosis effects.

Crosses HMP 9102 x RVPT 93(115) and HP 8601 x ICMV 95778 were observed as best on the basis of s_{ij} effects and performance *per se* for panicle length (Table 3). These crosses were also found best for panicle weight, and HMP 9102 x RVPT 93(115) was best for panicle girth. Considering the above results, two populations.

Table 2. Estimates of population (v_i) and population heterosis (h_i) effect from analysis II of Gardner and Eberhart (1966) for different panicle characters estimated for a diallel cross of 10 pearl millet populations evaluated at Hisar, Haryana, India, during the 1996 rainy season.

	Panicle length (cm)		Panicle girth (cm)		Panicle weight (kg)	
Population	v_i	h_i	v_i	h_i	v_i	h_i
HTP 88	-2.88*	0.86	0.22	-0.47	-0.10*	-0.34
HMP 9002	-1.43*	0.09	0.12	-0.07	-0.01	-0.40
HMP 9102	0.24	-1.03	0.18	0.08	0.03	-0.471
ICMV 91450	-0.86	-0.22	0.27	-0.19	-0.03	-0.38
HP 8601	-1.24*	0.87	0.14	0.22	-0.05*	-0.36
RVPT 93(102)	0.38	-0.14	0.82*	-0.12	0.07*	-0.35
RVPT 93(115)	-2.44*	1.15	-2.00*	0.18	-0.03	-0.50
ICMV 95501	1.74*	0.41	0.67*	0.08	0.10*	-0.43
ICMV 95778	5.43*	-0.45	-0.84*	0.33	0.01	-0.40
ICMV 94774	1.06	-0.03	0.42	-0.04	0.01	-0.46

*Greater than 2 x SE.

Table 3. Best crosses on the basis of performance *per se* and specific heterosis (s_{ij}) for different panicle characters in a diallel cross of 10 pearl millet populations evaluated at Hisar, Haryana, India, during the 1996 rainy season.

Characters	Performance *per se*	Specific heterosis
Panicle length (cm)	HP 8601 x ICMV 95778	HMP 9102 x RVPT 93(115)
	RVPT 93(102) x ICMV 95778	HTP 88 x HMP 9102
	ICMV 95501 x ICMV 95778	RVPT 93(102) x ICMV 95778
	HMP 9102 x RVPT 93(115)	HP 8601 x ICMV 95778
Panicle girth (cm)	RVPT 93(102) x ICMV 95501	HMP 9102 x RVPT 93(115)
	HMP 9002 x HP 8601	HMP 9002 x RVPT 93(102)
	ICMV 95501 x ICMV 94774	ICMV 91450 x ICMV 95501
	HMP 9102 x RVPT 93(115)	
Panicle weight (kg)	HMP 9002 x RVPT 93(102)	HMP 9002 x RVPT 93(102)
	RVPT 93(102) x ICMV 95501	HP 8601 x ICMV 95778
	HP 8601 x ICMV 95778	ICMV 91450 x ICMV 95501
	HMP 9102 x RVPT 93(115)	HMP 9102 x RVPT 93(115)

ICMV 95501 and RVPT 93(102), represent good choices with which to initiate intra-population improvement programs and three crosses, HMP 9002 x RVPT 93(102), HP 8601 x ICMV 95778 and HMP 9102 x RVPT 93(115), represent good choices with which to initiate inter-population improvement programs.

Conclusions

Heterotic patterns on three components of sink capacity for grain yield (panicle length, panicle girth, and panicle weight) were studied in a diallel cross of 10 diverse pearl millet populations. Population (v_i) effects and heterosis (h_{ij}) effects were significant for all the three traits. In the case of panicle weight, heterosis (h_{ij}) effects were more important than the population (v_i) effects. Among the heterosis (h_{ij}) components, specific heterosis (s_{ij}) showed more role than average heterosis (h) and population heterosis (h_i) for all three observed traits. Populations ICMV 95501 and RVPT 93(102) had high mean and v_i effects, and therefore can be chosen for intra-population improvement of panicle weight. Crosses HMP 9002 x RVPT 93(102), HP 8601 x ICMV 95778 and HMP 9102 x RVPT 93(115) will be better for inter-population improvement programs because these crosses have high mean and high specific heterosis effects.

References

Bainiwal CR and Yadav HP. 1996. Heterotic patterns and combining ability in pearl millet population crosses. Abstract *in* Symposium on Plant Science Research: Present Status and Future Challenges, pp. 37-38.

Gardner CO and Eberhart SA. 1966. Analysis and interpretation of variety cross diallel and related populations. Biometrics 22:439-452.

Singh D. 1978. On the variety cross diallel analysis of Gardner and Eberhart. Indian Journal of Genetics and Plant Breeding 38:115-118.

Singh O and Paroda RS. 1984. A comparison of different diallel analysis. Theoretical and Applied Genetics 65:541-545.

Singh M and Singh RK. 1984. A comparison of different methods of half diallel analysis. Theoretical and Applied Genetics 67:323-326.

Combining Ability for Seedling Heat Tolerance in Pearl Millet

RV Singh* and TR Sharma (Rajasthan Agricultural University, Agricultural Research Station, Fatehpur-Shekhawati 332 301, Rajasthan, India)

*Corresponding author

Introduction

Poor plant establishment in pearl millet [*Pennisetum glaucum* (L.) R. Br.] resulting in a reduction in grain yield has been frequently observed following high soil temperature and moisture stress conditions during seedling growth (Soman and Peacock 1985). Breeding varieties with seedling heat tolerance is the most effective way to overcome the problem of poor crop establishment under such conditions. Information about combining ability and heterotic pattern for seedling heat tolerance would be helpful in the development of a successful breeding program to evolve such varieties.

Materials and Methods

Experimental material consisted of eight inbred parental lines (HMS IB, HMS 3B, RIB 335/74, D23, 20-K86, FTR 250-2-1, FTR 285 and FTR 336) with diverse origins. Crosses were made in a diallel fashion excluding reciprocals, and the resultant 28 hybrids, 8 inbred parents (selfed), and a control (heat-tolerant hybrid HHB 67) were sown in a randomized block design with three replications during the hot, dry summer season (third week of May 1994) at the Agricultural Research Station, Fatehpur-Shekhawati, Rajasthan, India. Each plot was one row, 2.5 m long, with 30 cm between rows. On the night before sowing, 15 mm of water was applied uniformly on all plots from two parallel sprinkler lines placed 12 m apart. Rows were opened to a depth of 50 mm on the day of sowing using the sharp edge of a metal rake; 80 seeds were immediately sown by hand and the soil replaced and compacted lightly with the flat edge of the rake to ensure good seed-soil contact. The field technique described by Peacock et al. (1993) for screening pearl millet genotypes for seedling heat tolerance was then followed.

Seedling heat tolerance index was calculated as the ratio of the number of seedlings surviving on the 17^{th} day after sowing to the total number of seedlings emerged. The diallel data were arcsine transformed and analyzed following model 1 and method 2 of Griffing (1956). Heterosis was estimated as the percentage increase or decrease over the mid-parent (relative heterosis), superior parent (heterobeltiosis), and control entry HHB 67 (standard heterosis).

Table 1. GCA effects (diagonal) and SCA effects (above diagonal) for seedling heat tolerance index in pearl millet.

Parent	HMS 1B	HMS 3B	RIB 335/74	D 23	20-K86	FTR 250-2-1	FTR 285	FTR 336
HMS 1B	-3.8	0.4	-0.6	-5.9	7.8**	-5.4*	0.1	-0.9
HMS 3B		0.1	-7.4**	10.2**	13.3**	-2.0	5.4*	0.6
RIB 335/74			0.2	4.7	9.2**	6.6*	-3.8	7.8**
D 23				3.3**	0.1	-3.1	2.9	3.5
20-K86					1.5	3.6	-3.7	-13.0**
FTR 250-2-1						2.6*	-2.8	9.7**
FTR 285							-1.9	-2.1
FTR 336								-2.0*

* = significant at 5% level; ** = significant at 1% level.

Table 2. Means and heterosis (%) for seedling heat tolerance index in pearl millet

Cross	Mean	Relative heterosis	Heterobeltiosis	Standard heterosis
HMS 1B X HMS 3B	22.4	24.0	9.2	-9.2*
HMS 1B x RIB 335/74	21.6	12.5	5.4	-12.0**
HMS 1B X D 23	19.3	-17.0	-25.9	-21.5**
HMS 1B x 20-K86	31.2	53.7**	52.6**	26.9**
HMS 1B x FTR 250-2-1	19.1	-20.6	-31.0	-22.3*
HMS 1B x FTR 285	20.2	-9.1	-15.7	-17.9**
HMS 1B x FTR 336	19.0	-3.6	-7.2	-22.7**
HMS 3B x RIB 335/74	18.6	11.2	3.9	-24.4**
HMS 3B x D 23	39.2	88.3**	50.3**	59.3**
HMS 3B x 20-K86	40.:5	126.7**	100.7**	64.7**
HMS 3B x FTR 250-2-1	26.3	21.7	-4.9	7.0
HMS 3B x FTR 285	29.3	48.1*	22.2	18.9**
HMS 3B x FTR 336	24.3	40.7	28.1	-1.3
RIB 335/74 x D 23	33.9	54.2**	30.0	37.8**
RIB 335/74 x 20-K86	36.7	92.5**	81.6**	49.0**
RIB 335/74 x FTR 250-2-1	35.2	54.2**	26.9	42.9**
RIB 335/74 x FTR 285	20.3	-3.2	-15.4	-17.7**
RIB 335/74 x FTR 336	31.7	72.1**	67.4**	28.9**
D 23 x 20-K86	30.6	32.1*	17.1	24.1**
D 23 x FTR 250-2-1	28.5	5.9	2.8	15.8**
D 23 x FTR 285	30.0	19.9	15.0	21.9**
D 23 x FTR 336	30.5	35.4*	16.9	23.9**
20-K86 X FTR 250-2-1	33.4	39.5*	20.5	35.7**
20-K86 x FTR 285	21.7	-1.7	-9.4	-11.8**
20-K86 x FTR 336	12.2	-37.6*	39.5	-50.4**
FTR 250-2-1 x FTR 285	23.6	-8.6	-14.8	-4.0
FTR 250-2-1 x FTR 336	36.0	54.3**	29.9	46.3**
FTR 285 x FTR 336	19.7	-8.4	-18.0	-20.2**
CD (0.05)	8.4			

* = significant at 5% level; ** = significant at 1% level.

Results and Discussion

During the experimental period, the maximum daily sol temperature range (at 5 mm soil depth) was 45.0°C to 62.4°C and maximum daily air temperature range was 37.0°C to 45.5°C. Combining ability analysis revealed that general combining ability (GCA) variance and specific combining ability (SCA) variance were significant, indicating the importance of both additive and non-additive gene action in the inheritance of seedling heat tolerance index. However, narrow-sense heritability was low (0.25). Therefore improvement of this trait might be possible by reciprocal recurrent selection.

Among the parents evaluated, D23 and FTR 250-2-1 showed significant positive GCA effects (Table 1). Further, significant SCA effects for seedling heat tolerance index were found for crosses involving at least one poor general combiner. This indicated that SCA effects in this study might be due to dominance or epistatic gene effects for this trait. Means and heterosis (%) figures are presented in Table 1. Crosses HMS 3B x D 23 and HMS 3B x 20-K86 were found to have the highest values of seedling survival percentage. These crosses also exhibited high SCA effects (Table 1) along with high estimates of heterosis (Table 2). On the basis of this study, these crosses warrant further investigation including yield trials to test their superiority.

Acknowledgments. Thanks are due to Professor GD Singh, ADR Fatehpur, for providing facilities to conduct this experiment. Gratitude is also expressed to Dr FR Bidinger and MR Jayachandran of ICRISAT for guidance and necessary assistance.

References

Griffing B. 1956. Concept of general and specific combinjng ability in relation to diallel crossing system. Australian Journal of Biological Sciences 9:463-493.

Peacock JM, Soman F, Jayachandram R, Rani AU, Howarth CJ and Thomas A. 1993. Effects of high soil surface temperature on seedling survival in pearl millet. Experimental Agriculture 29:215-225.

Soman P and Peacock JM. 1985. A laboratory technique to screen seedling survival in pearl millet at high soil temperature. Experimental Agriculture 21:335—341.

Genetic Divergence for Anatomical Parameters Determining Blast Resistance in Finger Millet

AK Jain[1,*], SB Singh[2] and HS Yadava[3] (1. Department of Plant Pathology, JNKVV College of Agriculture, Rewa 486 001, Madhya Pradesh, India; 2. Department of Botany, Government Model Science College, Rewa, Madhya Pradesh, India; 3. Department of Plant Breeding and Genetics, RAK College of Agriculture, Sehore, Madhya Pradesh, India)
*Corresponding author

Introduction

Progeny of diverse origin are known to give high heterotic response and release a broad spectrum of genetic variability for selection of transgressive segregates in advance generations. Mahalanobis D^2 statistic has been found a powerful tool to quantify the degree of divergence. Very limited efforts (Nadof et al. 1986; Kwak et al. 1987) have been made to quantify the degree of divergence among host genotypes based on characters related to blast resistance in rice (*Oryza sativa* L.). However, the practical utility of this technique to quantify the degree of divergence in finger millet *[Eleusine coracana* (L.) Gaertn] based on anatomical characters related to blast resistance has not been tested. The present study was therefore undertaken to acertain the nature and magnitude of genetic diversity among 40 genotypes of finger millet based on anatomical traits.

Materials and Methods

During 1993/94 and 1994/95, a field experiment consisting of 40 diverse finger millet genotypes was conducted in randomized block designs with three replications at Regional Agricultural Research Station, Rewa, Madhya Pradesh (MP), in plots of 6.75 m^2 with row-to-row spacing of 22.5 cm and plant-to-plant spacing of 10.0 cm. Recommended agronomic practices were followed for optimum plant growth. Observations on anatomical parameters, namely leaf epidermal and cuticular thickness, neck epidermal thickness, and number of neck chlorenchymatous strands, were recorded by standard procedures. Leaf blast, neck blast and finger blast incidence (%) was recorded. To estimate genetic divergence among the genotypes, Mahalanobis D^2 statistic was calculated using computer software SPAR I. The genotypes were grouped into clusters by following Tocher's method.

Results and Discussion

Forty genotypes of finger millet were grouped in six and five clusters based on anatomical characters in the two years of this study (Table 1). In the pooled analysis, only four clusters were formed. GPU 28 appeared quite divergent from other genotypes in this study. Most genotypes resistant to blast, namely IE 1012, GE 3022, GE 3024, GE 3058 and GE 3060, were grouped in a separate cluster (III) along with a few other genotypes, in both years and thus exhibited real genetic diversity from the other genotypes based on anatomical characters. Otherwise the clustering patterns observed in the two years were not consistent and constituents of clusters varied year to year. This may be due to differential gene expression in the two years.

In general, clustering of the genotypes was not related to geographic diversity. The genotypes belonging to different regions of the country were grouped in the same clusters, while genotypes developed in the same center were grouped in different clusters. The frequent exchange of segregating material, genetic drift and selection in different environments could cause greater genetic diversity between genotypes developed at the same center than between genotypes developed in different regions of the country.

Several exotic genotypes, namely GE 1370, GE 3022, GE 3024, GE 3058 and GE 3060, were found resistant against blast and based on their observed anatomical traits exhibited real genetic diversity from the Indian gene pool. Hence, they likely can be used effectively for resistance breeding against blast in finger millet in India. Clusters I and III were most divergent followed by clusters I and IV; where as clusters IV and V were least divergent followed by clusters II and III (Table 2). The genotypes of cluster III exhibited least mean incidence of leaf blast (3.97%), neck blast (0.13%) and finger blast (0.55%). Thus the genotypes grouped in cluster III possess resistance against blast. These genotypes also possess comparatively higher estimates of leaf epidermal thickness, leaf cuticular thickness, neck epidermal thickness, and lower numbers of chlorenchymatous strands in the neck region (Table 3).

Table 1. Number and composition of clusters based on D^2 values computed on the basis of anatomical characters observed in 40 finger millet genotypes at Rewa, Madhya Pradesh, India during the rainy seasons of 1993/94 and 1994/95.

	1993/94		1994/95		Pooled	
Cluster	No.	Genotypes	No.	Genotypes	No.	Genotypes
I	19	VMEC 35, KM 200, KM 201. KM 202, KM 206, KM 208, VR 520,VR586,K7,L15-1, DPI 1534, PPR 2148, PPR 2679, RAU 12, TNAU 390, HR 374, PES 110, PES 400, REC 69	20	VMEC 35, KM 200, KM 201, KM 202, KM 206, KM 208, VR 520,VR 586. VL 172, VL 226, PR 202, L 15-1, DPI 1534, PPR 2148, PPR 2679, RAU 12, TNAU 390, HR 374, PES 110, PES 400	20	VMEC 35, KM 200, KM 201, KM 202, KM 206, KM 208, VR 520, VR 586. K 7, VL 172, VL 226, DPI 1534, PPR 2148, PPR 2679, RAU 12. TNAU 390, HR 374. PES 110, PES 400, REC 69
II	7	VL 146,VL 171,VL 172,MR 6, MR 7, GPU 28, GPU 32	10	GE 1370, SRS 2, VL 174, VL 228, VL 231,MR7,GPU32,I8IE, REC 13, REC 69	12	GE 1370, SRS 2, VL 146,VL 171, VL 174,VL 228, VL 231. MR 7, PR 202,18IE, REC 13, GPU 32
III	7	GE 3022, GE 3024, GE 1370, GE 3058, GE 3060, IE 1012,18IE	8	GE 3022, GE 3024, GE 3058, GE 3060, VL 146. VL 171, MR 6, IE 1012	6	GE 3022, GE 3024, GE 3058, GE 3060, MR 6. IE 1012
IV	4	SRS 2, VL 226, VL 231, PR 202	1	GPU 28	2	GPU 28, L 15-1
V	2	VL 174.VL 228	1	K7	-	-
VI	1	REC 13	-	-	-	-

Table 2. Inter- and infra-cluster distances based on anatomical characters in 40 finger millet genotypes at Rewa, Madhya Pradesh, India during the rainy seasons of 1993/94 and 1994/95.

Cluster	Year[1]	I	II	III	IV	V	VI
I	Y_1	**39.50**[2]	212.42	337.55	97.16	187.41	82.85
	Y_2	**46.16**	157.46	354.38	108.51	164.35	-
	P	**32.04**	149.18	303.15	98.22	-	-
II	Y_1		**37.41**	56.95	88.63	111.79	95.48
	Y_2		**54.78**	88.74	159.48	487.28	
	P		**42.88**	64.89	83.73	-	-
III	Y_1			**21.30**	135.63	100.46	156.12
	Y_2			**15.77**	318.15	837.20	-
	P			**10.48**	166.91	-	-
IV	Y_1				**47.89**	65.15	53.14
	Y_2				**0.00**	224.11	-
	P				**34.90**	-	-
V	Y_1					**50.90**	79.84
	Y_2					**0.00**	-
	P					-	-
VI	Y_1						0.00
	Y_2						-
	P						-

1. Y_1 = 1993/94; Y_2 = 1994/95; P - pooled across years.
2. Bold figures denote the intra-cluster distance.

Table 3. Cluster means for blast incidence and anatomical traits observed in 40 finger millet genotypes at Rewa, Madhya Pradesh, India, during the rainy seasons of 1993/94 and 1994/95.

Cluster	Year[1]	Leaf blast incidence (%)	Neck blast incidence (%)	Neck blast incidence (%)	Leaf epidermal thickness (µm)	Leaf cuticular thickness (µm)	Neck epidermal thickness (µm)	Number of chlorenchymatous strands
I	Y_1	17.16	38.97	21.54	19.41	8.31	19.07	20.00
	Y_2	22.51	38.88	23.28	19.92	8.57	19.61	19.75
	P	18.08	39.83	23.14	19.61	8 44	19.27	20.10
II	Y_1	6.13	8.34	7.06	22.84	10.37	27.98	12.00
	Y_2	10.24	14.00	6.01	21.24	9.49	24.34	14.13
	P	9.29	9.37	4.65	21.74	9.72	24.53	13.14
III	Y_1	4.13	0.00	0.38	23.67	10.72	28.23	10.57
	Y_2	5.56	1.12	0.35	23.37	10.57	27.13	10.50
	P	3.97	0.13	0.55	24.00	10.85	28.23	10.25
IV	Y_1	7.57	13.07	7.67	21.32	4.45	20.90	15.50
	Y_2	43.00	56.00	22.80	22.10	9.70	26.50	14.00
	P	33.55	21.50	14.90	20.37	8.97	25.67	13.25
V	Y_1	4.45	2.70	1.60	19.45	8.50	20.90	13.50
	Y_2	35.00	64.10	62.30	18.50	8.10	18.20	21.00
	P	-	-	-	-	-	-	-
VI	Y_1	25.90	8.90	660	18.90	8.10	22.30	13.00
	Y_2	-	-	-	-	-	-	-
	P	-	-	-	-	-	-	-

1. Y_1 = 1993/94; Y_2 = 1994/95; P = pooled across years.

These results clearly indicate that epidermal thickness of the leaves and neck contributes to blast resistance in finger millet.

It can thus be concluded that finger genotypes GE 3022, GE 3024, GE 3058, GE 3060 and IE 1012 have real genetic diversity from the Indian gene pool with resistance to blast. The resistance in these genotypes is governed, at least in part, by anatomical characters like thick epidermis and cuticle in leaf and neck region of the plant. Hence, these genotypes could be utilized in finger millet breeding programs aimed at development of high yielding lines with blast resistance.

References

Kwak TS, Kim VS and Machili DJ. 1987. Interpretation of international rice blast nursery data for consecutive two year periods by cluster analysis. Research Reports of the Rural Development Administration, Crops, Korea Republic 29:107-110.

Nadof SK, Singh IS and Singh BN. 1986. Genetic divergence and multiple disease resistance studies in rice (*Oryza sativa* L). International Rice Research Newsletter 11:16.

Germplasm

Meera (SR 16) - A Dual-purpose Variety of Foxtail Millet

SR Maloo*, DP Saini and RV Paliwal (Department of Plant Breeding and Genetics, Maharana Pratap University of Agriculture and Technology. Udaipur 313 001, Rajasthan, India)

*Corresponding author

Foxtail millet [*Setaria italica* (L.) Beauv.] is well recognized as a short duration, rainy season crop cultivated in Udaipur, Sirohi, Dungarpur, Banswara, and Chittorgarh districts and nearby areas of Rajasthan, India. It is mainly consumed by tribals/marginal farmers in various forms and marketed as bird feed. The straw is preferred by cattle. More man 95% of foxtail millet grown in this region is local landraces and their yield levels are extremely low. With the objective of developing foxtail millet varieties with higher grain and straw yield, an effective breeding program was initiated in 1990 at the Rajasthan College of Agriculture, Udaipur, Rajasthan, India.

SR 16 was developed by pure-line selection from local germplasm from Udaipur district. It has been extensively tested in the All India Coordinated Small Millet Improvement Project (AICSMIP), and also in station trials in Rajasthan during 1991-98. Yield trials conducted in Rajasthan over seven years/eight seasons at different locations have shown consistent superiority of SR 16 by more than 50% in comparison to standard national control entry SIA 326. SR 16 yielded 1.75 t ha^{-1} against SIA 326 (1.14 t ha^{-1}). Similarly, SR 16 produced 4.73 t ha^{-1} dry fodder while SIA 326 gave 3.40 t ha^{-1} dry fodder, reflecting a superiority of 40% (Table 1). However, SR 16 showed marginal superiority (6%) for grain yield to SR 11 (Gavari), the state control entry, while giving the same dry fodder yield. Besides having high grain and dry fodder yield potential, foliage of SR 16 remains almost green at physiological maturity, demonstrating "stay-green character/delayed senescence" and thereby SR 16 provides more green fodder. SR 16 yielded 19% more green fodder than the best control entry, SR 11. Performance of SR 16 at national level over three years (1993-95) in the All India Coordinated Foxtail Millet Trials (FAVT, AICSMIP) was again convincing and it produced 1.49 t ha^{-1} grain yield against national control entry SIA 326, which yielded 1.34 t ha^{-1} (ie, SR 16 provided 11% higher grain yield and more than 18% higher straw yield). It also expressed high tolerance against downy mildew. Various characters of SR 16 are presented in Table 1.

Table 1. Characters of foxtail millet variety Meera (SR 16).

Character	Meera (SR 16)	Control entries		
		Gavari(SR 11)*	SIA 326**	Arjuna
Plant height (cm)	105	125	95	100
Time to flower (d)	41	42	43	45
Time to maturity (d)	76	78	78	84
Productive tillers per plant	3.5	3.7	2.7	2.9
Main panicle length (cm)	16.5	18.0	13.0	15.0
Awn length (cm)	2.0	0.5	0.2	0.5
Grain yield of main panicle (g)	4.00	4.38	3.13	3.36
1000-grain mass (g)	3.17	3.08	2.41	3.03
Grain yield (t ha^{-1})	1.75	1.65	1.14	1.28
Dry fodder yield (t ha^{-1})	4.7	4.7	3.4	4.2
Grain protein content (%)	11.9	11.8	10.0	10.9
Grain fat content (%)	5.8	5.0	4.3	4.2
Grain moisture content (%)	8.6	8.6	8.6	8.9
Fe content (mg per 100 grains)	10.8	10.1	6.2	7.7
Water soluble seed protein (%)	6.0	4.9	4.8	
Ca content (mg per 100 grains)	304.6	280.6	248.5	224.4

* state control cultivar; ** national control cultivar.

Table 2. Biochemical composition of foxtail millet variety Meera (SR 16) for fodder quality parameters in comparison to control entries.

Fodder quality parameter	Meera (SR 16)	Control entries		
		Gavari (SR 11)*	SIA 326**	Arjuna
Dry matter (%)	70.93	65.79	66.66	66.19
Crude protein content (%)	4.68	3.20	2.83	3.56
Ether extract (%)	1.05	0.99	1.04	1.01
Crude fiber (%)	37.12	37.49	37.27	36.97
Ash (%)	6.40	4.43	5.71	6.90

* state control cultivar; ** national control cultivar.

SR 16 is a medium tall variety with erect and compact panicles. The most characteristic morphological feature is that its compact panicle is pigmented with purple violet color. Panicles bear long, stiff, violet awns (2 ± 0.5 cm), hence losses due to birds don't take place. Each plant bears 3-4 tillers. The crop matures in 75 to 80 days. The variety is tolerant of various foliar diseases and insect pests, and responds well to applications of nitrogenous fertilizer up to 60 kg ha^{-1}. The grain of SR 16 has better nutritional quality than control cultivars with respect to its contents of protein, fat and other inorganic elements (Table 1). Fodder of SR 16 is nutritionally superior to that of the controls and has the highest crude protein content (4.68%; Table 2), perhaps due to the delayed senescence of this genotype. Because of its superiority to the control cultivars, SR 16 was released and notified as Meera in 2000 by the Central Sub-Committee on Crop Standard Notification and Release of Varieties for Agriculture Crops, Government of India, Ministry of Agriculture, New Delhi.

First Forage Pearl Millet Hybrid Released in India

SK Gupta (Proagro Seed Co. Ltd., 8-1-39, Tolichowki, Hyderabad 500 008, Andhra Pradesh, India)

Release of the first forage pearl millet hybrid in India was made by a notification issued by the Government of India on December 18, 1997.

The hybrid, released as 'Proagro No. 1', was tested by the All India Coordinated Project for Research on Forage Crops as 'FMH-3' for three years, 1994 to 1996. Scientists of the Proagro Seed Company at Hyderabad, India have developed it. The release proposal was submitted to the Central Sub-committee on Crop Standards, Notification and Release of Varieties for Agriculture Crops and was considered during the 29th meeting of this committee on October 24,1997. It has been recommended for cultivation throughout the pearl millet growing areas of the country with irrigation during summer season, rainfed/irrigated during monsoon season and single cut or multi-cut as per needs. It is highly resistant to downy mildew and escapes ergot and smut as it is chopped at boot stage.

'Proagro No. 1' attains a plant height of 170-190 cm. It has non-hairy exposed nodes. All the plant parts viz., stems, nodes, leaf sheaths and blades etc. are green in color. The leaf sheath is non-hairy. The panicles are cylindrical in shape with small bristles and shriveled anthers. It is a male-sterile hybrid and does not set grain of its own. The hybrid has been developed as male sterile so that the forage remains nutritious till chopped and the regeneration is good. The hybrid is ready for first chopping after 50 days of growth and can be chopped at monthly intervals till September. It gives 6 cuttings if sown in March and three cutting if sown in June.

In the All India coordinated yield trials, Proagro No. 1 (FMH-3) has given 75.5 t ha^{-1} green forage yield and 15.7 t ha^{-1} dry matter yield under a multi-cut system when averaged over locations and years. It produced 36.4 t ha^{-1} green forage and 7.55 t ha^{-1} dry matter under a single-cut system. Our trials have shown that it has a potential to produce 130 t ha^{-1} of green forage under a multi-cut system with good management.

The official release of the forage pearl millet hybrid in India has opened a new era for exploiting the phenomenon of heterosis for biomass production in this crop. We hope many new forage hybrids would come up in future.

Agronomy and Physiology

Growth Analysis and Yield of Pearl Millet Hybrids and Varieties under Rainfed Conditions in Southwestern Haryana

B Singh, YP Yadav*, J Singh, A Kumar and SS Yadav
(CCS Haryana Agricultural University, Regional Research Station, Bawal 123 501, Haryana, India)
*Corresponding author

Introduction

Pearl millet *[Pennisetum glaucum* (L.) R. Br.] is the principal crop of rainfed areas of southwestern Haryana. The productivity of plants within a community is dependent on growth parameters; hence, understanding these parameters is of tremendous importance in order to realize maximum potential yield. Yield is a direct function of physiological parameters like leaf area index, leaf area duration and crop growth rate. Genotypes exhibiting superiority in these traits can be incorporated in crop improvement programs. Hence, mere is need to identify such genotypes that are photosynthetically more efficient. Since no such information is available with respect to newly released/identified hybrids/varieties of pearl millet, the present study was undertaken.

Materials and Methods

The experiment was conducted during the 1997 rainy season at CCS HAU, Regional Research Station, Bawal (Rewari). The experiment was laid out in a randomized design with three replications. Treatments were comprised of six released/identified hybrids (HHB 67, HHB 68. PNBH 15, PNBH 17, PNBH 18, and ICMH 356) and three open-pollinated varieties (APS 1, LCB 10, and ICTP 8203). Sowing was done in the first week of July on ridges spaced at 45 cm. Plant-to-plant spacing within rows was maintained at 15 cm by thinning 21 days after sowing. The crop was fertilized with 16 kg N and 8 kg $P_2$05 ha^{-1}. The soil was a loamy sand, low in organic carbon (0.18%), and alkaline in reaction (pH 8.2). Total rainfall received during the crop growth period was 1039 mm. Five randomly selected plants from each genotype were used for periodic recording of leaf area index (LAI) and dry matter production. Leaf area duration (LAD) and crop growth rate (CGR) were calculated per formulae suggested by Evans (1972).

Results and Discussion

LAI. Leaf area index of early-flowering hybrids HHB 67 and HHB 68 increased up to 40 days after sowing (DAS), whereas in the remaining later-flowering hybrids and varieties tested it increased up to 50 DAS. In all 10 genotypes, LAI then declined sharply as the crop approached maturity. In general, hybrids produced higher LAI than varieties at all stages except 50 DAS. At this stage varieties LCB 10, APS 1 and hybrid PNBH 17 recorded higher LAI values than other genotypes. Hybrids PNBH 15 and PNBH 17 maintained higher values of LAI during the entire growing season. Genotypic differences in LAI have been also reported by Maiti and Bidinger (1981) and Huda et al. (1984).

LAD. Leaf area duration increased up to 50 DAS in hybrids HHB 67 and HHB 68. In other hybrids and varieties tested it continued to increase appreciably up to maturity. Up to 40 DAS, LAD was higher in hybrids than varieties. However, by maturity open-pollinated varieties LCB 10 and APS 1 produced markedly higher LAD values than any other genotypes tested. Among hybrids, higher LAD values were produced throughout the growing season by PNBH 15 and PNBH 17.

Table 1. Grain and straw yield of pearl millet hybrids and open-pollinated varieties, Bawal, Haryana, India, 1997 rainy season.

Genotypes	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Hybrids		
HHB 67	1.9	7.4
HHB 68	2.3	7.5
PNBH 15	2.8	8.3
PNBH 17	2.6	7.7
PNBH 18	2.5	7.3
ICMH 356	2.2	7.5
Open-pollinated varieties		
APS 1	1.7	8.3
LCB 10	1.2	10.2
ICTP 8203	1.6	7.7
SEm	±0.8	±3.3
CD (*P*= 0.05)	2.3	9.7

CGR. At the start of the growing season crop growth rate was low for all genotypes, reaching values of 2 to 3 g m^{-2} d^{-1} by 20 DAS. CGR then increased considerably up to 40 DAS, reaching values of 33 to 43 g m^{-2} d^{-1}, and declined thereafter till maturity. This decline can be attributed to a sharp decrease in dry matter accumulation during the reproductive phase of crop growth (Coaldrake and Pearson 1985). Among genotypes tested, hybrids PNBH 15 and HHB 67 maintained higher CGR values up to 40 DAS but from 50 DAS to maturity open-pollinated variety LCB 10 recorded the highest CGR values.

Yield. In general, all tested hybrids produced significantly higher grain yields than the tested open-pollinated varieties (Table 1). Among hybrids tested, PNBH 15 produced significantly higher grain yield. This might be a consequence of this hybrid having better LAI, LAD, and CGR values than other hybrids. However, in the case of open-pollinated variety LCB 10, higher values of LAI at 50 DAS, and LAD and CGR from 50 DAS to harvest contributed towards straw yield rather than grain yield. This may be due to genotypic differences in source-sink relationships as it is evident that variety LCB 10 produced significantly higher than straw yields than any other genotype tested.

Correlations of LAD and yield. The correlations of LAD with grain, straw and total dry matter yields for both the hybrids and varieties were determined for me periods 41-50 DAS and 51 DAS to harvest. In the case of the hybrids tested, grain yield was significantly and positively correlated (r = 0.874) with LAD from 51 DAS to harvest whereas at the earlier stage this correlation was non-significant (r = 0.526). In contrast, among the open-pollinated varieties tested, grain yield was negatively correlated with LAD at both crop growth stages; however, this relationship was significant only at 41-50 DAS (r = 0.989). Correlation of LAD with straw yield was positive but non-significant at both crop growth stages in the case of both hybrids (r = 0.562 and 0.453) as well as open-pollinated varieties (r = 0.844 and 0.919). Total dry matter yield was significantly and positively correlated with LAD only at the pre-harvest growth stage (r = 0.955) and only in the case of open-pollinated varieties, but was not significantly correlated at either growth stage for hybrids (r = 0.706).

References

Coaldrake PD and Pearson CJ. 1985. Development and dry weight accumulation of pearl millet as affected by nitrogen supply. Field Crops Research 11:171-184.

Evans GC. 1972. Quantitative analysis of growth. Oxford, UK: Blackwell Scientific Publications.

Huda AKS, Siva Kumar MVK, Algarswamy G, Virmani SM and Vanderlip RL. 1984. Problems and prospects in modeling pearl millet growth and development. Pages 15-20 *in* Proceedings of International Symposium on Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics, 15-20 Nov 1982, Patancheru, India. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Maiti RK and Bidinger FR. 1981. Growth and development of the pearl millet plant. Research Bulletin no. 6. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Pathology

Reaction of Pearl Millet Varieties during Rust Epidemics in Haryana, India

MS Panwar[1] and JP Wilson[2] (1. Department of Plant Pathology, Chaudhary Charan Singh (CCS), Haryana Agricultural University, Hisar 125 004. Haryana, India; 2. United States Department of Agriculture-Agricultural Research Service, Crop Genetics and Breeding Research Unit, University of Georgia, Coastal Plain Experiment Station, Tifton, GA 31793-0748, USA)

Introduction

Rust (caused by *Puccinia substriata* Ellis & Barth. var. *indica* Ramachar & Cummins = *P. penniseti* Zimm.) appears late in the season in Haryana, India, so pearl millet (*Pennisetum glaucum* (L.) R. Br.) grain yield is not affected. Fodder production, however, is very important throughout the region, and the fodder quality of late-sown crops can be affected by rust. Although rust resistance is not a primary concern in the selection of varieties, knowledge of varietal reactions and conditions that promote rust infection can be important in producing high-quality fodder. The objectives of this experiment were to evaluate pearl millet inbreds, hybrids, and populations during late-season rust epidemics, and to assess environmental effects on the appearance and incidence of rust.

Materials and Methods

Twenty-eight pearl millet genotypes were evaluated at the Chaudhary Charan Singh (CCS) Haryana Agricultural University, Hisar, India in 1997 and 1988. Genotypes were sown on 27 Jul 1997 and 3 Aug 1998 in 5-m long, two-row plots (30 cm between rows) with 75-cm spacing between plots, arranged in a randomized complete-block design. Twenty days after sowing (DAS) plants were thinned to 10 cm within-row spacing. Fertilizers were applied at the rate of 50 kg N and 25 kg P ha^{-1}. Nitrogen was split-applied: half at sowing and the balance 30 DAS. Phosphorus was applied at sowing. Seeds were dressed with Apron S.D. 35® (6 g kg^{-1} of seed) to reduce early-season downy mildew infection caused by *Sclerospora graminicola* (Sacc.) J. Schrot.

Table 1. Reactions of pearl millet genotypes evaluated during rust epidemics at Hisar, India, 1997 and 1998.

Genotype	AUDPC[1]	Final rust severity (%)	Pedigree
HP 8601	1021 a[2]	95.0 a[2]	OPV from CCS HAU
RHB 58	983 ab	93.3 abc	$81A_1$x20-K-86
HB 3	966 ab	89.1 abc	Tift23A_1 x J 104
Pusa 266	960 ab	87.5 abc	OPV from IARI
861A	955 abc	87.5 abc	861A_1
HHB 50	954 abc	87.0 abc	81A_1 x H 90/4-5
HHB 67	937 abc	87.0 abc	843A_1 x H 77/833-2
ICMH 356	914 abc	89.2 abc	ICM$A_1$88004 x ICMR 356
861B	902 abc	89.2 abc	861B
ICMV 155	899 abc	93.3 abc	OPV from ICRISAT
HC 4	893 abc	85.0 abc	OPV from CCS HAU
Pusa 23	879 abcd	89.2 abc	841A_1x K 560-230-23
ICMV 221	858 abcd	85.0 abc	OPV from ICRISAT
HMS 1A	850 abcd	89.2 abc	H 90/4-5 in DSA 134A cytoplasm
Pusa 322	820 bcd	80.8 bc	841A_1 x PPMI 301
HMS 1B	815 bcd	79.2 c	H 90/4-5
GHB 15	768 cd	90.3 abc	5054A_1 x J 108
AHB 251	693 d	79.2 c	81A_1 x AIB 16
ICMH 451	480 e	56.7 d	81A_1 x ICMP 451
GHB 235	462 e	55.0 de	81A_1 x J 2296
X7	446 e	50.0 de	Pb 111A_1 x PT 1890
Eknath 301	303 ef	42.5 ef	Proprietary hybrid
X6	221 fg	34.2 f	PT 732A_β x PT 3095
ICMA 88001	94 gh	10.8 g	81A_v
ICMB 88001	90 gh	11.7 g	81B
HHB 117	0 h	0.0 g	HMS 7A_1 x H 77/29-2-2
LSD (P<0.05)	187	13.3	

1. AUPDC: Area under disease progress curve.
2. Means in a column that are followed by the same letter are not significantly different according to Fisher's LSD (P<0.05).

Rust severity of each plot (% leaf area infected) was assessed using a modified Cobb Scale at weekly intervals. The area under the disease progress curve (AUDPC) was calculated as AUDPC= $\sum[Y_{(j+n)} + Y_i]/2 \times [X_{(i+n)} - X_i]$, where Y. = rust severity (%) at time X_i, at n = 7 days intervals. Sums of squares in analyses of variance for AUDPC and final rust severity (%) were partitioned into: year, replication within year, genotype, and year x genotype effects. Means were compared by Fisher's LSD.

Weather data summarized by week for: total rainfall (mm), days with rain, weekly mean temperatures (minimum and maximum, °C), and weekly mean relative humidity (RH, minimum and maximum, %) were collected at the meteorological laboratory of the University. Rust severities for the pearl millet genotypes were plotted against environmental variables from the preceding week to determine the environmental effects on rust development.

Results and Discussion

In both 1997 and 1998, rust was not observed in the experimental plots until the average weekly temperatures fell below 27°C. An increase in rust infection was associated with a decrease in maximum and minimum temperatures. Average weekly minimum temperatures at the termination of epidemics (death of susceptible varieties) were 19.2°C in 1997 and 16.7°C in 1998. These are within the optimum temperature range for urediniospore germination of *P. substriata* var. *indica* (Tapsoba and Wilson 1997). Mean RH reached a low of 62.5% at the termination of the epidemic in 1998; lower than the RH recorded on several dates when no rust infection was observed by Muthusamy et al. (1981). Additional data are required to clarify the effects on environmental conditions on the progress of epidemics.

Among sources of variation considered, year was not significant for AUDPC or final rust severity, but genotype was highly significant (P<0.01). Mean separations by Fisher's LSD divided the genotypes into two distinct groups (Table 1). Most genotypes were susceptible to rust, but ICMH 451, GHB 235, Eknath 301, X6, ICMA 88001, and ICMB 88001 showed moderate levels of resistance. Hybrid HHB 117 was free from rust. HHB 117 is a new hybrid yet to be released by the CCS Haryana Agricultural University. Its resistance to both downy mildew (MS Panwar unpublished data) and rust will prove valuable in both grain and fodder production.

References

Muthusamy S, Padmanaban D, Nagarajan R and Ragupathy N. 1981. Incidence of pearl millet rust in relation to sowing time and relative humidity. Madras Agricultural Journal 68:526-529.

Tapsoba H and Wilson JP. 1997. Effects of temperature and light on germination of uredinospores of pearl millet rust pathogen, *Puccinia substrata* var. *indica.* Plant Disease 81:1049-1052.

Screening Pearl Millet against Eritrean Isolates of Downy Mildew

Negusse Abraha[1,*], Wendy A Breese[2], AG Bhasker Raj[3] and S Preston[4] (1. Department of Agricultural Research and Human Resource Development Paradizo. PO Box 4627, Ministry of Agriculture. Asmara, Eritrea; 2. Centre for Arid Zone Studies, Thoday Building, University of Wales Bangor, LL57 2UW, Gwynedd, UK; 3. ICRISAT, Patancheru 502 324, Andhra Pradesh, India; 4. Agriculture Sector Support Programme, Royal Danish Embassy, PO Box 6300, Asmara, Eritrea)

*Corresponding author: negussebraha@hotmail.com

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the second most important cereal (after sorghum, [*Sorghum bicolor* (L.) Moench]) in Eritrea, and was grown on 83,000 ha in 2000 (Saini 2001). In 2000, >50% of plants in most pearl millet surveyed in Anseba and Gash Barka were found to be infected with downy mildew, caused by the pseudo-fungus *Sclerospora graminicola* (Sacc.) J. Schrot. (Bhasker Raj et al. 2000). This disease causes major yield reductions, estimated at 30% in Anseba in 2000. Its resting spores survive in the soil and can reinfect subsequent crops for up to 15 years once a field is infested. Because pearl millet is the staple food and fodder crop in Anseba, extension workers there have described the prevalence of downy mildew as 'a catastrophe' (Samson Zeray, pers. comm.).

A further complication is that this pathogen is highly variable. Several strains probably exist in Eritrea, each adapted to different pearl millet landraces. The experience in other countries is that new, virulent races often develop following the introduction of new varieties. It is therefore important to monitor the development of new races over the years.

The main research strategy to help farmers deal with this devastating disease is to develop resistant varieties, coupled with regular monitoring to follow the development of virulent strains. A secondary strategy is to use fungicidal seed treatment of moderately susceptible pearl millet varieties. Good progress is being made in breeding pearl millet for resistance to downy mildew in Eritrea. This is done by screening for resistance to downy mildew in naturally-infested 'sick plots' (i.e., using field observations) and by crossing selected landraces with selected exotic varieties having reasonable levels of host-plant resistance. However, the shortage of cereal pathologists and infrastructure for controlled screening puts limits on what can be done within the country.

Following the downy mildew survey in 2000, a unique scientific collaboration between Eritrea, ICRISAT, and the Centre for Arid Zone Studies (CAZS) at Bangor, Wales, UK, has produced valuable data on the resistance of 70 pearl millet genotypes to an Eritrean isolate of the pathogen. The screening was done in a tropical greenhouse at the CAZS but provided extremely valuable information for the Eritrean pearl millet breeding program. The pearl millet genotypes tested included Eritrean landraces and promising new varieties from ICRISAT populations for the Eritrean breeding program.

Materials and Methods

Samples of Eritrean isolates of *S. graminicola* were sent to CAZS with the initial objective of using these in resistance and mapping studies. The universally susceptible host cultivar 7042(S) was mixed with ground oospore material (sample F23, from Sosana in Barentu Sub-Zoba) in the CAZS greenhouse in late December 2000. Successful downy mildew infection of pearl millet seedlings was obtained. After 6-8 weeks, these provided enough sporangial inoculum to allow screening of a large number of host genotypes against this isolate.

Table 1. Screening for downy mildew resistance in pearl millet: percentage of infected seedlings in each of five single-pot replications (A-E), in Bangor, Wales, UK, three weeks after spraying with a sporangial suspension of Eritrean isolate F23 of *Sclerospora graminicola*.

Pearl millet entries	Downy mildew incidence (%)					Mean		
	A	B	C	D	E	%	Sq. root	Arcsine
Introduced populations								
ICMP 93508	23.5	16.7	22.9	29.4	26.3	23.76	4.86	29.08
ICMP 95490	2.9	0.0	25.0	5.9	3.2	7.40	2.18	12.83
ICMP 96593	11.6	11.9	14.0	9.8	16.3	12.72	3.55	20.82
ICMP 96601	6.3	4.2	21.7	21.7	47.4	20.26	4.15	25.08
ICMP 97754	19.0	0.0	3.6	12.5	22.7	11.56	2.91	17.19
ICMP 98551	12.5	31.0	9.4	10.0	16.7	15.92	3.89	22.99
ICMP 98791	11.4	27.0	32.3	27.8	40.5	27.80	5.18	31.40
ICMR 501	4.8	8.3	4.9	5.1	0.0	4.62	1.91	11.05
PRLDMR TCP1	0.0	0.0	0.0	22.2	22.2	8.88	1.88	11.24
HTBC	5.3	7.1	2.4	8.1	5.1	5.60	2.32	13.45
SRBC	0.0	0.0	0.0	5.6	6.3	2.38	0.98	5.65
AfPop 88	4.8	7.9	7.5	2.6	9.3	6.42	2.48	14.38
AfPop 90	5.3	3.0	3.3	2.8	10.8	5.04	2.16	12.51
SenPop 88	7.7	3.3	4.8	4.7	4.0	5.90	2.38	13.79
ICMV 155 Bristled	10.8	16.2	5.4	26.3	16.2	14.98	3.76	22.19
1CMV 87901 Bristled	26.3	21.1	11.1	23.7	28.9	22.22	4.66	27.86
ICMV 221	17.9	22.5	7.1	5.0	5.3	11.56	3.23	19.01
ICMV 155	14.3	17.9	9.7	22.2	11.4	15.10	3.84	22.65
ICMV 91450	10.3	10.8	0.0	9.5	19.4	10.00	2.80	16.40
Sudan Pop. I CO	11.6	14.3	5.1	7.1	5.1	8.64	2.87	16.74
Sudan Pop. II CO	19.4	5.4	14.3	11.1	15.4	13.12	3.55	20.87
Sudan Pop. III CO	17.1	6.5	6.9	11.4	10.3	10.44	3.18	18.58
MCNELC	2.5	10.0	12.2	7.0	9.3	8.20	2.79	16.21
MCSRC	9.8	17.5	17.1	16.3	21.1	16.36	4.02	23.71
ICMP 89410	10.8	28.1	8.6	21.9	37.0	21.28	4.46	26.72
ICMP 98107	2.9	16.2	16.2	28.6	14.3	15.64	3.77	22.36
EERC CO	11.9	23.3	16.7	21.4	18.6	18.38	4.26	25.25
ICMR 312	15.4	25.0	18.5	6.9	31.0	19.36	4.28	25.53
IAC ISC TCP1	2.4	0.0	12.2	4.8	4.8	4.84	1.88	10.93
IAC ISC TCP3	7.1	29.7	9.5	15.4	23.1	16.96	3.98	23.65
IAC ISC TCP4	4.9	9.8	9.3	7.0	16.7	9.54	3.03	17.65
IAC ISC TCP6	2.6	2.4	0.0	2.4	2.5	1.98	1.26	7.24
IPC MBJ TCP CO	14.3	12.5	14.3	11.8	0.0	10.58	2.91	17.05
POLCOL TCP1	7.7	22.9	13.5	12.1	16.7	14.58	3.76	22.15
Introduced male-sterile lines								
863A	28.0	13.6	16.7	24.1	11.1	18.70	4.26	25.31
ICMA 89111	5.7	0.0	5.9	0.0	5.0	3.32	1.41	8.16
ICMA 91222	0.0	2.9	0.0	2.5	5.0	2.08	1.10	6.36
ICMA 91777	0.0	2.9	2.5	5.0	2.5	2.58	1.42	8.18
ICMA 92444	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
ICMA 95333	2.4	5.9	0.0	3.1	5.9	3.46	1.63	9.43
ICMA 96222	0.0	2.6	2.7	5.4	8.1	3.76	1.68	9.74
ICMA 97 111	0.0	2.4	2.3	4.9	0.0	1.92	1.06	6.08
ICMA 97333	9.8	4.9	2.6	7.7	0.0	5.00	1.94	11.28
ICMA 98222	0.0	2.4	2.6	2.4	7.5	2.98	1.49	8.60

Continued

Table 1.(*continued*)

Pearl millet entries	Downy mildew incidence (%)					Mean		
	A	B	C	D	E	%	Sq. root	Arcsine
ICMA 98333	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
ICMA 99111	0.0	6.5	0.0	0.0	3.6	2.02	0.89	5.14
ICMA 99222	10.5	18.4	16.7	18.2	16.2	16.00	3.98	23.48
ICMA 00888	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00
Eritrean cultivars								
Bultug Keren	75.6	79.1	50.0	79.1	84.2	73.60	8.54	59.52
Bultug Mebred	44.2	47.6	46.3	51.2	57.9	49.44	7.02	44.68
Bultug Mogolo	59.0	59.0	65.9	82.5	80.0	69.28	8.30	56.67
Tosho	42.9	47.5	37.2	47.4	66.7	48.34	6.92	44.07
Zibedi	39.5	53.7	45.0	37.2	27.9	40.66	6.34	39.53
Gudmay	58.1	69.2	58.5	83.7	60.0	65.90	8.10	54.56
ICMV 221	10.0	9.5	9.8	12.8	14.3	11.28	3.35	19.56
Tokroray	67.5	79.1	59.0	47.4	71.4	64.88	8.02	53.88
Mapping population parents								
IP 18293	5.6	4.0	0.0	20.0	25.0	10.92	2.77	16.36
Tift 238Dl	100.0	95.2	100.0	79.2	64.7	87.82	9.34	74.75
841B-P3	12.5	16.0	8.0	15.6	22.7	14.96	3.82	22.48
863B-P2	15.2	18.4	27.5	28.2	48.6	27.58	5.14	31.25
H 77/833-2	56.1	47.6	31.7	65.0	33.3	46.74	6.77	43.07
PRLT 2/89-33	0.0	2.5	24.4	-	7.0	9.02	2.36	13.98
PT 732B-P2	52.9	57.1	20.7	73.9	66.7	54.26	7.23	47.37
P 1449-2	0.0	0.0	7.7	0.0	0.0	1.55	0.55	3.22
ICMP 451-P6	0.0	0.0	3.3	8.3	0.0	2.32	0.94	5.44
W 504-1-1	23.8	37.9	36.0	67.9	52.2	43.56	6.50	41.16
P310-17B	0.0	9.1	0.0	0.0	0.0	1.82	0.60	3.51
Controls								
7042(S) (susceptible)	57 5	48.8	50.0	69.4	65.8	58.30	7.62	49.85
7042(S) (susceptible)	39.5	62.9	50.0	58.3	51.4	52.42	7.22	46.40
HB 3 (susceptible)	38.5	47.5	40.0	64.1	48.8	47.78	6.88	43.73
P 7-3 (resistant)	42.3	31.3	57.7	60.9	41.4	46.72	6.78	43.07
Mean						20.00	3.70	22.99
SE						±3.56	±0.47	±3.11
CV(%)						39.85	28.27	30.29
F ratio						34.48	24.97	26.95
h^2 (plot-basis)						0.87	0.83	0.84

Seventy-two pearl millet genotypes were screened. These included:

- Eritrean landraces (Bultug Keren, Bultug Mebred, Bultug Mogolo, Tosho, Zibedi, Gudmay and Tokroray),
- promising new open-pollinated varieties (notably ICMV 221),
- 48 populations and male-sterile lines from ICRISAT-Hyderabad (potential parental material),
- two susceptible controls 7042(S) and HB 3, and one resistant control (P 7-3), and
- 11 parents of the pearl millet mapping populations available at CAZS.

The latter are part of a DFID-PSP-supported project to map pearl millet downy mildew resistance genes, in which ICRISAT and CAZS are collaborating.

There were 5 pots per host entry, with 42 seeds sown per pot. The pots were arranged in 5 randomized complete blocks on flood benching. The seed was sown on 26 February 2001 and the seedlings were spray-inoculated with sporangial suspension of isolate F23, on 2 March 2001, when most seedlings were at the one to two leaf stage, using the method described by Jones et al. (2001). The inoculum concentration used was 1.7×10^5 sporangia mL^{-1}, and each pot of seedlings received approximately 4 mL of inoculum. Seedlings were assessed for disease during 19-22 March 2001. Downy mildew incidence (percentage infected seedling per pot, and its square root and arcsine-transformed values) data were subjected to ANOVA, and broad-sense heritabilities (plot-wise) were calculated.

Results and Discussion

The results are given in Table 1, where the number of infected plants in each replication is expressed as a percentage of the total number of plants per pot. Note the general consistency across replicates achievable by this screening method. The high heritability estimates reflect the effective control of inoculum quantity and uniformity, and seedling growth (ie, tight control of environmentally-induced variation) in this experiment.

Susceptible control genotypes 7042(S) and HB 3 showed approximately 50% infection (rather less than expected), and the resistant control genotype P 7-3 proved surprisingly susceptible to this isolate of the pathogen. There was a good range of values among the other materials tested: the Bultug Keren landrace was particularly susceptible with an overall mean infection of 79.5% (omitting block C as an outlying value). Three introduced male-sterile lines (ICMA 98333,ICMA 92444 and ICMA 00888) had 0% infection for each block, and three other introductions (ICMA 99111, P 1449-2 and P 310-17B) showed <2% downy mildew incidence. Downy mildew resistant lines P 1449-2 and P 310-17B are parents of pearl millet mapping populations derived from crosses to susceptible lines PT 732B-P2 and W 504-1-1, respectively, so it should be possible to map resistance loci effective against this pathogen isolate using genetic stocks previously developed by ICRISAT and its DFID-PSP-supported UK collaborators. Finally, improved cultivar ICMV 221 (recently released as 'Kona') showed 11.3-11.6% disease incidence.

The results were used in developing crossing programs from which future pearl millet varieties for Eritrea will be derived. It is clear that the Eritrea-ICRISAT-CAZS collaboration works well and is tackling a serious problem in an efficient and cost-effective way. However, studies to date have looked at just one Eritrean isolate of the pathogen that causes downy mildew. Further, at present all the pearl millet breeding work in Eritrea is done at Hagaz in Anseba. It is therefore important to determine whether resistance identified by field screening at Hagaz is valid for the rest of the country. Is there just one, or more than one, major pathotype of downy mildew in Eritrea? It would be of great value to have information on this.

Acknowledgments. Thanks are due to the Plant Sciences Research Programme of the UK's Department for International Development (which supported the DM screening work in the UK) and the Danish Ministry of Foreign Affairs to the Agriculture Sector Support Programme in Eritrea, and to Fran Bidinger, Tom Hash, and Panduranga Rao of ICRISAT for valuable technical assistance.

References

Bhasker Raj AG, Bidinger FR, Panduranga Rao V and Negusse Abraha. 2000. Report of a survey of downy mildew incidence in farmers' fields in Anseba and Gash Barka Regions and an evaluation of the pearl millet breeding trials and nurseries at the Hagaz research station. ICRISAT, Patancheru, India, and ARHRD, Ministry of Agriculture, Eritrea.

Jones ES, Breese WA and Shaw DS. 2001. Infection of pearl millet by the downy mildew fungus *Sclerospora graminicola:* chilling inoculum to prevent zoospore release and subsequent spray damage to zoospores. Plant Pathology 50:1-8.

Saini RS. 2001. Operational plan for seed production programme. Asmara, Eritrea: Department of Land Resources and Crop Production, Ministry of Agriculture.

Evaluation of Pearl Millet Varieties for Resistance to *Striga hermonthica*

NA Gworgwor (Department of Crop Science, University of Maiduguri, PMB 1069, Maiduguri, Borno State, Nigeria) gwor@unimaid.edu.ng

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br] is a major crop in the semi-arid savanna zone of Africa where the parasitic weed *Striga hermonthica* (Del.) Benth. causes serious yield losses to millet and other cereal crops. Sauerbom (1991) estimated that in Africa 21 million ha are infested with *Striga,* resulting in an annual loss of 4.1 million tonnes of grain.

Host-plant resistance may play a role in reducing *S. hermonthica* reproduction, while tolerant varieties may result in long-term build up of *S. hermonthica* seed numbers in the soil (Doggett 1988). Indigenous varieties of crops have co-evolved with *S. hermonthica* and are able to produce moderate yields while supporting a high density of 5. *hermonthica* plants to the reproductive stage, thereby contributing to increases in *S. hermonthica* seed numbers in the soil as shown by Weber et al. (1995) in northern Nigeria. On the other hand, complete host-plant resistance through low production of 5. *hermonthica* germination stimulant would result in no increase or even a decrease in soilborne seed numbers. Cultural practices that reduce *Striga* populations in crops such as maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench] can be adapted to pearl millet cultivation, but little information is available on genetic resistance in pearl millet.

Based on an unpublished field survey conducted by Gworgwor et al. in 1994, several pearl millet landraces were identified as supporting very few *Striga* plants per unit area in the semi-arid zone of northeastern Nigeria. The objective of the reported research work was to evaluate these varieties for resistance to *S. hermonthica* and to identify the best for use in future breeding programs. 'Resistance' in this report is defined as supporting only a few emerged *Striga* plants.

Materials and Methods

A trial was conducted in 1995 at the teaching and research farm of the Department of Crop Science, University of Maiduguri in the semi-arid zone of Nigeria (11 °51' N, 13°15' E), where the growing season lasts for 3 months - from early Jun to early Sep. The trial area soil, a sandy loam naturally infested with *S. hermonthica,* was harrowed to a fine tilth before plots (3 m x 3 m) were marked out and banded with 60 kg N ha^{-1} applied as compound NPK (15:15:15) in two equal splits. The first application was broadcast before sowing and incorporated into the soil, and the second was hand-placed 15 cm away from the plants and covered with soil 5 weeks after sowing (WAS).

The treatments consisted of three pearl millet varieties, the collected landraces Buduma-Chad and Ex-Pulka, and Ex-Borno (a locally adapted improved variety). These were laid out in a completely randomized-block design with 4 replications. The data collected were on plant height (cm), time to 50% flowering (days after sowing, DAS), number of tillers $plant^{-1}$, number of effective tillers $plant^{-1}$, stem diameter (mm), panicle length (cm), panicle diameter (m), number of *Striga* plants $plot^{-1}$, *Striga* plant height (cm), and host grain yield (t ha^{-1}). The data collected were subjected to analysis of variances and the treatments means compared by LSD (P<0.05) when F-values were significant.

Results

The results show significant variation in plant height, time to 50% flowering, and both total and effective numbers of tillers among the three pearl millet varieties (Table 1). Ex-Borno had the tallest plants followed by Ex-Pulka and the shortest variety was Buduma-Chad. However, Buduma-Chad flowered first (36 DAS) followed by Ex-Borno (53 DAS), while Ex-Pulka flowered very late (62 DAS). Both Buduma-Chad and Ex-Pulka produced similar numbers of total tillers and effective tillers, significantly more than the Ex-Borno variety (Table 1).

Statistically significant differences were observed in stem diameter, panicle length, and panicle diameter among the three pearl millet varieties (Table 1). Ex-Borno had the thickest stems and panicles, while Buduma-Chad had the thinnest stems and panicles. Ex-Pulka and Ex-Borno varieties both produced significantly longer panicles than Buduma-Chad (Table 1).

There were no statistically significant differences in the numbers of emerged *Striga* plants supported by the varieties, but significant differences were observed in *Striga* plant height (Table 1). *Striga* plant height was significantly positively correlated with time to 50% flowering. Wilson et al. (1998) reported the positive correlation of *Striga* count data with time to 50% flowering in wild *Pennisetum* spp. and observed that the emergence of *Striga* was lower for early flowering accessions. Although differences were not significant, the Buduma-Chad variety supported the least number of *Striga* plants followed by the Ex-Borno and Ex-Pulka. Further, Buduma-Chad supported the shortest *Striga* plants, which were significantly shorter than those supported by Ex-Pulka, but comparable with those supported by Ex-Borno. Ex-Pulka and Ex-Borno supported *Striga* plants of comparable height.

There was significant variation in grain yield among the three pearl millet varieties (Table 1). Ex-Bomo produced significantly more grain than the others, while Buduma-Chad produced the lowest yield.

Table 2 shows the correlation between grain yield, growth parameters, and *Striga* infestation. Pearl millet grain yield was significantly positively correlated with plant height, time to 50% flowering, stem diameter, and panicle length and diameter. Panicle diameter was significantly positively correlated with plant height, time to 50% flowering, stem diameter, and panicle length. Panicle length was significantly positively correlated with time to 50% flowering and stem diameter. Stem diameter, on the other hand, was significantly positively correlated with plant height, time to 50% flowering, and *Striga* plant height, but was significantly negatively correlated with total numbers of tillers. Total number of tillers was significantly negatively correlated only with plant height, while *Striga* plant height was positively significantly correlated with time to 50% flowering.

Discussion

Although no significant difference was observed in the number of emerged *Striga* supported by the varieties, Buduma-Chad supported numerically fewer *Striga* plants than Ex-Pulka and Ex-Bomo. This indicates that the varieties have similar levels of resistance to *Striga.* The lower numbers of *Striga* plants supported by Buduma-Chad could be due to an escape mechanism because such earlier-maturing host genotypes stop feeding their *Striga* parasites before they are able to mature. The significantly shorter height of *Striga* plants supported by Buduma-Chad (Table 1) supports this interpretation. This character of Buduma-Chad, however, did not allow it to produce higher yields. Instead, it produced the lowest grain yield among the three host varieties. This low grain yield of Buduma-Chad could be due to its genetic composition that resulted in its short stature, thin stems, and short, thin panicles. All these features contribute naturally to its yielding less than the other two varieties that had higher values for these characters. Gworgwor (1998) reported improved pearl millet variety 3/4 HIC-2-2 as exhibiting some resistance to *Striga* but as having poor yield potential that was attributable to its genetic composition.

Buduma-Chad flowered earlier than the other two varieties in this study and had a higher tillering ability than Ex-Borno. To develop a variety with improved resistance to *Striga* and high grain yield, Buduma-Chad could be crossed with Ex-Borno to combine its possible *Striga* resistance, superior tillering ability, and early flowering characters with the tall height, thick stem, and long thick panicles of Ex-Borno. The possibility of

Table 1. Effect of pearl millet variety on the growth parameters, yield, and *Striga* infestation, Maiduguri, Nigeria, 1995.

Variety	Plant height (cm) at harvest	Time (d) to 50% flowering	Total tillers plant^{-1}	Effective tillers plant^{-1}	Stem diameter (mm)	Panicle length (cm)	Panicle diameter (mm)	Number of *Striga* plants plot^{-1}	*Striga* plant height (cm)	Grain yield (t ha^{-1})
Buduma-Chad	177.6	36.0	2.4	1.0	10.4	19.6	19.4	5.8	6.2	2.2
Ex-Pulka	201.6	62.7	2.9	1.2	12.0	23.9	22.2	10.0	32.2	5.5
Ex-Borno	256.2	53.0	1.3	0.4	13.8	23.2	25.0	7.8	24.3	7.6
SE	±5.85	±0.20	±0.42	±0.26	±0.33	±0.97	±0.53	±4.06	±8.40	±1.8
LSD(*P*>0.05)	14.31	0.50	1.04	0.64	0.81	2.39	1.30	NS	20.56	4.3

Table 2. Correlation coefficients (r) between pearl millet growth parameters, *Striga* infestation and grain yield, Maiduguri, Nigeria, 1995.

	1	2	3	4	5	6	7	8	9	10
Plant height	-	0.326	0.058	0.350	-0.601*	-0.346	0.937	-0.393	-0.914**	0.812**
Time to 50% flowering		-	0.312	0.740**	0.101	0.330	0.572*	0.845**	0.596*	0.635*
Number of *Striga* plants plot^{-1}			-	0.442	0.373	-0.102	0.095	0.096	0.213	0.076
Striga plant height				-	-0.064	0.309	0.552*	0.453	0.507	0.492
Total tillers					-	0.104	-0.582*	-0.017	-0.421	-0.466
Effective tillers						-	-0.174	0.220	-0.259	-0.080
Stem diameter							-	0.586*	0.925**	0.893**
Panicle length								-	0.558*	0.622*
Panicle diameter									-	0.840**
Grain yield										-

*P>0.05; ** P>0.01;*** P>0.001

successfully obtaining such a recombination of characters is supported by the correlation coefficient results (Table 2) that show grain yield is significantly positively correlated with plant height, time to 50% flowering, stem diameter, and panicle length and diameter.

The continuing interests of farmers in keeping landraces are obviously due to socio-economic reasons (Carr 1989, Rower 1996). It is therefore important to maintain the morphological features of the local landraces while improving their resistance to *Striga,* tillering ability, and early flowering if possible. In the long run, development of pearl millet varieties resistant to *Striga* could help to substantially reduce the amount of soilborne seed of this parasitic weed and could substantially increase yields by more than use of a tolerant variety that would definitely increase the number of such seeds in the soil each year. The advantage of using resistant sorghum varieties in reducing numbers of *Striga* seeds in the soil and increasing host grain yield in northern Nigeria and Cameroon has already been reported (Weber et al. 1995, Carsky et al. 1996).

References

Carr SJ. 1989. Technology for small-scale farmers in the sub-Saharan Africa. World Bank Technical Paper 109.

Carsky RJ, Ndikawa R, Kenga R, Singh L, Fobasso M and Kamuanga M. 1996. Effect of sorghum variety on *Striga hermonthica* parasitism and reproduction. Plant Varieties and Seeds 9:111-118.

Doggett H. 1988. Sorghum, 2nd edn. London, UK: Longmans. 512 pp.

Flower DJ. 1996. Physiological and morphological features determining the performance of the sorghum landraces of northern Nigeria. Experimental Agriculture 32:129-141.

Gworgwor NA. 1998. Studies on the biology and control of *Striga.* Effect of variety and nitrogen fertilization on the control *Striga hermonthica* (Del.) Benth. on millet. Annals of Borno.

Sauerborn J. 1991. The economic importance of the phytoparasites *Orbanche* and *Striga.* Pages 137-143 *in* Proceedings of the 5th International Symposium on Parasitic Weeds, Apr 1991, Nairobi, Kenya. (Ransom JK, Musselman LJ, Worsham AD and Parker C, eds.). Mexico DF, Mexico: Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT).

Weber G, Elemo K, Lagoke STO, Awad A and Oikeh S. 1995. Population dynamics and determinants of *Striga hermonthica* on maize and sorghum in savanna farming systems. Crop Protection 14:283-290.

Wilson JP, Hess DE, Hanna WW and Youm O. 1998. *Striga hermonthica* infection of wild *Pennisetum* germplasm is related to time of flowering and downy mildew incidence. International Sorghum and Millets Newsletter 39:49-150.

Evaluation of *Striga* Resistance in the Secondary and Tertiary Gene Pools of Pearl Millet

JP Wilson[1*], DE Hess[2,3] and WW Hanna[1] (1. USDA-ARS, Coastal Plain Experiment Station. Tifton, GA 31793-0748, USA; 2. ICR1SAT, BP 320, Bamako, Mali; 3. Agronomy Department, Purdue University, West Lafayette, IN 47907, USA)

*Corresponding author: jwilson@tifton.usda.gov

Introduction

The secondary and tertiary gene pools of pearl millet [*Pennisetum glaucum* (L.) R. Br.] consist of species with various degrees of chromosome homology and interspecific sexual compatibility with *P. glaucum.* Because pearl millet is reproductively isolated from these gene pools, it is likely that genetic variation for resistance to *Striga hermonthica* (Del.) Benth. that has not been apparent in cultivated pearl millet may exist in these species.

The secondary gene pool of pearl millet consists of napiergrass, *Pennisetum purpureum* Schumach. Accessions of this species are maintained at Tifton, Georgia, USA. However, at this location seed rarely develops before frost, and accessions must be propagated vegetatively. Evaluating the secondary gene pool accessions in Georgia would require rooted stem sections - an atypical approach to evaluate *Striga* resistance. To circumvent this problem, pollen can be collected from these accessions and crossed onto cytoplasmic male-sterile selections of pearl millet to produce interspecific F_1 seed to evaluate dominant or additive expression of resistance.

The tertiary gene pool species tend to be resistant to many diseases common to pearl millet (Wilson and Hanna 1992). Although seed set can be relatively low and resulting seeds are often rather small in size, seed is available for direct evaluation of several tertiary gene pool species.

Materials and Methods

Secondary gene pool. Pollen was collected from napier-grass plants grown at Tifton, Georgia, and crossed onto cytoplasmic male-sterile pearl millet in the greenhouse. Resulting hybrids were evaluated in three trials.

At Cinzana, Mali, in 1998, seed was sown in a randomized complete block design with four replications on 10 July. Plots consisted of single rows spaced 1 m apart with 7 hills per entry. *Striga* counts within plots were made 59, 74, and 89 days after sowing. The average maximum number of *Striga* per hill was calculated within plots. At Samanko,

Mali, in 1999, the experiment was conducted in a randomized complete block design with four replications. Each replication consisted of a single-row plot with 6 plants per row. Rows were spaced 1 m apart. Plants were started by germinating seeds in flats in a greenhouse. Seed was sown on 1 July and seedlings transplanted on 13 July. Natural infestation was augmented by artificially infesting in-furrow with *Striga* seed. *Striga* counts were made per plant at 56, 70, 84, 98, and 112 days after transplanting. Average maximum number of *Striga* per plant was determined. At Sadore, Niger, in 1999, seed was sown in pots maintained outdoors in a randomized complete block design with 15 replications. Seed was sown on 9 June and transplanted on 14 June. All pots were artificially infested with *Striga* seed. Numbers of emerged *Striga* per pot were counted at weekly intervals from 25 to 99 days after transplanting.

Tertiary gene pool. Tests were conducted at Samanko in 1998 and at Samanko and Sadore in 1999. Experiments were conducted in randomized complete block designs with four replications. In 1998, seed was sown directly into the field. In 1999, seed was sown in flats in the greenhouse in mid-June and seedlings were transplanted to the field two weeks later. Plots were infested with *Striga* seed in-furrow. *Striga* emergence at Samanko was evaluated at 65, 78, and 92 days after transplanting. In 1999, plant vigor was assessed on a 0 to 5 scale, where 0 = dead and 5 = fully vigorous and healthy.

Species evaluated and number of accessions of each species (in parentheses) included *P. orientate* L.C. Rich. (5), *P. setaceum* (Forsskal) Chiov. (5), *P. nervosum* Trin. (4), *P. pedicillatum* Trin. (4), *P. polystachion* (L.) Schult. (4), *P. schweinfurthii* Pilger (4), *P. squamulatum* Fresen. (4),

Table 1. Average numbers of emerged *Striga* per host plant of F_1 hybrids of pearl millet x napiergrass (N) accessions, Mali and Niger, 1998-1999.

	Average number of emerged *Striga* per host plant			
Hybrid Female x male	Cinzana 1998	Samanko 1999	Sadore 1999	3-test average
Tift $23A_1$x N69	6.7 a	-	-	_
Tift $23A_1$ x N12	5.7 abcd	-	-	-
Tift $23A_1$ x N73	3.4 abcde	-	-	-
Tift $23A_4$E x N 158	2.2 abcde	-	-	-
Tift $23DA_1$x N13	1.0 de	-	-	-
Tift $23A_1$ x N36-1	0.5 e	-	-	-
Tift $23A_4$E x N138	3.3 abcde	0.2 ef	-	-
Tift $23A_1$ x N51	6.5 ab	0.5 de	14.3 abcde	7.1
Tift $23A_4$E x N170	1.4 cde	0.0 f	18.8 a	6.7
Tift $23A_4$E x N166	2.4 abcde	0.3 def	15.2 abc	6.0
Tift $23A_1$ x N9	1.2 de	0.1 ef	16.4 ab	5.9
Tift $23A_4$E x N186	3.1 abcde	0.4 def	12.5 abcdef	5.3
Tift $23A_4$E x N68	0.9 de	0.1 ef	14.6 abcd	5.2
Tift $23A_4$E x N34-1	2.9 abcde	0.4 def	11.6 bcdefg	5.0
Tift $23A_1$x N57	1.4 cde	0.8 cde	12.2 abcdefg	4.8
Tift $23A_4$E x N24-1	2.3 abcde	0.0 f	12.0 abcdefg	4.8
Tift $23A_1$ x N16	3.3 abcde	1.4 c	9.4 bedefg	4.7
Tift $23A_4$E x N185	6.3 abc	0.2 ef	7.2 fg	4.6
Tift $23A_1$ x N74	0.7 e	0.1 ef	12.7 abcdef	4.5
Tift $23A_1$ x N39-2	0.6 e	0.2 ef	11.7abcdefg	4.2
Tift $23A_4$E x N131	0.0 e	0.9 cd	9.1 cdefg	3.3
Tift $23A_4$E x N66	1.0 de	0.4 def	7.0 fg	2.8
Tift $23A_1$ x N14	0.8 de	0.1 ef	7.5 defg	2.8
Tift $23A_1$ x N20	1.6 bcde	0.0 f	6.6 fg	2.7
Tift $23A_4$E x N137	1.3 de	0.3 def	5.1 g	2.2
Controls				
Toronio	2.0 abcde	-	-	-
Boboni	2.3 b	-	-	-
E 36-1 (sorghum)	4.9 a	-	-	-
Sadore local	10.5 bcdefg	-	-	-
lsd (P = 0.05)	4.9	0.7	7.3	-

P. ramosum (Hochst.) Schweinf. (3), *P. villosum* R. Brown ex Fresen (3), *P. alopecuroides* (L.) Sprengel (2), *P. macrourum* Trin. (1), *P. mezianum* Leeke (1), P. *setosum* (Swartz) L.C. Rich. (1), *P. subangustum* (Schumach.) Stapf & C.E. Hubbard (1), *Cenchrus ciliaris* L. (2), and *C. setigres* Vahl (1).

Results

Secondary gene pool. *Striga* infestation varied across locations in this experiment. Levels were lowest at Samanko in 1999 (an unusually wet year) and greatest in the pot trial at Sadore in 1999 (Table 1). Coefficients of variation were characteristically high in each experiment, and ranged from 75% at Sadore to 191% at Samanko. Although numeric differences in *Striga* infestation among entries existed, statistically significant differences were often noted only among the extreme entries. Definitive identification of resistance is not possible from the present data, but parental lines of several hybrids merit further evaluation as sources of resistance. Hybrids involving napiergrass entries 131,66,14,20, and 137 tended to have lower overall *Striga* infestation across the three evaluations.

In addition to *Striga* in the 1999 Samanko and Sadore trials, leaf spots caused by *Pyricularia grisea* (Cke.) Sacc. were evident. No infection by downy mildew (caused by *Sclerospora graminicola* (Sacc.) J. Schrot.) was observed although pearl millet in adjacent trials was infected.

Tertiary gene pool. *Pennisetum* germination was extremely low in 1998 and few plants emerged. No useful data could be obtained from the experiment. In 1999, the tertiary gene pool species tended to be poorly adapted to both the Samanko and Sadore environments. High rainfall at Samanko was a likely cause of poor plant development as was drought at Sadore. Stands of many entries declined from the time of transplanting. At Samanko, many plants were cut off at ground level by insect feeding and roots of many stunted plants appeared to exhibit nematode damage. No downy mildew was observed.

Striga emergence at Samanko was extremely low. Average number of emerged *Striga* per host plant was 0.25 for Boboni, 0.17 for Srriga-susceptible sorghum *[Sorghum bicolor* (L.) Moench] control entry E 36-1, and 0.08 for *P. squamulatum* PS262. No *Striga* was observed on the remaining entries. For comparison, in 2000, an average rainfall year at Samanko, emerged *Striga* on single plants of Boboni and E 36-1 averaged 10.5 and 25.2, respectively. No *Striga* emerged in the Sadore experiment.

Vigor ratings collected in 1999 were analyzed to identify species that might be adapted to sub-Saharan Africa and useful for further studies. Species and their ranges of vigor scores ($1sd_{0.05}$ = 1.0) were: *P. pedicillatum* (4.3-4.9), *P. setosum* (4.1), *P. subangustum* (4.0), *P. macrourum* (4.0), *P. polystachion* (2.1-4.0), *P. nervosum* (0.4-4.4), *P. mezianum* (1.9), *P. schweinfurthii* (1.0-1.9), *P. ramosum* (0.8-1.8), *P. setaceum* (0.9-1.7), *P. squamulatum* (1.3-1.6), *Cenchrus ciliaris* (0.4-1.4), *C. setigres* (1.1), *P. villosum* (0.6-1.1), *P. orientale* (0.3-1.0), and *P. alopecuroides* (0.4-0.6). The *P. pedicellatum* accessions were adapted to both locations and might be further evaluated for their response to *Striga* infestation.

Acknowledgments. This research was funded in part by a US AID-sponsored Initiative on Development of Linkages with International Agricultural Research Centers and the U.S. Department of Energy grant DE-FG02-93ER20099.

References

Wilson JP and Hanna WW. 1992. Disease resistance in wild *Pennisetum* species. Plant Disease 76:1171-1175.

Anatomical Factors Associated with Resistance to Blast in Finger Millet

AK Jain[1]*, SB Singh[2] and HS Yadava[3] (1. Department of Plant Pathology, JNKVV College of Agriculture, Rewa 486 001, Madhya Pradesh, India; 2. Department of Botany, Government Model Science College, Rewa, Madhya Pradesh, India; 3. Department of Plant Breeding & Genetics, RAK College of Agriculture, Sehore, Madhya Pradesh, India)
*Corresponding author

Introduction

Finger millet *[Eleusine coracana* (L.) Gaertn] is one of the important small millet crops widely cultivated in South Asia and Africa. The crop suffers due to occurrence of blast caused by *Pyricularia grisea* at all stages of crop growth. The disease causes recurring yield losses of around 28%, which can be much higher in epidemic years. Understanding mechanisms of resistance is essential for an effective breeding program. Some attempts (Mohanti et al. 1983) have been made to understand mechanisms of resistance against *Pyricularia* sp. in rice *(Oryza sativa* L.). However, attempts to determine defense mechanisms in finger millet are scanty.

Table 1. Phenotypic correlations (upper diagonal) and genotypic correlations (lower diagonal) among blast incidence and anatomical traits in finger millet at Rewa, Madhya Pradesh, India, during the rainy seasons of 1993/94 and 1994/95.

Characters	Leaf blast incidence	Neck blast incidence	Finger blast incidence	Leaf epidermal thickness	Leaf cuticular thickness	Neck epidermal thickness	Number of neck chlorenchymatous strands	Grain yield
Leaf blast incidence	–	0.658**	0.695**	–0.612**	–0.612**	–0.619**	0.567**	0.002
Neck blast incidence	0.790	–	0.873**	–0.592**	–0.634**	–0.970**	0.942**	–0.187*
Finger blast incidence	0.799	0.975	–	–0.574**	–0.576**	–0.843**	0.848**	–0.144
Leaf epidermal thickness	–0.822	–0.799	–0.706	–	0.622**	0.594**	–0.525**	0.112
Leaf cuticular thickness	–0.795	–0.839	–0.734	1.010	–	0.643**	–0.580**	0.139
Neck epidermal thickness	–0.708	–1.086	–0.908	0.776	0.843	–	–0.873**	0.109
No. of chlorenchymatous strands	0.679	1.096	0.932	–0.689	–0.770	–1.007	–	–0.173
Grain yield	0.025	0.246	–0.266	0.307	0.250	0.184	–0.331	–

* = significant at 5% level; ** = significant at 1% level.

In the present study, an attempt was therefore made to establish the anatomical basis of resistance to blast in finger millet.

Material and Methods

A field experiment was conducted in randomized block designs with three replications during the rainy seasons of 1993/94 and 1994/95 using 40 diverse finger millet genotypes at the Regional Agricultural Research Station, Rewa, Madhya Pradesh, India. Genotypes were sown in 10-row plots, with 22.5 cm between rows and 10 cm between plants within rows. The package of practices recommended for finger millet cultivation in MP were strictly adapted for optimum crop growth. Leaf and neck samples were collected from selected healthy plants of each genotype to record anatomical characters (thickness of leaf cuticle and epidermis, thickness of neck epidermis, and number of neck chlorenchymatous strands). Leaf blast, neck blast and finger blast incidence (%) were recorded. Genotypic and phenotypic correlation coefficients among blast incidence, anatomical parameters and grain yield were calculated.

Results and Discussion

The range of observed variation was 17.65 to 24.85 µm for leaf epidermal thickness, 7.55 to 11.38 µm for leaf cuticular thickness, 7.14 to 29.02 µm for neck epidermal thickness, and 9.5 to 24.0 for number of neck chlorenchymatous strands. Resistant genotypes, such as GE 3022, GE 3024, GE 3058, GE 3060, IE 1012 and MR 6, possessed thick leaf cuticle, thick leaf epidermis, thick neck epidermis and relatively low numbers of neck chlorenchymatous strands. On other hand, susceptible genotypes K 7, VR 586, PES 110, PPR 2679 and VMEC 35 possessed thin epidermis and cuticle layers and relatively large numbers of neck chlorenchymatous strands. These observations suggest that in finger millet, as previously reported by Mohanti and Gangopadhyay (1983) in rice, epidermal and cuticular thickness of leaves and neck create surface structural barriers to entry by the pathogen that provide defense mechanisms against *Pyricularia* sp.

Correlations of anatomical characters with blast incidence showed consistency in results across the two years of this study. In the pooled analysis, number of neck chlorenchymatous strands showed positive and significant associations with incidence of all forms of blast (Table 1). However, number of neck chlorenchymatous strands exhibited significant negative associations with epidermal and cuticular thickness of leaf and neck regions of the plant. This clearly indicates that increases in number of chlorenchymatous strands favors blast incidence. Epidermal and cuticular thickness showed significant negative

associations with incidence of all forms of blast. This indicates that epidermis thickness of leaf and neck, and leaf cuticle thickness contribute to resistance against blast in finger millet.

The present study revealed that epidermal and cuticular thickness play a major role in determining resistance of finger millet against *P. grisea.* Hence, these traits can be effectively utilized as selection criteria for identification of resistant lines in finger millet breeding programs.

References

Mohanti CR and Gangopadhyay S. 1983. Association of anatomical characters in the neck region of panicle with resistance in rice for neck blast. Indian Phytopathology 36:496-502.

Mohanti CR, Gangopadhyay S and Sahoo K. 1983. Correlation and path coefficient analysis study between some leaf characters and blast incidence at seedling stage of rice. Indian Phytopathology 36:508-515.

Biotechnology

Application of Anther Culture to Hybrid Breeding of Pearl Millet

Akiko Shigemune[1] * and Tomohiko Yoshida (Faculty of Agriculture, Kyushu University, Fukuoka, 821-8581, Japan. 1. Present address: Hokuriku National Agricultural Experiment Station, Inada 1-2-1, Joetsu, Niigata 943-0193, Japan)

*Corresponding author

Introduction

Anther culture is an effective method to breed inbred lines in a short time. In pearl millet [*Pennisetum glaucum* (L.) R. Br.] there are only a few reports about anther culture and the reported regeneration ratio from anther culture of this crop is very low (Choi et al. 1997). Bui Dang Ha and Pernes (1982) also reported that anther culture derived pearl millet lines were completely sterile.

The objective of this study is to breed pearl millet inbred lines by anther culture and estimate their combining ability and discuss the possibility to utilize this method for hybrid breeding.

Materials and Methods

The anthers of a short-statured population, ICMV 89074 (SP), and a tall-statured population (TP, Totok et al. 1998) were cultured on the dedifferentiation medium (Table 1)

Table 1. Effects of media composition and genotype on plant regeneration in anther culture of pearl millet.

Name		D2	D3
Basal medium[1]		MS	MS
Plant growth regulator (mgL^{-1})	2,4-D	2.5	2.5
	IAA	2.5	2.5
	NAA	2.5	1.0
	Kinetin	2.5	1.0
No. of anthers cultured	SP[2]	1770	1740
	TP	2100	2010
No. of regenerated plants (albino)	SP	5	0
	TP	0(1)	7
Green plants regeneration ratio per E callus (%)	SP	40.4	0
	TP	0	30.8

1. All media (including regeneration medium) contain sucrose (20 g L^{-1}) and gellun gum (1.5 g L^{-1}).
2. SP = short population (ICMV 89074); TP = tall population.

Table 2. Coefficients of variation, days to heading[1] and yield of line AC5, its original population and hybrids.

	Coefficients of variation (%)									
	1st[2]			2nd			Days to heading		Yield (g m^{-2})	
Genotype	D	C	P	D	C	P	1st	2nd	1st	2nd
AC5	8.0	23.4	19.7	3.5	11.2	8.0	97	58	317	289
ICMV 89074	4.1	19.6	14.6	6.8	16.6	11.9	95	58	411	86
843A x AC5	-	-	-	5.6	9.1	6.3	-	50	-	279
843A x EERC	-	-	-	9.4	11.2	14.3	-	44	-	233
843A	-	-	-	4.7	11.6	13.2	-	46	-	-

1. D = days to heading; C = culm length; P = panicle length.
2. 1st, 2nd: 1st (summer) and 2nd (autumn) seasons' trials transplanted on 9 May and 26 August in 2000, respectively.

in 1999. After callus formation, embryogenic calli (E calli) were transplanted on the regeneration medium [MS + IAA (3.0 mg L^{-1}) + kinetin (2.5 mg L^{-1})]. The chromosome number of regenerated plants was determined by microscopic observation. A total of 11 plants produced seeds and these 11 lines were tested in the field for two seasons in 2000.

Among the anther culture derived lines, crossings were conducted in summer 2000. In addition to yield and yield components, coefficients of variation for days to heading, culm length and panicle length within the line were calculated. Combining ability was estimated from the field experiment conducted in the autumn of 2000. Hybrids between anther culture derived lines and 843A were also examined.

Results and Discussion

A total of five dedifferentiation media (D1-D5) were used for this experiment, but most of plants were regenerated from D2 and D3 medium (Table 1). The highest regeneration ratio (no. of green plants regenerated / no. of anthers cultured) was only 0.3%, and was obtained when TP was cultured on D3 medium. However, plant regeneration from E callus was very high and the ratio of albino plants was low. Chromosome observation confirmed that spontaneous chromosome doubling had already occurred in most of the plantlets. Therefore, the efficiency of obtaining doubled haploid plants through anther culture seems to be increased when E callus induction can be improved. Using young anthers (0.5-1.0 mm) and low temperature treatment (10°C, 1 week) was effective for plant regeneration in this study.

From the field trial we selected one line (AC5) as promising. Several lines among the 11 tested performed poorly and their coefficients of variation were high. As shown in Table 2, the field performance of AC5 was good, and its coefficient of variation was lower than 843 A (inbred line). Therefore, AC5 is expected to be genetically fixed.

Hybrids between anther culture derived lines showed heterosis (Fig. 1). Anther culture derived lines restored the fertility of 843A, and the hybrid 843A x AC5 yielded higher than topcross hybrid 843 A x EERC C_2 (Table 2). AC5 is expected to have good combining ability. These results show the possibility of application of the anther culture method to the breeding of pearl millet hybrid parental lines.

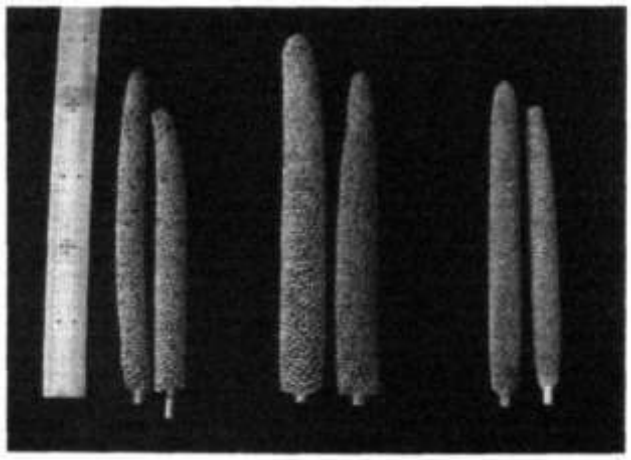


Figure 1. Panicles of hybrid (middle) and its parents (anther culture derived pearl millet inbred lines).

References

Botti C and Vasil IK. 1984. Ontogeny of somatic embryos of *Pennisetum americanum.* II. In cultured immature inflorescences. Canadian Journal of Botany 62:1629-1635.

Bui Dang Ha D and Pernes J. 1982. Androgenesis in pearl millet. 1. Analysis of plants obtained from microspore culture. Zeitschrift fur Pflanzenphysiologie 108:317-327.

Choi BH, Park KY and Park RK. 1997. Haploidy in pearl millet. Pages 171-179 *in In vitro* Haploid production in higher plants, Vol. 4 (Jain SM, Sopory SK and Veilleux RE, eds). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Totok ADH, Shon TK and Yoshida T. 1998. Effects of selection for yield components on grain yield in pearl millet *(Pennisetum typhoideum* Rich.). Plant Production Science 1:52-55.

Effect of Pollen and DNA Source on RFLP Pattern of Mitochondrial DNA in Pearl Millet

AK Chhabra[1,*], KN Rai[2], CT Hash[2], IS Khairwal[1,3] and S Sivaramakrishnan[2,4] (1. Department of Plant Breeding, CCS Haryana Agricultural University, Hisar 125 004, Haryana, India; 2. ICRISAT, Patancheru 502 324, Andhra Pradesh, India; 3. All-India Coordinated Pearl Millet Improvement Program (AICPMIP), ARS, Mandore, Jodhpur 342 304, Rajasthan, India; 4. Department of Agricultural Biotechnology, Acharya NG Ranga Agricultural University (ANGRAU), Rajendranagar, Hyderabad 500 030 Andhra Pradesh, India)

*Corresponding author: cchabraak@hotmail.com

Introduction

Mitochondrial genome variation, and interactions of the mitochondrial and nuclear genomes, have been implicated in the cytoplasmic-nuclear male-sterility systems available for commercial hybrid seed multiplication in many crop species (Leaver et al. 1988). Molecular characterization of plant mitochondrial genomes typically requires isolation of mitochondrial DNA (mtDNA) from young seedlings following protocols that efficiently exclude nuclear DNA and RNA by DNAse and RNAse treatments followed by differential centrifugation to isolate mitochondria. The maternally inherited cytoplasmic genome, of which the mitochondrial genome is a part, constitutes a very small proportion of the total plant genome. Thus, large numbers of seedlings are required to meet experimental requirements for mtDNA studies. This is a constraint, particularly in highly cross-pollinated crops like pearl millet (*Pennisetum glaucum* (L.) R. Br.) where production of selfed/sibbed seed is much more expensive, tedious and time-consuming than that of open-pollinated (OP) seed.

While characterizing cytoplasmic-nuclear male sterility (CMS) sources in pearl millet, we faced problems in producing selfed or sibbed seed of several materials in quantities sufficient to give mtDNA for RFLP analysis. Alternative approaches with potential to provide sufficient DNA were evaluated. Use of OP seed instead of sibbed-seed was explored as both have the same cytoplasmic genome. We also explored use of total DNA (tDNA) for this purpose, as it is more quickly isolated, requires less seed, and is potentially more cost-effective than using mtDNA.

Materials and Methods

Plant material. In this study we used one male-fertile line (81B) and five iso-nuclear male-sterile lines (A-lines) with diverse CMS systems in the nuclear genetic-background of their common maintainer (81B). The A-lines include 81 A_1 having the A_1 cytoplasm (Burton 1965), 81A_2 and 81A_3 having the A_2 and A_3 cytoplasms (Burton and Athwal 1967), 81A_v having the cytoplasm of *P. glaucum* subsp. *violaceum* (Lam.) L. Rich. (Marchais and Pernes 1985), and 81A_4 = 81A_m having the cytoplasm of *P. glaucum* subsp. *monodii (=violaceum)* (Maire) Brunken (Hanna 1989). The isonuclear A-lines studied here were developed, or assembled from other sources, at ICRISAT (Rai et al. 1996).

Seed multiplication. Two types of seed lots were produced: open-pollinated and sibbed seed. Open-pollinated seed lots came from the bulk harvest of open-pollinated panicles of each line. Sibbed seed lots were produced by bagging the panicles of each line at the boot stage and pollinating them with 81B pollen at the time of stigma emergence. Panicles from each line were harvested separately and bulked. Care was taken to ensure that off-type plants and pollen shedders were excluded from seed production of each A-line for this study.

DNA probes. One homologous (pearl millet) and two heterologous (maize) mtDNA probes were used in the RFLP analysis. The homologous probe was a 4.7 kb fragment from *P*srI-digested mtDNA of A_1 pearl millet male-sterile cytoplasm, provided by RL Smith, University of Florida, USA (Smith and Chowdhury 1991). The two maize mtDNA probes were *atp6* and *coxI.* The F_1-F_0 ATPase subunit 6, *atp6* (Dewey et al. 1985), was provided by C.S. Levings III, Genetics Department, North Carolina State University, Raleigh, NC, USA, as purified plasmid DNA with this insert. A clone of cytochrome *c* oxidase subunit 1, *coxI* (Isaac et al. 1985) was provided by CJ Leaver, Department of Botany. University of Oxford, Oxford, UK.

The three probes were used to hybridize mtDNA/tDNA digested with three restriction enzymes in eight different combinations (Table 1).

DNA analysis. Previously described protocols were followed for mtDNA isolation, its digestion with *Bam*HI, *Hind*III and *Pst*I, separation of DNA fragments and their staining, Southern transfer, random-primed DNA probe labeling, hybridization, and autoradiography (Chhabra et al. 1998).

Table 1. Enzyme-probe combinations tested for detection of RFLP in mtDNA (mt) and tDNA (t) using open-pollinated (O) and sibbed-seed (S) of pearl millet male-fertile maintainer line 81B and five isonuclear cytoplasmic male-sterile lines ($81A_1$, $81A_2$, $81A_3$, $81A_4$ = $81A_m$ and $81A_v$).

Enzyme-probe combination	$81A_1$				$81A_2$				$81A_3$				$81A_4$				$81A_v$			
	mt	t	O	S	mt	t	O	S	mt	t	O	S	mt	t	O	S	O	S	mt	t
*Hind*III-4.7 kb	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
*Hind*III-*coxI*	+	+	-	-	+	+	+	+	+	+	+	+	+	+	+	+	-	-	+	+
*Pst*I-4.7 kb	-	-	-	-	-	-	+	+	-	-	+	+	-	-	+	+	+	+	-	-
*Pst*I-*atp6*	-	-	-	-	-	-	+	+	-	-	+	+	-	-	+	+	-	-	-	-
*Pst*I-*coxI*	-	-	-	-	-	-	+	+	-	-	+	+	-	-	+	+	-	-	-	-
*Bam*HI-4.7 kb	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
*Bam*HI-*atp6*	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+	+	+	+	-	-
*Bam*HI-*coxI*	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

+ indicates that the particular enzyme-probe combination was tested.

Total DNA was isolated using the method of Dellaporta et al. (1983). Restriction enzyme digestion reactions were set up as per supplier's instructions with ~15 µg DNA in a final volume of 30 µL. Southern blotting, prehybridization, probe labeling, and hybridization procedures were the same as those used for the mtDNA samples.

Results and Discussion

RFLP banding patterns based on mtDNA for the OP seed were identical to those based on mtDNA from sibbed seed (not shown) with all 31 cytoplasm x enzyme-probe combinations tested (Table 1). This clearly indicated that OP and sibbed seed can be used of mtDNA-RFLP analysis with equal reliability.

In all four enzyme-probe combinations tested (Table 1), RFLP banding patterns were identical from tDNA and mtDNA Southern blots as illustrated for *Bam*HI-*coxI* in Figure 1. The only difference observed was that bands appeared hazy and their resolution was reduced when tDNA was used. A few bands with very similar molecular weights appeared fused, resulting in thick hazy bands when digested tDNA was used in place of digested mtDNA.

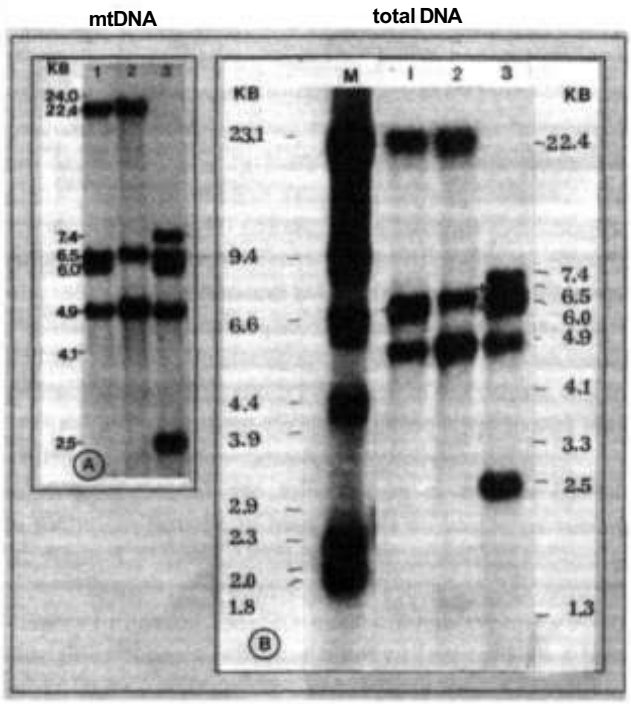


Figure 1. Southern blot hybridizations of tDNA (A) and mtDNA (B) of pearl millet male-fertile (81B) and two cytoplasmic male-sterile lines (81 A_1 and 81A_m= 81A_4). The tDNA and mtDNA samples were digested with *Hind*III and *Bam*HI, respectively, and probed with *coxI*. Fragment sizes are given in kilobases (kb). Arrows indicate apparent fusion of two (6.5 kb and 6.0 kb) or three (7.4 kb, 6.5 kb and 6.0 kb) fragments in tDNA Southern blots. Genotypes: B = 81B, A_1 = 81A_1, A_m = 81A_m = 81A_4.

For example, 6.5 kb and 6.0 kb bands in 81B merged to form a single thick band in *BamHI-coxI* Southern blots of tDNA (Fig. 1B), whereas, they appeared as independent distinct bands in mtDNA Southern blots (Fig. 1A). Similarly, three bands of 7.4 kb, 6.5 kb and 6.0 kb were not well resolved in tDNA blots (Fig. 1B). This might be because tDNA digested with restriction enzymes yields a larger number of fragments, which then require 1) longer gels, 2) shorter exposure times of autorads, or 3) use of a phospho-imager, in order to achieve effective separation of each fragment comparable to that possible for the smaller fragment numbers from digested mtDNA. The similarity in intensity of hybridization for the tDNA and mtDNA blots is indicative of the high specificity of probes that were used in this study. Results might not have been as favorable if less-specific probes had been used. The resolution in tDNA bands increased when longer gels were used for digested tDNA (data not shown). Our results indicate that mtDNA probes can be used with tDNA preparations for RFLP analysis of mitochondrial genome differences. However, this approach will need to be used with caution if repeated sequences are used as probes or copies of the mitochondrial genome are present in the nucleus.

References

Burton GW. 1965. Pearl millet Tift 23A released. Crop and Soils 17:19.

Burton GW and Athwal DS. 1967. Two additional source of cytoplasmic male sterility in pearl millet and their relationship to Tift 23A. Crop Science 7:209-211.

Chhabra AK, Rai KN, Khairwal IS, Sivaramakrishnan S and Hash CT. 1998. Mitochondrial DNA-RFLP analysis distinguishes new CMS sources in pearl millet (*Pennisetum glaucum* (L.) R. Br.). Journal of Plant Biochemistry and Biotechnology 7:85-92.

Dellaporta SL, Wood J and Hicks JB. 1983. A plant DNA minipreparation: version II. Plant Molecular Biology Reporter 1:19-21.

Dewey RE, Levings III CS and Timothy DH. 1985. Nucleotide sequence of ATPase subunit 6 gene of maize mitochondria. Plant Physiology 79:914-919.

Hanna WW. 1989. Characteristics and stability of a new cytoplasmic-nuclear male-sterile source in pearl millet. Crop Science 29:1457-1459.

Isaac PG, Jones VP and Leaver CJ. 1985. The maize cytochrome c oxidase subunit I gene: Sequence, expression, and rearrangement in cytoplasmic male-sterile plants. EMBO Journal 4:1617-1623.

Leaver CJ, Isaac PG, Small ID, Bailey-Serres J, Liddell AD and Hawkesford MJ. 1988. Mitochondrial genome diversity and cytoplasmic male sterility in higher plants. Philosophical Transactions of the Royal Society (London) B 319:165-176.

Marchais L and Pernes J. 1985. Genetic divergence between wild and cultivated pearl millets (*Pennisetum typhoides*). I. Male sterility. Zietschrift fur PflanzenUchtung 95:103-112.

Rai KN, Virk DS, Harinaryana G and Rao AS. 1996. Stability of male-sterile sources and fertility restoration of their hybrids in pearl millet. Plant Breeding 115:494-500.

Smith RL and Chowdhury MKU. 1991. Characterization of pearl millet mitochondrial DNA fragments rearranged by reversion from cytoplasmic male-sterility to fertility. Theoretical and Applied Genetics 81:793-799.

Popping Quality and Sensory Quality of Small Millets

Sarita Srivastava*, Sangita Kumari and Shadab Masud (Department of Food and Nutrion, College of Home Science, GB Pant University of Agriculture & Technology, Pantnagar 263 145, Uttar Pradesh, India)
*Corresponding author: sarita_sri56@rediffmail.com

Introduction

Popped cereal, especially popcorn, is widely used as a snack food in India and several other parts of the world. The technique of popping is quick, relatively simple, and improves the digestibility of starch in cereal grains. The small millets are rich sources of minerals and B-vitamins (Malleshi 1986). They are generally consumed in the form of *chapathi* (unleavened bread) or boiled like rice. Some studies have shown that they can be popped. Popped finger millet (*Eleusine coracana* Gaertn.) is eaten in some villages of South India, but the popped form of other small millets is uncommon. The present study was undertaken to develop simple technology of popping small millets and to test the sensory quality of popped grains of small millets to assess their suitability for use as snack foods.

Material and Methods

A total of 29 improved genotypes and 23 local samples of barnyard millet [*Echinochloa colona* (L.) Link], finger millet, foxtail millet [*Setaria italica* (L.) Beauv.J, and proso millet (*Pancium miliacem* L.), obtained from the Kumaon region of Uttar Pradesh, were studied. The moisture content of grains was standardized by soaking the grains in water for varying periods and thereafter drying at room temperature for varying periods. On the basis of preliminary trials, the following treatments were selected and given to the grains before popping:

- finger millet 10 minutes soaking and 3 hours drying;
- foxtail millet 5 minutes soaking and 1 hour drying;
- proso millet 1 hour soaking and 12 hours drying; and
- barnyard millet no soaking.

Popping was in common salt following the method of Srivastava and Batra (1998). Popping percentage and volume of popped kernels were recorded. Flake size was calculated as the ratio of volume of popped kernels to number of popped kernels. Sensory quality of popped samples were evaluated on a nine-point hedonic scale by a trained panel of 10 members (Amerine et al. 1965).

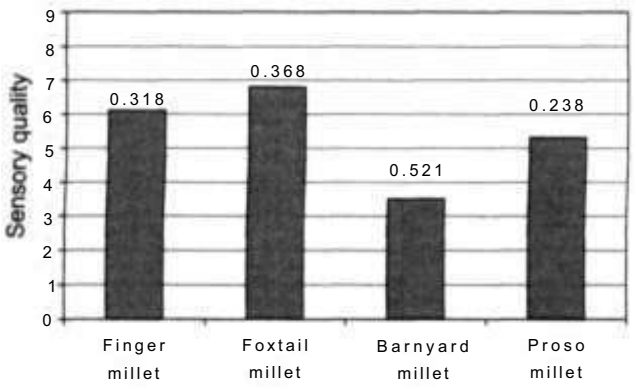


Figure 1. Sensory quality (means of 10 replicates) of popped grains of four species of small millets on a nine-point hedonic scale. Standard errors are given above the bar for each species.

Results and Discussion

Popping percentages of finger millet samples ranged from 86 to 95%, while those of foxtail millet ranged from 75 to 96%, barnyard millet ranged from 78 to 84%, and proso millet ranged from 52 to 58%. The highest mean popping percentages were observed for finger millet, followed by foxtail millet, barnyard millet and proso millet. However, the percentage of fully popped grains was highest for foxtail millet (46 to 75%) and lowest in finger millet (20 to 78%). Flake size was highest for proso millet (0.033 to 0.035) and lowest in finger millet (0.006 to 0.015). Of all the small millets tested, foxtail millet had the best sensory quality, followed by finger millet, proso millet and barnyard millet (Fig. 1). Popped grains of foxtail millet, finger millet and proso millet were acceptable, but popped grains of barnyard millet had a slightly bitter taste.

References

Amerine MA, Pangborn RM and Roseller EB. 1965. Principles of sensory evaluation of Food. New York and London: Academic Press.

Malleshi NG. 1986. Processing of small millets for food and industrial uses. Pages 325-339 *in* Small millets in global agriculture (Seetharam A, Riley KW and Harinarayana G, eds.). New Delhi: Oxford & IBH.

Srivastava S and Batra A. 1998. Popping quality of minor millets and their relationship with grain physical properties. Journal of Food Science and Technology 35:265-267.

Workshop Reports

Workshop on Breeding for *Striga* Resistance in Cereals

BIG Haussmann[1,*], DE Hess[2], ML Koyama[3], J DeVries[4], JG Kling[5], A Melake-Berhan[5] and HH Geiger[1] (1. University of Hohenheim. Inst. 350/3, D-70593 Stuttgart, Germany; 2. ICRISAT, BP 320, Bamako, Mali; 2. John Innes Centre, Colney Lane, Norwich, NR4 7UH, UK; 4. The Rockefeller Foundation, PO Box 47543, Nairobi, Kenya; 5. International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan, Nigeria)
*Corresponding author

The phanerogamous root parasite *Striga hermonthica* (Del.) Benth. causes major yield reductions in the principal cereal crops of semi-arid Africa. A workshop on breeding for *Striga* resistance in cereals was held at the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, from 18 to 20 August 1999. The meeting was organized by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), IITA, the University of Hohenheim, Eberhard-Karls University of Tubingen, and the Rockefeller Foundation. Funding was provided by the Bundesministerium fur wirtschaftliche Zusammenarbeit (BMZ), Germany, the Rockefeller Foundation, and the International Fund for Agricultural Development (IFAD). The 56 participants comprised 26 cereal breeders or weed specialists from national agricultural research systems (NARS) of 17 African countries, and 30 scientists or representatives from the International Maize and Wheat Improvement Center (CIMMYT), Centre de cooperation internationale en recherche agronomique pour le developpement (CIRAD), ICRISAT, IITA, John Innes Centre (JIC), the Natural Resources Institute (NRI), Pan African *Striga* Control Network (PASCON), ProAgro Seed Company, the Rockefeller Foundation, Cornell University, University of Hohenheim, Purdue University, University of Sheffield, University of Tubingen, West Africa Rice Development Association (WARDA), and the Weizmann Institute of Science.

Objectives of the workshop were two-fold: 1) to summarize the "state of the art" of cereal breeding for *Striga* resistance (including conventional and biotechnological approaches), and; 2) to develop with NARS scientists future strategies for *Striga* control in sorghum, maize, millet and rice, emphasizing host plant resistance. The workshop included presentations related to physiology of the host/parasite interaction; resistance mechanisms; inheritance of resistance; new sources of resistance in wild relatives of sorghum; actual breeding programs for *Striga* resistance in maize, sorghum, millet, and rice; molecular markers for *Striga* resistance; identification of *Striga* tolerance genes in maize using transposable elements; other biotechnological approaches for *Striga* control; diversity of *Striga* populations and consequences for resistance breeding; and breeding towards integrated *Striga* control. Since so many presentations dealt with molecular markers, the workshop was preceded by a two-day training course on the application of molecular markers in plant breeding programs (16-17 August; training manual available on-line at http://www.icrisat.org/gt1/mol/molecular.htm). Participants visited the IITA screenhouses at Ibadan, and several field trials (on-station and on-farm) at Mokwa. On the final day, working groups discussed future strategies in *Striga* research and developed the following recommendations.

Strategies essential for efficient **conventional breeding** for *Striga* resistance include:

- careful definition of target environments;
- determination of the most important selection traits for each target environment;
- identification of adapted parents for use in a backcross program;
- training of NARS scientists to use both laboratory and field screening methods;
- transfer of available resistance into farmer-selected varieties, through combined use of laboratory (e.g., agar-gel and paper-roll assay) and field screening methodologies;
- combining different resistance mechanisms and tolerance to *Striga* in individual varieties; and
- networking and exchange of useful plant genotypes.

Population improvement through development of a random-mating population combining several different resistance genes could be very useful, but would have to be carried out on a large scale by a dedicated, able breeder.

Targeted searches for new resistance sources in pearl millet, sorghum, and their **wild relatives** are important using recently perfected field and laboratory screening methodologies.

Marker technology and QTL analyses were considered to be potentially very useful. Verification of results is essential, as preliminary results suggest complex QTL patterns and low repeatability of individual QTL across environments and different mapping population samples.

Future research efforts should continue to

- develop universal marker systems, especially allele-specific markers;
- develop isogenic lines to quantify QTL effects for *Striga* resistance;
- create an integrated, PCR-based sorghum reference map (begin by integrating *Striga* resistance mapping populations);
- identify adapted sorghum parents for use in marker-assisted selection programs;
- determine whether the low-stimulant genes in SRN 39 and IS 9830 are identical; and
- develop a sorghum data base (ICRISAT leadership).

Once resistance genes have been identified, efforts should be made to exploit **synteny** in sorghum, maize, rice and millet. Transfer of resistance genes from cowpea into cereals was not considered a priority.

The continued **search for resistance mechanisms** and their genetic basis should always run parallel to the marker approach, with a final aim of identifying allele-specific markers. Enhanced knowledge of the physiology of the host/parasite interaction is urgently required to:

- examine interactions between host root exudates and exudates from the *Striga* radicle;
- determine how *Striga* induces its strong sink reaction;
- study how early host plant flowering minimizes the "bewitching" effect of *Striga* on its host;
- clarify the role of ABA; and
- study mechanisms of antibiosis.

An unconventional approach to *Striga* control would **reduce *Striga* vigor by genetic engineering.** In this approach enzymes are identified that reduce the vigor of *Striga,* using deleterious transposons (DTs) to reduce *Striga* vigor. First model studies are underway at the Weizmann Institute of Science.

The development of cultivars with target site **resistance to acetolactate synthase (ALS) inhibiting herbicides** was considered to be (probably) appropriate for maize in Africa and pearl millet and sorghum in Asia (i.e., in regions where the crops do not have feral or weedy relatives). It seems less appropriate for rice in Asia and Africa, pearl millet in West Africa, and sorghum in Africa (i.e., in crop/region combinations where feral or weedy relatives are present).

Transposon-based mutation breeding may allow researchers to:

- find resistant phenotypes that previously did not exist, due to transposon insertion into relevant genes;
- tag genes that are involved in host response to *Striga* (forward genetics);
- isolate and clone the gene; and
- use the cloned gene in both the host and other host plant species.

Future research related to ***Striga* variability** should:

- study inheritance of isoenzyme and DNA markers;
- analyze linkage between markers;
- perform cytological studies on *Striga* chromosome number and degree of polyploidy;
- develop 10 to 15 micro-satellites for *Striga* diversity studies;
- estimate polymorphism in *Striga hermonthica* populations that are naturally adapted to different hosts;
- test more populations from wide geographic sites across Africa, and from a variety of different resistant and susceptible hosts;
- extend host range tests;
- standardize sampling procedures;
- include farmer consultation on field history;
- create genetic stocks of various *Striga* strains by developing full-sib families;
- develop a set of host plant differential lines; and
- elucidate mechanisms and inheritance of *Striga* virulence focussing on *Striga* sensitivity to germination stimulants, *Striga* penetration into host roots, and the role of exoenzymes.

Inter-Center collaboration is highly encouraged in this respect.

With respect to **integrated *Striga* control,** methodologies immediately available for technology transfer/extension services include:

- maize/legume (groundnut, soybean, cowpea) inter-cropping, plus weeding and fertilization: 100-120 kg N and 50-60 kg P_2O_5 for moist savannas;
- sorghum/cowpea intercropping: two rows sorghum + four rows cowpea, strip planting;
- rotations of cereals and legumes; and
- tied ridges for the Sahel.

Further research on integrated *Striga* control should focus on:

- location-specific laboratory screening of cultivars of non-host species for their ability to germinate *Striga* (cowpea, soybean, groundnut, cotton, pigeon pea, *Phaseolus* beans, cassava, sorghum, millet, maize, *Stylosanthes,* and sesame);
- participatory, on-farm development of individual, integrated *Striga* control packages, adapted to each target area; especially consider rotation or intercropping of sorghum/maize with legumes (soybean, cowpea, groundnut, *Phaseolus* bean); and
- impact studies.

Individuals/organizations have been identified to carry forward on most of the above topics. A CD proceedings of the workshop is in preparation.

Identification of Technological Research and Demands for Extending Pearl Millet Cultivation in Brazil: Final Report of the First International Pearl Millet Workshop Organized by JICA and Embrapa at Planaltina, Brazil, 9-10 June 1999

Mauricio Antonio Lopes (Assistant Head of Research & Development, Embrapa Com & Sorghum, Sete Lagoas, MG Brazil)

Pearl millet has been used in Brazil as an excellent option for producing mulch to cover soils in no-till farming areas, or as a source of winter forage or grazing forage in arid regions or during dry seasons, and to a lesser extent as a source of grains for use in animal fodder. Due to its versatility, rusticity and rapid growth, particularly in areas where Brazil's *cerrado* savanna soils predominate, the demand for new cultivars and information has been rising rapidly over recent years. For this reason, the Japan International Cooperation Agency (JICA), Embrapa *Cerrados* (CPAC) and Embrapa Corn and Sorghum (CNPMS) organized the first international Pearl Millet Workshop held at Embrapa *Cerrados* near Brasilia, on 9-10 June 1999. This event was attended by renowned scientists from Brazil and abroad, as well as representatives of professional associations, ranchers, growers and farmers interested in various aspects of the development and use of this grass. Because of the high level of presentations and discussions, which focused on the main problems and issues of a practical nature related to growing pearl millet in Brazil, this event provided an excellent opportunity for probing demands for technological research supporting pearl millet-growing in Brazil. The Organizing Committee thus decided to prepare this Final Report, presenting in a brief and objective manner the main concerns and recommendations put forward by the various speakers and discussants. Listed below are the topics covered at each of the Workshop Sessions, indicating the main research recommendations put forward during this event.

Breeding and Seed Production
Dr C Tom Hash, ICRISAT-Patancheru, India

Dr Hash explained that pearl millet is a robust diploid annual grass which is predominately cross-pollinated, and whose genetic enhancement methodologies are very similar to those used for maize. The main types of pearl millet cultivars are:

Varieties

- Open-pollinated cultivars - synthetics and composites
- Produced from base stocks;
- Selection methods include recurrent selection, population backcrossing, etc.

Hybrids

- Use the concept of combining ability: line x tester and topcross;
- Enhancement of specific combining ability is tagged as top priority;
- Reciprocal recurrent selection is used to increase heterosis;
- To produce hybrids, it is necessary to generate gene pools or define heterotic groups.

Desired traits for pearl millet hybrids

- In grain production fields, the plants must be male fertile;
- Which is assigned higher priority: enhancement to maximize yield potential or general performance including seed production characters?
- General performance should be assigned higher priority (deliverable hybrids):
  - Stable male-sterility of the seed parent;
  - Predictable flowering of hybrid parents in seed production environments;
  - The male parent should be taller and the female shorter;
  - The female should have good seed yield capacity;
  - Special care should be taken when assessing pollen production capacity of the hybrid and stigma receptivity of its seed parent;
  - Other important features: lodging, pest/disease resistance, etc.

Molecular genetics

- Pearl millet has a relatively small genome - 3 pg/ haploid - and only 7 chromosomes;
- This species may become a good model for marker-assisted selection because of its relatively short genetic linkage map and high levels of polymorphism;
- There are also possibilities that this species could become a good model for genomic studies (control mechanisms for drought tolerance, grain quality, etc.).

Pearl Millet in Brazil
Dr Luis Albino Bonamigo, Sementes Bonamigo, Campo Grande, MS, Brazil

Dr Bonamigo presented an excellent analysis of the impacts of introduction of pearl millet on the development of no-till agriculture in Brazil. According to Dr Bonamigo, no other crop has managed to achieve the biomass

production levels of pearl millet. Data was presented indicating a dry matter output in 57 days of 6.3 t ha^{-1}, equivalent to 112 kg ha^{-1} d^{-1}. The most important points in the presentation included:

Factors affecting the success of pearl millet:

- Drought tolerance making it well-adapted to poor water availability conditions in Brazil's *cerrado* savannas;
- Good development in high and low fertility soils;
- Rapid growth and impressive mass production capacity;
- Growing operations can be mechanized;
- Low weed encroachment;
- Few problems with pests and diseases;
- Good tolerance to low temperatures;
- Good seed production.

Dr Bonamigo analyzed the main problems and concerns requiring responses from pearl millet research and development institutions in Brazil:

Aircraft overlay sowing:

- Has not worked well - very uneven results;
- Water availability for establishing the system is a limiting factor - need 35 mm during a period of up to 10 days after sowing;
- Seed quality is a limiting factor for the effective introduction of this system.

Sementes Bonamigo is not developing new cultivars:

- Due to the specific characteristics of the market for open-pollinated varieties this activity offers poor returns for the company;
- However, there is a demand for more detailed work on genetic enhancement to produce varieties and hybrids.

PANEL SESSION 1: Pearl Millet in No-till Farming Systems

First Panelist
Dr Carlos Pitol, Fundacao MS, Maracaju, MS, Brazil

Dr Carlos Pitol expounded on the objectives and projects undertaken by the MS Foundation, which include seeking solutions to problems perceived as imposing constraints on pearl millet in Central and western Brazil. One of the main problems identified at the start of the work with pearl millet was the large number of doubts on how to control pearl millet, as there were fears about its potential as a weed. The main contributions were:

Guidance on management:

- Development of technologies based on the use of herbicides.
- Management practices to reduce the rate of decomposition of pearl millet straw.

Problems requiring research:

- Multiplication of *Meloydogine javanica,* a nematode that affects soybeans:
  - Some species - such as maize - are nematode multipliers, while pearl millet apparently has the effect of reducing their numbers.
- There is need to develop technologies to make good use of pearl millet for grazing lands:
  - Many farmers have tested combinations in an empirical manner.
  - Pearl millet/oats, pearl millet/Tanzania grass, etc.
- Uneven germination under drier conditions is a problem for subsequent crops.
- Uneven flowering results in contamination of the soybean crop with pearl millet volunteers.
- Correct management of pearl millet for mulch involves herbicide application to desiccate the crop when 5 to 10% of the panicles have emerged.
- Maize following pearl millet very frequently leads to phytosanitary problems.
- More research is required into the development of pearl millet cultivars:
  - Development of better adapted cultivars for the various forms of use: for mulch, forage or grain.
  - Better crop duration, particularly when it is necessary to maintain mulch for long periods.

Second Panelist
Dr Lucien Seguy, CIRAD-CA, Goiania, GO, Brazil

Dr Lucien Seguy stressed the pioneering role of CIRAD-CA in the introduction of pearl millet in the Brazilian *cerrados,* which interrupted the destructive cycle represented by monoculture + use of harrow by restructuring crop production system which is now based on more intensive soil mulching practices and no-till farming.

Dr Seguy stressed the following advantages for pearl millet:

- It provides an excellent soil restructuring system as well as soil carbon replenishment.
- Because of its rapid growth it is an excellent weed suppressant.
- It is also an effective biological plough.
- The pearl millet mulch and root system provide a cushioning effect on soil structure, reducing problems with soil compaction.

Problems for research:

- Soil fungi populations increase with heavier mulching:
  - The low C/N ratio of pearl millet mulch may be making this problem worse.
- Grasses with higher C/N ratios are required, in order to allow the straw to lie on the soil surface for longer periods.

- Development of photoperiod-insensitive genotypes is necessary to produce forage cultivars that are better able to withstand short day lengths and cooler nights.

New opportunities for pearl millet in Brazil:

- There is still little interest in this crop for use in human nutrition.
- It could be an excellent source of additional income for farmers, with an output of 2,000 - 3,000 kg ha^{-1} of grains as a second crop.

Third Panelist
Dr Marcio Scalea, Monsanto de Brasil

Dr Marcio Scalea analyzed the situation of pearl millet in Brazil and highlighted some concerns to be taken under consideration by research projects:

- There has been very rapid expansion of this crop in Brazil over a short period of time.
- The genetic base for this crop in Brazil is very narrow, which represents a hazard.
- The appearance of more severe diseases and pests would result in marked vulnerability of this crop and the no-till production systems that it facilitates.
- It is necessary to broaden the range of options for genetic materials available to farmers, seeking:
  - tolerance to cold temperatures,
  - resistance to diseases - particularly rust, and
  - higher grain yields.

Another concern is the fact that pearl millet is not producing good amounts of straw when sequentially cropped after maize.

Finally, Dr Scalea stressed the need to treat the pearl millet crop with a more professional and technical approach, such as row planting, fertilization, etc. There is also much concern over the indiscriminate or uncontrolled introduction of seeds from Africa, which might also introduce the *Striga* weed, which invades rapidly and is hard to control.

Fourth Panelist
Dr Roberto Pereira, Embrapa Cerrados, Planaltina, DF, Brazil

Dr Roberto Pereira presented and discussed a series of data on research projects assessing the effects of mulching on weed control, as well as the competitive capacity of the mulch, compared to the weeds, and the restrictive effects of mulching crops on subsequent crops.

PANEL SESSION 2: Pearl Millet as a Forage Crop

Panelist 1
Dr Roger Gates, USDA-ARS, Tifton, GA, USA

Dr Roger Gates presented results from experiments focused on the use of pearl millet as a forage plant in the southeastern USA, stressing the work of the US Department of Agriculture (USDA) in the state of Georgia. He emphasized mat the genetic variability of this species is immense, offering a great opportunity for the development of pearl millet cultivars enhanced for a wide variety of traits.

A pearl millet forage hybrid program should take the following aspects into consideration, in terms of nutritive value of this grass:

- The yield and quality of forage dry matter are affected by crop maturity.
- Cellulose content (cell wall) and lignin content increase as the plant matures.
- Crude protein levels drop as the plant matures.
- As a result, forage digestibility also drops as the plant matures.

What should be taken into consideration when breeding pearl millet to produce forage?

- Pearl millet is a crop that builds up high moisture levels.
- This results in problems related to storage and processing for silage or hay.

What should be taken into consideration when breeding hybrids to produce forage?

- Efficient testing of qualities for forage production is required.
- Dramatic changes occur for both composition and quality of forage during the period 50-80 days after crop emergence.
- A check should be carried out on the proportions of grains/stems/leaves at different phases of crop development, in order to determine the best period to harvest in order to maximize forage yield and quality.

Important aspects of the pearl millet forage hybrids breeding program run by the USDA at Tifton, Georgia include:

1. This program was launched with multi-line hybrid production - intercrossing several pure lines to produce hybrids. The Gahi 1 hybrid is a mixture produced by field-scale intermating of four inbred lines. In the forage production field, only F_1 plants prevail, as the

inbred lines lack the vigor to compete. This could be an interesting option as a initial step towards the production of hybrids in Brazil.

2. Introduction of cytoplasmic male sterility allowed production of genetically uniform single-cross hybrids such as Gahi 3.
3. Introduction of dwarfing genes to reduce stem length between nodes and boost leaf production increased forage quality and allowed the production of dwarf hybrids for grazing that are easier to manage than traditional tall cultivars.
4. Breeding for disease resistance - particularly rust. This disease has a drastic effect in terms of reducing digestibility, and should be taken into consideration in breeding programs.
5. Development of three-way hybrids to boost seed production efficiency without losing the impact of heterosis.
6. Encouraging prospects for inter-specific hybrids (pearl millet x elephant grass) - such a strategy allows seed-sown crop that last perennially.

Dr Gates also made the following important observations:

- Pearl millet forage production costs are high, so its forage should be assigned to livestock with higher response capacity.
- In order to produce hay, pearl millet should be grown in regions with a clearly-defined dry season, in order to help with processing.
- The high moisture content of this crop adversely affects the fermentation process for silage. Materials being ensiled need to have sufficient quantities of fermentable carbohydrates, and pearl millet forage should be partially dried before use in production of silage.
- To produce feed and food grain, pearl millet has an advantage over other cereals, as it has low susceptibility to aflatoxin contamination.

Panelist 2
Dr Armindo Kichel, Embrapa Beef Cattle, Campo Grande, MS, Brazil

Dr Armindo Kichel presented an excellent summary of the prospects for the use of pearl millet in beef cattle-raising systems, illustrating various experiences of Embrapa Beef Cattle, such as:

- management of pearl millet crops for reducing use of grazing lands;
- management of pearl millet crops for direct grazing;
- management of pearl millet crops for silage;
- management of pearl millet crops in grazing land recovery systems; and
- management of pearl millet crops as protein banks in association with traditional grasses (brachiaria).

Dr Kichel outlined research concerns regarding the capacity of pearl millet crops to extract N and K, with adverse effects on the subsequent crop.

Panelist 3
Dr Edmundo Benedetti, Uberlandia Federal University, Uberlandia, MG, Brazil

Professor Benedetti discussed the use of pearl millet in dairy farming, stressing the potential of this crop in upgrading milk production systems through enhancing the nutritional standards of the herd, which is extremely important in maintaining the competitive edge of the farmer. During his presentation, he stressed that good digestibility is important in pearl millet, but not vital. In some situations, lower digestibility may be offset by higher mass consumption (better leaf production).

PANEL SESSION 3: Pearl Millet Grain as a Livestock Feed

Panelist 1
Dr Carlos Roberto Pacheco, Granja Rezende, Uberlandia, MG, Brazil

Dr Carlos Roberto Pacheco presented a summary of the difficulties faced by livestock feeding industry when using pearl millet grains. Based on the experience of Granja Rezende with processing and using this grain for animal consumption, the following recommendations were emphasized:

- Basic information about use of this crop as a feed grain is in short supply.
- The volume of grain available on an annual basis is insufficient for more intensive use by the industry.
- There is a lack of information on grain grading standards and procedures guiding receipt of this grain by the industry.
- More accurate information is required on the chemical composition of pearl millet grains as well as better characterization of the genotypes currently grown.
- Data is lacking on the energy density of the grain to guide its use in poultry and swine.
- Data is lacking on the amino acids profile of pearl millet grain, and digestibility of the protein/amino acids, in order to guide its use in poultry feed and swine.
- Further information and studies are necessary to define the limits on the use of this grain as a feed source for animals.

Panelist 2
Dr Jose Henrique Stringhini, Uberlandia Federal University, Uberlandia, MG, Brazil

Professor Stringhini presented a broad-ranging overview of the data available at both the domestic and international levels covering the qualitative aspects of pearl millet grain and its use as a feed source for animals. This presentation outlined the following points:

- Pearl millet grain does not contain appreciable levels of xanthophylls and carotenes, which are important pigments affecting the appearance of carcasses and eggs.
- There is wide variation in the composition of pearl millet grain samples, in terms of crude protein, starch, ether extract, essential amino acids, etc.
- Comparative analytical data is lacking for current pearl millet cultivars compared to other grains such as maize and sorghum.
- Adjustments are required in grain processing in order to avoid whole grains or heterogeneity of constituents in ground bran. This concern is related to the small size of the pearl millet grain and the inadequate mesh of screens used by feed processing industries.
- Digestibility of fiber present in pearl millet grain is apparently less than that of fiber present in other feed grains.
- It is necessary to assess genetic variability for the build-up of tannins and phenolic compounds in pearl millet grains.
- There are prospects, to be confirmed, of high concentrations of omega-3 fatty acid in pearl millet grain (compared to other grains), which could have an effect on reducing arteriosclerosis.
- There are reports, to be confirmed, of the presence in pearl millet of substances that could worsen thyroid problems. These cases seem to be restricted to regions where iodine-deficient diets are based on pearl millet.
- Compared to other cereals, there is higher trend towards the rancidification of fatty acids in pearl millet, which may affect grain processing and storage.

Workshop Proceedings Published

A proceedings of this International Pearl Millet Workshop has been published in Portuguese by JICA and Embrapa, along with a limited number of copies of an English translation. While stocks permit, copies are available from Embrapa Cerrados (milheto@cpac.embrapa.br) and Embrapa Corn and Sorghum (cnpms@cnpms.embrapa.br).

Farmers in Targeted Area Using a Wider Range of Crop Management Options Leading to Increased Productivity in Zimbabwe

GM Heinrich (SADC/ICRISAT Sorghum and Millet Improvement Program, PO Box 776, Bulawayo, Zimbabwe) g.heinrich@cgiar.org

Introduction

One of the major research themes or Intermediate Results (IRs) in Phase IV of the Sorghum and Millet Improvement Program (SMIP) is to increase the productivity of sorghum- and pearl millet-based systems—IR1.2. Highlights of work conducted under this research theme in Zimbabwe to date are described. It should be noted that this work is interlinked with that of other SMIP themes on seed systems and improving output markets.

The objectives of IR1.2 are to increase the productivity and incomes of smallholder farmers, and to protect the environment through the adoption of integrated soil water and nutrient management (ISWNM) technologies. Soil nutrient status is extremely important in crop production because it has a direct effect on the productive potential of the environment. Soil nutrients in communal areas in Zimbabwe are declining due to net nutrient outflows (Mapfumo and Giller 2001). (Zimbabwe is one of SMIP's Phase IV target countries.) These areas are also semi-arid, and often their crop productivity is limited by lack of moisture. This makes improved soil water management important. Poor soil water management can also cause erosion that contributes to major nutrient losses and environmental degradation. Research has shown that better management of these two key resources holds tremendous potential for increasing productivity and incomes at the farm level in the semi-arid areas of southern Africa.

Progress of Activities

SMIP's activities on soil water management target *both* the identification and adaptation of improved management options, and the pilot testing of approaches aimed to facilitate adoption of better management systems by smallholder farmers. In tests for approaches for management options, links with input supply and output marketing efforts are crucial. Research in this area is being conducted in both Tanzania and Zimbabwe and the key partners are the national research and extension systems. In Zimbabwe, other partners include the University of Zimbabwe Department of Soil Science; the FAO; the Rockefeller Foundation (which contributes financial support); Tropical Soils Biology and Fertility (TSBF) Program; and NGOs: Intermediate Technology Development Group (ITDG), CARE, and the Citizens Network; and farmers. Private sector companies like the Zimbabwe Fertilizer Company are also becoming involved.

In both Tanzania and Zimbabwe, work on increasing productivity began with in-depth literature reviews on past research on soil fertility and soil water management, the examination of technology options currently considered to be effective, levels of adoption of recommended practices, and farmers' current production systems. Baseline surveys were implemented on farmers' current practices and production constraints in target research areas. Information generated in the ICRISAT crop growth simulation program helped to guide the choice of input levels mat were examined. Discussions were also held with research, extension, and NGO personnel and farmers on identifying technology options that appeared to be practical and effective and were of interest to farmers.

Identification of promising technologies in Zimbabwe. Interaction with target communities was initiated in the 1998/99 cropping season, and a systematic on-farm, farmer participatory research (FPR) process was launched during the 1999/2000 cropping season. The purpose of farmer participatory research is to test and adapt a range of soil fertility and soil water management options identified earlier in the program. Options that prove successful were to be fed into a subsequent pilot program aimed to facilitate broad adoption in target areas. Two representative target districts, Tsholotsho and Gwanda South, were selected in 1998/99 and a third, Zvishavane, was added in 2000/01.

To institute the FPR program in communities, initial village level meetings were held to introduce and discuss the program with the communities at which interested farmers volunteered to participate in the program. Further meetings were held with groups of volunteer farmers to discuss and choose the technology options and methods for conducting trials. The majority of the volunteers were women.

A series of dials were implemented. These included two trial types: Researcher Managed trials (RM) and Farmer Managed trials (FM). The RM trials were designed

to address topics of particular interest to research, and to provide good quantitative data on specific questions. Researchers supervised all field operations and data collection activities, and provided the necessary inputs. In the FM trials, farmers individually selected the technology options they wished to evaluate. However, for the different options tested, farmers had to agree on trial design and systems for applying experimental variables. Farmers individually decided on the levels at which they would apply all non-experimental variables, and conducted all field operations including the maintenance of records of the operations. Researchers assisted farmers to collect harvest data. The main cereal crops in the trials were sorghum and pearl millet and the main legume crops were groundnuts, cowpeas, and bambara groundnuts.

Field days were held prior to harvesting at trial sites identified as exemplifying the most important lessons emerging from the trials program (from both the RM and FM trials). Attendance at field days was generally about 100 to 150 farmers.

After harvesting, farmers jointly evaluated all technology options that were under experimentation—scoring and ranking the various treatments using their own evaluation criteria.

Technology options evaluated during the 1999/2000 season include the following:

- Modified tied ridging in combination with fertility improvement treatments (modified tied ridging involves using a plough to make furrows between crop rows, and "tying" the furrows with soil after every 1 or 2 meters to trap rain water in the field. The operation was implemented in place of the first weeding.)
- The use of farmyard manure (FYM) and combinations of minimal amounts of FYM and inorganic nitrogen
- Management systems to improve the quality of FYM
- The use of legume rotations to improve soil fertility
- Seed priming (seed is soaked overnight in water, before planting. The purpose is to improve the rate of emergence. Stand establishment is a common problem in the semi-arid areas).

Rainfall in the 1999/2000 season was about 100% above normal in the two target research areas in Zimbabwe. This was also the first year of the trials program. Results should therefore be interpreted with caution. None-the-less, several results are of interest. Highlights include the following:

- No yield benefits could be attributed to water conservation measures for the year because rainfall was abundant. Although modified tied ridging did not show yield benefits, farmers found it easy and practical to use. Researchers observed that the system appeared to slow down water movement/runoff in the field and to help in reducing erosion. The system looks promising in drier years.
- An "exchange visit" to see on-farm research being conducted in other semi-arid areas of the country stimulated participating farmers' interest in a water conservation system known as "dead-level contours and infiltration pits". About five farmers spontaneously started testing these systems in their own fields.
- Grain yield response to FYM was limited in this first year of application. However, improved management of FYM (in this case, heaping and covering the manure in July, prior to application at planting) significantly improved the grain yield response. This appeared to be related to an increase in the amount of available nitrate in the FYM, as a result of the treatment.
- There was a significant difference in grain yield response to different FYM types. Goat manure gave significantly higher yields than cattle manure, at the 7% level of probability, across manure management systems. In these trials, goat manure also had higher initial levels of N.
- On average, there was a significant response to the application of limited amounts of mineral nitrogen (9 and 18 kg ha^{-1} N applied as ammonium nitrate). This was not unexpected in a year of good rainfall.
- In end of year assessments, farmers concluded that goat manure is more "powerful" than cattle manure. In one location, farmers concluded that if a farmer has no cash at the start of the season he should apply FYM. But where cash is available, a farmer would get more immediate benefits from applying small amounts of inorganic N. Resources permitting, the best option would be to apply both FYM and N.
- Farmers consistently indicated that seed priming did increase the rate of emergence in both cereal and legume crops (cowpeas and bambara - it was not tried on groundnuts). While the yield benefit was not evident in this wet year, however, farmers felt that seed priming was a low-cost and practical option that can be useful in improving stand establishment in drier years.

The FPR program initiated in 1999/2000 was continued in 2000/01. The purpose was to obtain a more thorough evaluation of the options, and compare responses across years. In addition, the second year of testing included evaluation of residual effects of different manure management treatments and different levels of manure applications and of effects of rotation treatments.

The 2000/01 season was quite different from the preceding season. In Gwanda South, there was almost no rain in November and December. In January, rainfall was rather limited and from February onwards became quite regular. As a consequence, crops were planted late—in January instead of November/December.

In Tsholotsho, rainfall at the start of the season was reasonably good, and most of the trials were planted in December. However, there was a severe drought in January. Much of the maize died. In the experiments, most of the crops survived, but yield potential was reduced. Analysis of results of the second year, and a combined analysis across years, will be completed in August 2001.

In October 2000, a "Farmer Field Schools" (FFS) program was initiated, with support from extension personnel and other partner institutions (financial support has been provided by the Rockefeller Foundation). FFS groups (with 15 to 30 farmers each, the majority of whom are women) were formed in Tsholotsho (3 groups), Gwanda South (2 groups), and Zvishavane (2 groups). The groups meet weekly with a "facilitator" to discuss issues on principles of integrated soil fertility and water management and the related technology options to test. Each group's members decide on topics to examine, and jointly implements trials on a designated site.

The objective of the FFS program is to help farmers understand the basic principles of integrated soil water and nutrient management. The program also includes other relevant technology options. Participating farmers are encouraged to experiment on the management of resources which they already have, based on an understanding of certain underlying principles. A greater understanding of the principles of integrated soil water and nutrient management is expected to enhance farmers' ability to make rational management decisions in response to changes in their biophysical and socio-economic environment, and to make them less dependent on receiving specific technical recommendations from external sources. In the same target areas, SMIP is also initiating collaborative programs with NGOs and private sector companies to simultaneously improve farmers' access to input and output markets.

To date, implementation of the FFS program has gone well, and it is particularly popular with farmers. However, the current system is also fairly expensive (per farmer reached), particularly with regard to the training of FFS facilitators (extension officers). At a recent workshop, partners in the program discussed methods for reducing costs, increasing the number of FFSs and beneficiaries, and improving the sustainability of the FFS approach. Some innovative ideas developed will be tested in the coming season.

Seed Policy in Mozambique

DD Rohrbach (SADC/ICRISAT Sorghum and Millet Improvement (Program, PO Box 776, Bulawayo, Zimbabwe) d.rohrbach @cgiar.org

Sorghum and Millet Improvement Program (SMIP) recently completed a review of seed policies in Mozambique in collaboration with the national Ministerio da Agricultura e Desenvolvimento Rural and Michigan State University. This study estimates Mozambique is annually losing up to US $77 million in productivity gains from the failure of the national seed system to disseminate new varieties of grain and grain legume crops currently identified on the national registration list. This includes an annual loss of US$14 million resulting from the failure to disseminate improved varieties of sorghum and pearl millet. Substantially larger sums are being lost if one considers the complementary costs of continuing food insecurity and poverty.

The study offers a number of recommendations for strengthening the national seed system. For example, several recommendations are provided for the simplification of procedures for variety registration and release. Formal release procedures are suggested for varieties developed within Mozambique. However, the country would benefit by allowing the simple registration of varieties released in neighboring counties.

The analysis recommends the allocation of a specific budget to maintain breeder seed stocks of all released varieties. Cost recovery is recommended through sales of foundation seed to seed companies and development projects.

Mozambique is advised to encourage the entry of additional seed companies into the market. Companies producing seed locally can be favored in tenders for seed destined for emergency and development programs. However, free distribution of seed should be limited. If concessionary seed distribution through relief and development programs is necessary, strategies should be employed to promote the development of seed markets. Options include the use of small pack sales, and voucher programs linking seed delivery with the expansion of retail trading networks.

The study notes that emergency seed requirements are commonly over-estimated in Mozambique. Better procedures are needed to more accurately estimate these requirements. The analysis identifies areas of the country most prone to drought and flooding, and estimates approximate seed requirements in these areas. This analysis will be pursued in more detail when ICRISAT hires a seed system development specialist for Mozambique under a new project targeting the development of strategies for improving the efficiency of emergency seed supply.

The report suggests that community seed production should be explicitly recognized as a component of the national seed system. These programs should aim to complement the development of the commercial seed market by concentrating on seed crops of lesser commercial interest, or by working in areas of the country poorly served by commercial markets. Non-governmental organizations can also support the development of a sustainable national seed system by helping companies test the demand for new varieties and evaluate alternative marketing strategies.

The study notes that Mozambique currently relies on regional markets for more than 95% of the seed flowing through commercial and emergency channels of supply. This is unusually high by historical standards, and more efforts are needed to promote local seed production. Nonetheless, the availability of seed imports has been highly beneficial to the country. In this context, the regional seed market should be viewed as complementary to the national seed system. The efficiency of this link can be improved with the harmonization of regional seed laws, the encouragement of regional stockholding and sale of varieties most suited to Mozambique, and more active efforts to promote sharing of regionally suited varieties and germplasm.

The report notes the need to evaluate trade-offs between the benefits of seed regulation and the costs of delayed seed access to the nation's farmers. Cheaper seed of acceptable quality may be more beneficial to most farmers than expensive seed of extremely high quality. In this context, Mozambique is encouraged to promote truth in seed labeling and allow the sale of quality declared seed.

The study ultimately argues that seed policy should not simply be viewed as a series of regulations designed to protect the seed producer or consumer. Instead, seed policy should encompass a positive investment strategy targeting the delivery of better seeds to as wide a market of farmers as possible. The strength of the seed system should be assessed in terms of higher rates of adoption of a shifting array of improving varieties.

These findings were presented to a national seed workshop in early March 2001. Many of the recommendations were accepted for implementation.

A copy of the report titled "Investment priorities for the development of Mozambique's seed system" by David D Rohrbach, Jan Low, Alfredo Cucu, Jaquelino Massingue, Duncan Boughton, Guilhermina Rafael, Antonio Paulo, and Domingos Jocene, can be obtained from SMIP.

Fighting Food Insecurity through Seed Entrepreneurship at Community Level

MK Mbunji (SHAPES, Programme Against Malnutrition, PO Box 30599, Lusaka, Zambia)
pam@zamnet.zm

One of Africa's biggest problems, in Eastern and Southern Africa in particular, is household food insecurity. In Zambia, lack of access to seed of improved crop varieties by most households has been identified as one of the factors limiting household food security. Seed production and trade has for a long time been a preserve of advanced commercial farmers and financially strong seed companies. Profit motives have continued to undermine the supply of seed of improved food security crops, which generally include non-hybrid seed types, in preference for hybrid seed. The poverty situation of rural people, coupled with formal sector's insistence on cash as the only mode of acquiring seed, have further weakened the position of rural households in benefiting from the advances of science in crop improvement. Other organizations have come up to address the situation; and, in any case, the formal sector meets only 30% of the national seed requirements. One such organization is the nongovernmental organization Programme Against Malnutrition (PAM). Through its Seed Entrepreneurship programmes, PAM aims to transform smallholder farmers into commercial seed farmers so as to increase access to seed of improved crop varieties by the majority of rural farmers. The ultimate goal is to improve food security in rural areas.

The concept of seed entrepreneurship combines the advantages of both formal and informal seed supply systems. It is premised on the fact that producing good seed requires use of improved production practices and attention to detail, and on the assumption that in every community there are farmers, who with proper training and extension, can become reliable commercial suppliers of improved seed to their communities. In terms of marketing, the concept employs the efficiency of the informal sector in distributing seed while at the same time maintaining business acumen. The program encourages the seed acquisition and distribution through commodity exchange transactions, seed for work transactions, and cash purchases. A combination of these exchange modes has proved to be more efficient in distributing seed than the formal sector requirement for cash under the Zambian rural setup.

PAM started the Seed Entrepreneurship program as part of its Drought Rehabilitation Programme (DRP) during the 1997/98 season. The program is implemented in collaboration with the Ministry of Agriculture Food and Fisheries (MAFF) and extension network, which provides

the required production extension and quality control services to the seed entrepreneurs. A number of rural farmers are selected per district (average 35 farmers per district) and developed into seed entrepreneurs. To qualify, a farmer needs to have the following:

- A high food security status: seed entrepreneurs have to be food secure to avoid eating seed. This is a good indicator of the farmers' production capacity;
- A high personal integrity: the farmer has to be of high standing in their community as seed is bought on integrity basis; and
- A business mind: the farmer needs to have a business acumen as seed enterprising requires patience due to time lapses and also aggressiveness in marketing.

The farmers are trained on on-farm seed production procedures and entrepreneurship, and are advanced with all basic materials required for production including parent seed, fertilizer (in some cases), chemicals, and packaging materials as a loan, which is recovered after the farmer has harvested. This is because the program seeks to promote a business mentality. PAM also helps promote the seed farmers' activities through field days and advertisements.

The farmers choose the type of crops to multiply for seed, based on their assessment of the market (local farmers' interest). Each year, they are provided with fresh parent seed by the project. Seed of legumes and cereals is procured from seed companies, since the seeds are some of the products that the formal sector already deals in. But, for the root and tuber (cassava and sweet potatoes) crops a different system had to be developed, as they are not available in the formal sector. Elite planting material for these crops is obtained from primary nurseries situated at research stations. Keeping the nurseries at research stations makes it easier for plant breeders to closely supervise the nurseries so as to ensure that only very clean materials are released in the system. Produce from the primary nurseries are multiplied into secondary nurseries in districts where the crops will be grown. District nurseries are allocated to farmers with better production capacity—equipment and infrastructure. (Sweet potato farmers at this level need to have irrigation facilities.) It is from these district nurseries that seed entrepreneurs get their planting materials for bulking before distributing to other farmers in their community. Such a system addresses the problem of short shelf life (quick deterioration) of cuttings and vines, which is experienced when they are transported over long distances.

During the cropping season, farmers are individually visited by extension staff for monitoring and are registered with the Seed Control and Certification Institute (SCCI) for quality control and regulatory purposes. The SCCI has delegated some of its responsibilities for the informal seed sector at local level to the District Crop Husbandry Office (CHO). The decentralization of the SCCI has led to the setting up of seed testing laboratories in various provincial centers. All seed produced is tested for planting value. Only seed that has passed and a certificate issued to that effect, is treated with chemicals and packaged for sale to the other community farmers as Quality Declared Seed (QDS).

Entrepreneur farmers in the participating districts have formed seed associations. These associations are expected to take over current responsibilities of PAM at the end of the project's financing period.

Lessons Learned

A number of lessons have emerged from implementing the seed entrepreneurship program. Some of these include the following:

- Farmers acknowledge that improved varieties produce high yields.
- Seed farmers demonstrated improved cultural practices and business acumen in producing various crops.
- Farmers acquired the knowledge and skills necessary to produce improved seed.
- The extension service has gained its integrity as farmers on the program look up to them for advice and services.
- A serious attempt to develop a seed supply system for non-orthodox seed types like the cassava and sweet potatoes has been started,
- Seed of high cultivar purity and planting value is being produced and marketed commercially at local level by small-scale farmers.
- Loan repayments are almost 100% and the project is expanding both in number of farmers participating on the program and in the area put under seed production per farmer.
- Seed entrepreneurs are showing signs of improved living standards.

The seed entrepreneurship program now faces a new challenge-to keep up to date with consumption trends and to feed this information to research. By so doing, research would be able to develop new improved varieties that meet consumer and market needs.

Testing the Demand for Sorghum Meal in Tanzania: a Case Study with Power Foods

DD Rohrbach[1] and JAB Kiriwaggulu[2,*] (1. SADC/ ICRISAT Sorghum and Millet Improvement Program. PO Box 776, Bulawayo, Zimbabwe; 2. Marketing Development Bureau, Ministry of Agriculture, PO Box 2, Dar es Salaam, Tanzania)

*Corresponding author: kiriwaggulu@yahoo.com

Sorghum is the second most important cereal in the Tanzanian economy. The country's farmers annually produce over 600,000 t, enough to supply 30 kg of grain to every consumer in the country. Yet virtually all of this is consumed on the farms where it is produced.

The importance of sorghum as a national food security crop contrasts sharply with the lack of commercial marketing and utilization. During a reconnaissance survey conducted in 1999 (Rohrbach and Kiriwaggulu 1999), we estimated that less than 40 t of sorghum is being commercially milled for sale as meal each year. This compares with an estimated annual commercial milling of over 300,000 t of maize meal.

Millers expressed skepticism about the levels of commercial demand for sorghum meal. They argued that urban consumers, in particular, prefer maize, rice or wheat based food products. However, this perception contrasts with the experiences of countries like Botswana where 60,000 t sorghum meal is sold each year (50 kg per capita), and in South Africa where at least 15,000 t sorghum meal are sold each year. In particular we would expect that people migrating to urban areas from sorghum growing regions of the country would maintain a taste preference for sorghum meal.

One clue to the lack of sorghum meal demand, obtained during the 1999 reconnaissance study, was the high relative price of sorghum meal. In mid-1999, sorghum meal was selling in the Dar es Salaam at three to four times the retail price of maize meal. In effect, sorghum meal only represented a specialty food product.

Yet the justification for this price premium was difficult to establish. While sorghum prices in Tanzania's wholesale markets fluctuate sharply from year to year, these are commonly similar to the price of maize grain. In Dodoma, a major sorghum producing region, sorghum prices tend to be less than those for maize.

The two millers found to be processing small quantities of sorghum complained about the difficulty of grain processing. In particular, sorghum grain found in the wholesale market tends to be contaminated with sand and stones that can only be cleaned through a laborious process of grain washing. In addition, sorghum needs to be dehulled before it is ground into flour. Finally, milling throughput is reduced by the variability of grain quality associated with mixtures of varieties, and poor grain storage conditions in the market.

However, none of these factors fully explain the limited commercial milling of sorghum, and limited sale of sorghum meal. Grain quality can be improved by communication about grain standards. Grain processing can be improved with the purchase of grain cleaners. While questions remain about the levels and determinants of consumer demand, it is reasonable to target sorghum meal sales at minimum rates of one to five percent of the level of maize meal sales. This would increase sorghum sales from about 40 t per year to at least 3,000 t per year.

Response

In view of this potential, a pilot project was established to test the demand for sorghum meal in the Dar es Salaam market. This pilot project tested the assumptions that if sorghum meal is priced more competitively with maize meal, and if the quality of the milled product is found to be acceptable, the market for sorghum meal will grow. Project components were designed to examine consumer preferences for sorghum meal, consumer preferences for alternative sorts of packaging, and the sensitivity of consumer demand to retail price discounts.

The evaluation of consumer preferences was conducted through sensory taste panels outside the market, as well as through surveys of consumers purchasing sorghum meal in the market. Assessment of market demand for sorghum meal was pursued through testing for consumer interest in alternative types and sizes of packaging, and by reducing the price of sorghum meal to a level closer to the retail costs of maize meal. The latter experiment included a review of the costs of sorghum meal production.

In order to assess the commercial viability of the market for sorghum meal, the pilot project was led by a small private miller in Dar es Salaam - Power Foods. This miller had previously experimented with sorghum meal production. However, when the pilot study was initiated, the company's sales of sorghum meal were negligible—less than 2 t per year. Backstop support was provided by the Sokoine University of Agriculture (SUA), the Tanzania Food and Nutrition Centre (TFNC), the Ministry of Agriculture and Cooperatives (MAC), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Results

Over the period of the pilot project more than 30 t of sorghum meal were sold by Power Foods. A major factor explaining this expansion of sales was the reduction of sorghum meal prices. The average wholesale price declined by 50%. The average retail price of sorghum meal sold by Power Foods similarly declined.

However, sorghum meal still costs 50 to 100% more than the price of maize meal. This is largely the result of higher grain processing costs - particularly for grain cleaning and dehulling. The mechanization of these operations with appropriate equipment should significantly improve the efficiency of grain processing. Sorghum meal may then be sold at prices equal to or lower than for maize meal.

Most of the consumers buying sorghum meal were purchasing this product for the first time. This implies a need for continuing promotion to introduce new buyers to the product.

The results of sensory taste tests suggest a strong preference for whiter sorghum meal. This can be assured by purchasing grain from the modern varieties (like Macia and Pato) now commonly grown in the Dodoma region. As a result of seed production programs, these varieties are also spreading across other parts of the country. The sensory profile suggests a continuing preference for maize meal compared to sorghum, though the strength of this preference is not strong. Further analysis may be needed to test the preferences of households that have historically consumed this crop.

The retail surveys indicated a preference for clear, plastic packaging, as opposed to opaque, paper packaging by the majority of consumers. Buyers want to see the color and quality of the grain meal. Plastic packages are also perceived to be more robust than paper. However, there is also a demand for more attractive and informative packaging. The latter could include nutritional information and a recipe.

In sum, the national market for sorghum meal is in the early stages of development. Demand is growing. But the market may take many years to establish. The volume of sales is still too low to attract larger investments in improved grain processing technologies. And the opportunity to pursue such investments is limited by credit constraints and high interest costs. In an effort to resolve these constraints, ICRISAT and Power Foods are exploring the opportunity to sell sorghum meal through school feeding programs.

Reference

Rohrbach DD and Kiriwaggulu JAB. 1999. Commercialization prospects for sorghum and pearl millet in Tanzania. ICRISAT Bulawayo, PO Box 776, Bulawayo, Zimbabwe: Sorghum and Millet Improvement Program, ICRISAT Bulawayo. Mimeo.

Breeding for Drought Tolerance in Sorghum in South Africa

WG Wenzel[1,*], K Ayisi[2], G Donaldson[3] and J Mohammed[4] (1. Agricultural Research Council-Grain Crops Institute, Private Bag X1251, Potchefstroom, South Africa; 2. Department of Plant Production, University of the North, Sovenga, South Africa; 3. Northern Province Department of Agriculture and Environment, Potgietersrus, South Africa; 4. National University of Lesotho, Maseru, Lesotho)
*Corresponding author: wenzel@igg2.agric.za

Drought stress is the major constraint in the production of sorghum. Of all grain crops, sorghum (*Sorghum bicolor*) and millets (*Pennisetum glaucum*) require the least amount of moisture for development. Drought tolerance is the degree to which a cultivar or crop can maintain production under increasing drought stress. The most drought tolerant cultivar or crop is therefore least responsive to improved moisture conditions. This means, that on average, sorghum will not have the same yield potential as that of maize. A drought tolerant cultivar increases yield stability by reducing crop failure during droughts and limiting overproduction during high rainfall seasons as experienced during the 1999/2000 season in South Africa.

Table 1. Drought tolerance of sorghum varieties and inbred lines, Potchefstroom, South Africa, 1999/2000.

Degree of drought tolerance		
High (up to 15% loss under stress)	Intermediate (16 to 44% loss)	Low (45 to 76% loss)
RSA* 498	RSA 1222	VSA 967
RSA 1110	RSA 1225	RSA 1486
A/BSA 1288	RSA 1488	RSA 2516
A/BSA 2465	A/BSA 2447	A/BSA 2845
A/BSA 2861	BSA 3101	A/BSA 2849
SA 3006	SA 3105	A/BSA 2894
VSA 3716	VSA 3699	A/BSA 2896
VSA 3728	VSA 3737	VSA 3744
RSA 4114	RSA 3984	SA 3802
VSA 4158	VSA 4159	VSA 4170
RSA 4206	VSA 4162	VSA 4173
A/BSA 4293	VSA 4166	VSA 4175
A/BSA 4305	RSA 4201	VSA 4179
	A/BSA 4301	VSA 4258
	A/BSA 4322	VSA 4368
		VSA 4396

* RSA = R-line; BSA - B-line; A/BSA = A/B-line; VSA = variety; SA = unknown fertility reaction.

Table 2. Description of drought tolerant sorghum varieties and inbred lines, Potchefstroom, South Africa, 1997-2000.

Genotype/variety	Pedigree	Seed color	Plant color	Stature (m)	Season	Yield potential (t ha^{-1})
SA 3101	535*1206	white	tan	1.7	late	1.8
SA 3699	MSU sel549	brown	pigmented	1.5	medium	1.8
SA 3716	P898012	brown	tan	1.0	late	2.0
SA 3728	ICSV 219	white	tan	1.7	late	2.0
SA 3737	245*146	white	tan	1.5	very late	3.3
SA 4158	SPV 351	white	tan	1.6	late	2.3
SA 4162	SV 1	white	tan	1.8	late	2.8
SA 4166	LARSVYT 19	red	pigmented	1.7	very late	2.3
A/B-lines						
SA 1288	BTx623	white	pigmented	1.5	medium	1.1
SA 2465	A3091	white	pigmented	1.4	early	0.9
SA 2861	889*1202	white	tan	1.5	medium	2.3
SA 4293	1288*954	white	pigmented	1.3	medium	1.0
SA 4301	1442*1436	red	pigmented	1.4	medium	2.1
SA 4305	47*1288	red	pigmented	1.4	medium	0.8
R-lines						
SA 1488	RTx432	white	pigmented	1.4	medium	1.3
SA 3984	1568*1670	white	tan	1.5	late	1.5
SA 4201	SDSR9105	white	tan	1.5	medium	1.4
SA 4206	R8602	red	pigmented	1.5	late	1.6

Drought tolerance in sorghum is difficult to assess because of the crop's differential response to stress during its ontogeny. Many drought tolerance mechanisms have been reported, but their relation to grain yield is not yet fully understood (Rosenow et al. 1996; Turner 1997). Because of the observed negative correlation between drought tolerance and yield potential (Wenzel 1999) and the relatively poor response of tolerant cultivars to improved moisture conditions, we set out to determine the yield potential and drought tolerance of sorghum cultivars.

The experiments were conducted in two trials consisting of randomized block experiments with three replications. One trial was irrigated. Drought tolerance was quantified by 100*(1 - Xd/Xi), where Xd is the cultivar mean of yield, or of any other trait observed under dryland conditions and Xi the mean of that trait under irrigation conditions. Xi for yield is a measure of a cultivar's yield potential. The average yield loss of a random sample of cultivars is interpreted as the drought stress intensity of that trial and can be used to compare results with other experiments.

During the 1999/2000 season, we evaluated 44 sorghum varieties and inbred lines. Severe drought stress was experienced resulting in an average yield loss of 44%. The genotypes were divided into three tolerance groups: tolerant exhibiting yield losses of up to 15%, intermediate with losses of between 16 and 44%, and sensitive with between 45 and 75% losses (Table 1). The drought tolerance of accessions shown in Table 2 were assessed for three seasons: 1997/1998, 1998/1999 and 1999/2000 (Wenzel 1997, 1999).

A set of promising sorghum genotypes exhibiting superior drought tolerance and relatively high yield potential is now available. The varieties and inbred lines have the potential to increase and stabilize yields.

Acknowledgment. The financial support from the Southern African Center for Cooperation in Agricultural Research and Training (SACCAR) is gratefully acknowledged.

References

Rosenow DT, Ejeta G, Clark LE, Gilbert ML, Henzell RG, Borrell AR and Muchow RC. 1997. Breeding for pre- and post-flowering drought stress resistance in sorghum. Pages 406-411 *in* Proceedings of the International Conference of Genetic Improvement of Sorghum and Pearl Millet. September 23-27, Lubbock, Texas, USA. Publication No. 97-5.

Turner NC. 1997. Further progress in crop water relations. Advances in Agronomy 58:293-338.

Wenzel WG. 1997. Drought resistance of sorghum inbred lines and varieties. Applied Botany 71:201-204.

Wenzel WG. 1999. Effect of moisture stress on sorghum yield and its components. South African Journal of Plant and Soil 16:153-157.

On-farm Seed Priming: a Key Technology to Improve Crop Establishment and Yield in Semi-arid Tropics

W Chivasa[1,*], D Harris[2] and P Nyamudeza[3] (1. SADC/ ICRISAT Sorghum and Millet Improvement Program, PO Box 776, Bulawayo, Zimbabwe; 2. Centre for Arid Zone Studies, University of Wales, Bangor. Gwynedd LL57 2UW, UK; 3. Save Valley Experiment Station, Private Bag 2037, Chipinge, Zimbabwe)
*Corresponding author: w.chivasa@cgiar.org

Introduction

Poor crop stand establishment is a major constraint in smallholder farming in semi-arid areas of Zimbabwe. Observations in Siabuwa (Chiduza et al. 1995) and in Chiredzi (Chivasa 1995) revealed high sorghum seeding rates of 1,200,000 to 1,800,000 seeds ha^{-1}, yet plant populations in farmers' fields ranged from only 22,000 to 160,000 plants ha^{-1} - a 2-9% germination and emergence rate. Farmers replant several times to achieve good stands, often at considerable costs in labor, materials, draught power, and yields lost because of delayed sowing. Poor smallholder farmers in semi-arid areas cannot easily afford these extra costs.

Reasons for poor stand establishment in tropical crops include inadequate seedbed preparation, low quality seed, untimely sowing, poor sowing techniques, inadequate soil moisture, and soil with such adverse physical properties as a propensity to form surface crusts. These constraints can be addressed, but at a cost. One low-cost, low-risk intervention measure is 'on-farm' seed priming; so termed to distinguish it from the energy-intensive, high technology seed priming, seed hardening, or seed conditioning processes available in high-input temperate agriculture (Harris et al. 1999).

Conventional seed priming is well documented (Parera and Cantliffe 1994, Paul and Chaudhury 1991, Taylor et al. 1988). It involves controlled hydration, which induces a series of enzyme systems whose benefits are maintained after seeds have been dried to their original water content and stored normally. Subsequent germination is faster, more uniform, and often more complete. These aspects are very important under cool, damp conditions prevalent where temperate, commercial crops are grown. In contrast, tropical crops are often sown in hot, drying conditions using unsophisticated sowing techniques. 'On-farm seed priming' involves hydration of seed by soaking it in water, usually overnight. This helps counter any adverse effects of the dry environment by promoting fast emergence and vigorous seedling growth (Harris et al. 1999).

Sorghum is one of the major rainfed crops grown in semi-arid Zimbabwe and is quite drought-tolerant. Nevertheless, land allocated to sorghum is often reduced because seed is in short supply. This is because of persistent droughts and low crop yields which lead to the consumption of all the grain that is harvested, so very little is retained for seed. Any agronomic interventions that increase the proportion of sown seed that emerges and also increase the rate of emergence will significantly help farmers reduce costs incurred by seed purchases and labor. The following is a report of participatory on-farm research conducted in Musikavanhu Communal Area, Chipinge, Zimbabwe, with the objective of developing and testing sorghum seed priming techniques.

Participatory Testing of On-farm Seed Priming

Participatory Rural Appraisals (PRAs) conducted in Musikavanhu Communal Area identified poor crop establishment as one of the main problems in sorghum production. This was also confirmed by observations of standing crop characteristics in farmers' fields. On-farm seed priming with water immediately before sowing to speed up emergence was chosen as a low-cost, low-risk intervention to improve sorghum stand establishment. Before the on-farm trials, pot experiments were conducted to obtain information on the performance of different sorghum varieties following seed priming in order to develop recommendations that could be used in the study villages. A 'safe limit' of 10 hours for priming seed of Red Swazi and Muchayeni varieties was established. On-farm trials began during the 1997/98 season in collaboration with Department of Agricultural, Technical, and Extension Services (AGRITEX) extension staff. Participants included 40 sorghum growers (male and female).

Farmers were given 1 kg seed each, half of which they soaked overnight, then surface-dried the seed and sowed it next to non-primed seed in their fields using traditional methods. The trials were evaluated during Focus Group Discussions (FGDs), farm walks, and matrix-ranking exercises. During the FGDs, farmers' opinions were sought on the advantages and disadvantages of seed priming compared to their normal practices in a number of researcher-defined, but mutually agreed categories relating to agronomy, crop development, and grain yield.

Results of the Participatory Testing of On-farm Seed Priming

During the 1997/98 season, the first rains were extremely late, starting in January rather than November. Consequently, only a proportion of crops flowered and formed grains.

Perceptions on performance were therefore from a subset of trials. Farmers who reported that it was easier to sow primed than non-primed seed indicated that heavier primed seed was easier to throw into the planting hole without drifting off-course. This improved control enabled farmers to regulate spacings and number of seeds per station much more accurately. Priming also made it easier for farmers to reject damaged and poor quality seed because it floated during soaking.

Farmers also noticed that primed seed emerged faster (1-3 days), fields sown to the primed seed had better stands, and primed plants grew faster and more vigorously. There was however no consensus on whether priming had advantages in drought conditions or against weeds. Farmers agreed that crops from primed seeds developed faster, flowered, headed and matured earlier than non-primed. Ninety-eight percent of all farmers expressed a wish to prime seed in subsequent seasons.

On-farm seed priming was not unknown to farmers in Musikavanhu communal area. About 37% of farmers reported having tried seed priming with maize, but they were not very successful because they had been poorly informed on priming times. As a result their seed had been damaged due to oversoaking. Also, farmers had only used priming when optimal sowing conditions had been missed as a way to 'catch up'. They saw on-farm seed priming as a 'conditional' practice, to be used only under adverse cropping circumstances. Farmers had not applied the technique under otherwise optimal sowing conditions.

Importance of Farmer Participation in Technology Testing and Adoption

Although on-farm seed priming was not a new technology in Musikavanhu communal area, we were unable to detect any systematic use of the technology for either sorghum or maize. Farmers will not appreciate the wide range of benefits from this low-cost, low-risk practice unless they have an opportunity to experiment with the practice on their own. Hence our choice of the participatory approach in this study. It is highly effective in empowering farmers to test, develop and adapt seed priming and to appreciate its effects. It exposes farmers to a wide range of crop-by-environment interactions within their own context, which they would otherwise not be able to see in researchers' trials.

Acceptance of on-farm seed priming by farmers has been very good in the Musikavanhu communal area. Almost all farmers who tested the technology said that they would continue with the practice. This suggests that simple, paired-plot participatory trials are effective for extension as well as for adaptive research. On-farm seed priming is a good example of a 'key technology' - a simple, low cost intervention whose impact is large enough to induce farmers to adopt it. Seed priming is clearly good insurance for farmers. There virtually has been no negative effect on crops; although sometimes there is no effect, mostly there are profound benefits.

Future work should be to disseminate the technology more widely and to quantify its effects on farmer livelihoods. In drier years there is potential for on-farm seed priming to contribute a great deal to food security in marginal areas. Future work should also seek to exploit this potential. There is potential for priming other crops once their safe limits have been determined.

Acknowledgments. The authors thank colleagues who helped with data collection during the conduct of the study. This document is an output from a project (Plant Science Research Programme R6395) funded by the UK Department for International Development (DFID) and administered by the Centre for Arid Zone Studies (CAZS) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

References

Chiduza C, Waddington SR and Rukuni M. 1995. Evaluation of sorghum technologies in a semi-arid region of Zimbabwe. Part 1: Production practices and development of an experimental agenda. Journal of Applied Science in Southern Africa 1:1-10.

Chivasa W. 1995. Survey of sunflower production constraints and comparative performance with maize and sorghum in Matibi II communal area of Zimbabwe. Department of Crop Science, University of Zimbabwe. BSc. Agriculture Thesis.

Harris D, Joshi A, Khan PA, Gothkar P and Sodhi PS. 1999 On-farm seed priming in semi-arid agriculture: development and evaluation in maize (*Zea mays,* L.), rice *(Oryza sativa)* and chickpea *(Cicer arietinum)* in India using participatory methods. Experimental Agriculture 35:15-29.

Parera CA and Cantliffe DJ. 1994. Presowing seed priming. Horticultural Reviews 16:109-141.

Paul SR and Choudhury AK. 1991. Effect of seed priming with potassium salts on growth and yield of wheat under rainfed conditions. Annals of Agricultural Research 12:415-418.

Taylor AG, Klein DE and Whitlow TH. 1988. Solid matrix priming of seeds. Scientia Horticulturae 37:1-11.

Small-scale Farmers Venture into Commercial Seed Production

ES Monyo (ICRISAT, Bulawayo, PO Box 776, Bulawayo, Zimbabwe)

e.monyo@cgiar.org

There is virtually no seed of improved semi-arid crops (like pearl millet, sorghum, cowpeas, and groundnuts) sold on the market in southern Africa, in-spite of the importance of these crops to the livelihoods of people in semi-arid tropics in the region. To address this shortcoming, ICRISAT is collaborating with Commutech, a non-governmental organization, and two private seed companies, the Seed Company of Zimbabwe (Seed Co.) and PANNAR, in a pilot project on on-farm commercial seed production by small-scale farmers in Zimbabwe. The project was initiated during the 1999/2000 season in Wards 9 and 13, Tsholotsho district, Matabeleland North, and Ward 21, Chivi district. Over 600 farmers operating in groups of 20 to 30 are participating with each allocating 1 to 3 ha for the production of seed of pearl millet variety PMV 3 and sorghum variety Macia.

Collaborating partners in the project have different responsibilities. Commutech is responsible for community mobilization, organization, and local supervision and monitoring of implementation through its technicians based in the project Wards. The seed companies are responsible for contractual arrangements with farmers, registration of the venture with appropriate authorities, compliance of the project with rules and regulations of the national seed service in Zimbabwe, and the sampling and testing of seed produced by farmers prior to purchasing it. And ICRISAT is responsible for training farmers on appropriate management procedures for on-farm seed production, and catalysing linkages between other stakeholders (the Departments of Research and Extension Services) and the project.

Most of the farmers failed to meet the isolation distance required to avoid contamination of the seed crop and were dropped from the scheme. Only 22-23% of farmers in both Tsholotsho and Chivi were successful in producing and delivering seed of acceptable quality (Table 1). Of the 124 ha put under the multiplication of PMV 3 seed in Tsholotsho by 336 farmers, only 74.2 ha was declared harvestable as seed. Slightly over 27 tons of seed was delivered to the seed companies, though the expected harvest was 44.6 tons. In Chivi, 330 farmers took part in the project. They multiplied seed of Macia on 133 ha. Only 75 farmers were successful in producing a seed crop of good quality and purity, delivering 22.4 tons of seed.

Constraints: Semi-arid areas in southern Africa are under threat of food insecurity. The top priority for most farmers in these areas is food for their families before selling. As a result, those farmers who harvested a good quality seed crop had to first ensure that their families retain enough for food before selling. This greatly reduced the amount of seed that was eventually delivered for sale.

Contribution towards Achieving Project Goals

The project has provided collaborators and farmers involved with an opportunity to learn about the likely problems of on-farm seed multiplication. As a result of experiences from the last season, farmers in Kulumusenza, Vaghazini, and Dlamini areas of Tsholotsho and the successful Village Development Committees (VIDCOs) in Chivi have grouped themselves into seed production clubs and approached their village headman to be allocated special land for seed that is properly isolated. A new pilot project for Tsholotsho for the coming season targets only 138 farmers, all of whom have registered as members of small-scale seed production associations in their respective villages. It is hoped that this will help address the quality problems encountered during the 1999/2000 season.

Table 1. Summary of small-scale seed production in 1999/2000.

Seed of the sorghum variety Macia produced in Chivi, Zimbabwe, 1999/2000.			
Farmers involved	Successful farmers	Farmers who delivered seed	Seed produced (t)
330	112	75	22.4
Seed of the pearl millet variety PMV 3 produced in Tsholotsho, Zimbabwe, 1999/2000.			
Farmers involved	Successful farmers	Farmers who delivered seed	Seed produced (t)
336	127	76	27.5

Book Reviews

Chandrashekar A, Bandyopadhyay R and Hall AJ. (eds.) 2000. Technical and institutional options for sorghum grain mold management: proceedings of an International Consultation, 18-19 May 2000, ICRISAT, Patancheru, India. (In En. Summaries in En, Fr.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 299 pp. ISBN 92-9066-428-2 HDC $79.00, LDC $30.00, India Rs 1100.

Sorghum grain mold constitutes one of the most important biotic constraints to sorghum improvement and production worldwide. It is estimated that annual economic losses in Asia and Africa that result from grain mold are in excess of US$ 130 million. The poverty implications include: loss of access to food, exposure to health risks through contaminated food, and income losses through lower prices. Papers in these proceedings review advances in biochemical and genetic studies, and institutional developments in the sorghum utilization sector. The opportunities these developments present, and the potential for impact on the poor are discussed. Recommendations are presented as three themes. The first recommends further work to de-link grain hardness and antifungal properties and to identify resistance genes, underpinned by the development of molecular markers. The second recommends that grain mold needs to be tackled as part of a cluster of quality-related issues important to industrial users of the crop. New marketing institutions, such as contract growing, need to be explored. The third focuses on the need for networking activities to link public research with private-sector activities related to market development. Stronger markets for sorghum are essential to maintain the crop in the farming systems on which the poor depend for food, fodder, and employment. An approach that combines technical and institutional innovations could provide enormous benefits by bringing the power of science to bear on the livelihoods of the poor.

Heinrich GM, Monyo ES, Nkhori S and Obilana AB. 2000. Enhancing farmer participation in cultivar development: a primer for sorghum and pearl millet breeders in SADC: developed from a workshop on farmer participation in sorghum and pearl millet breeding, 25-28 April 1995, Omahenene, Namibia. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 32 pp.

Cultivars developed but never used by farmers represent a considerable waste of resources. Involving farmers and any other potential end-users in the process of cultivar development is the most effective way of ensuring that they are acceptable and widely adopted. This book, compiled from the discussions generated at a workshop on farmer participation in sorghum and pearl millet breeding, reviews the need for farmer participation in breeding programs and discusses the important contributions they can make. It then identifies phases during cultivar development when farmers inputs are crucial, and some ways such input can be realized.

Klein, Ulrich, Bala Ravi S, Dayakar Rao B and Yoganand B. 2000. Industrial utilization of sorghum in India. Working Paper Series no. 4. PO Box 776, Bulawayo, Zimbabwe: Socioeconomics and Policy Program, International Crops Research Institute for the Semi-Arid Tropics. 44 pp.

Patterns of human consumption of sorghum are well-documented. Much less is known about the industrial utilization of the crop, and the market opportunities this presents for poor sorghum producers. The study documents the emerging patterns of industrial utilization and provides evidence that between 10-40% of rainy-season sorghum is used for nonfood uses. Postrainy-season sorghum is solely grown for food, as it is not price-competitive as an industrial raw material. The main utilization sectors are poultry feed (approximately 0.5 million t annum^{-1}); dairy feed (approximately 0.2 million t annum^{-1}); and grain alcohol (approximately 0.1 million t annum^{-1}). In the most important sector, poultry feed, sorghum use is related to the price of competing cereals, particularly maize. Sorghum is used when prices are 20-30% lower than those of maize. With the demand for poultry feed estimated to be growing by 15% annum^{-1}, and with limited opportunities for increased maize production, the demand for sorghum is likely to strengthen. However, the impact of trade liberalization and particularly of maize imports will have to be considered. In the past, institutional arrangements linking the key utilization industries and related public-sector research have been weak. Improving these linkages through public-private sector partnerships would help to further support private-sector market development for a commodity produced by some of India's poorest farmers.

Ramasamy C, Bantilan MCS, Elangovan S and Asokan M. 2000. Improved cultivars of pearl millet in Tamil Nadu: adoption, impact, and returns to research investment. (In En. Summaries in En, Fr.) Impact Series no. 7. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 64 pp. ISBN 92-9066-417-7. HDC $32.00, LDC $12.00, India Rs 460.

Improved cultivars of pearl millet have been widely adopted in Tamil Nadu, India, where both public and private sectors

play a significant role in making them available to farmers. The early breakthroughs in pearl millet breeding made by ICRISAT provided a strong base for further research. Farmers prefer improved cultivars because of their high yield, good grain size, pest and disease tolerance, and short duration. Research investment in pearl millet breeding has a high payoff.

Most of the extra grain production resulting from adoption of improved cultivars goes to the animal feed industry. Consumption of pearl millet has sharply declined in Tamil Nadu. Analysis of farm-level efficiency of pearl millet production shows some degree of inefficiency and that strengthening extension education in the precise application of inputs is important.

Reddy Belum VS, Ceballos H and Ortiz R. (eds.) 2000. A research and network strategy for sustainable sorghum and pearl millet production systems for Latin America: proceedings of the workshop, 24-26 Nov 1998, Villavicencio, Meta, Colombia. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and Cali, Colombia: Centro Internacional de Agriculture Tropical (CIAT). 86 pp. ISBN 92-9066-413-4. Order code: CPE 125. HDC $28.00, LDC $12.00, India Rs 380.00.

During the reported workshop 28 scientists from Colombia, Brazil, Venezuela, and Honduras were joined by ICRISAT and Centro Internacional de Agriculture Tropical (CIAT) staff. The workshop reviewed research work carried out during a project funded by the Inter-American Development Bank (IDB). Project milestones, methodology adapted, and progress made to achieve the milestones; network trials results, and the status of sorghum and pearl millet research in the region were all reviewed. The workshop also identified bottlenecks in returning data, formulated methods for trials and seed distribution, identified coordinators for each country, and outlined thrusts for further research. These thrusts include: extending the research to fertile and drought-prone areas, in addition to acid savanna soils; enhancing research on pearl millet to 30% (and reducing sorghum to 70%) from the present 10%; nutrient uptake efficiency (sorghum); and use of pearl millet as a soil organic content enricher. The publication contains presentations made at the meeting and a summary of its recommendations. It thus provides an overview of the current status of research and discusses the problems and prospects for sorghum and pearl millet production in the region.

Rohrbach D, Mupanda K and Seleka T. 2000. Commercialization of sorghum milling in Botswana: trends and prospects. Working Paper Series no. 6. PO Box 776, Bulawayo, Zimbabwe: Socioeconomics and Policy Program, International Crops Research Institute for the Semi-Arid Tropics. 24 pp. Order code: WPS #6.

Commercial sorghum processing in Botswana has grown rapidly during the past decade. The number of sorghum millers has increased four-fold, and sorghum meal has become competitive with maize in urban and rural food markets. In early 1999, ICRISAT conducted a study of the factors underlying this growth, and the prospects for further market expansion. The study showed that growth was driven largely by four factors: the traditional consumer preference for sorghum meal; strong financial support to millers from the government; the availability of reliable, high-quality supplies of grain; and effective promotion of processing technology by a parastatal agency. However, development of the milling industry had little impact on domestic sorghum production. Productivity in Botswana remains too low for the crop to complete with South African imports, and only 2% of the industry's grain purchases are grown domestically.

Key issues likely to affect future expansion include: the identification of alternative sources of grain supplies (e.g., from Zimbabwe); improvements in product promotion, market intelligence, and product differentiation (e.g., targeting distinct products for breakfast porridge vs stiff porridge); and the prospects for industry consolidation into a few larger millers. While the Botswana case is not specifically replicable in neighboring countries, the stimulus created by linking technology, finance, and raw material supply offers important lessons for the development of commercial crop processing throughout southern Africa.

Yapi A M, Kergna A O, Debrah SK, Sidibe A and Sanogo O. 2000. Analysis of the economic impact of sorghum and millet research in Mali. (In En. Summaries in En, Fr.) Impact Series no. 8. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 60 pp. ISBN 92-9066-419-3. Order code: ISE 008. HDC $32.00, LDC $12.00, India Rs 460.00.

Sorghum *[Sorghum bicolor* (L.) Moench] and pearl millet *[Pennisetum glaucum* (L.)] R. Br.] are very important to the economy and people of Mali. But, their productivity is low due to traditional, low-input production practices. The Institut d'Economie Rurale (IER) after Mali's independence began to seek ways of improving the productivity of food crops in collaboration with regional and international agricultural research institutes. A number of improved seed-based sorghum and millet technologies have since been developed and diffused. They were developed via two approaches: 1. Selection within local germplasm, which consisted of collecting, testing, purifying, and supplying fanners with readily available materials (Generation 1) and 2. Plant breeding which consisted of crossing with exotic germplasm, and pedigree selection (Generation 2). This study evaluates the returns to sorghum and pearl millet research investments in Mali by combining farm-level survey information from 1990 to 1995 with that from

research and extension in an economic surplus framework. The results indicate that by 1995, 30% of the sorghum and 37% of the pearl millet growing areas were sown to improved varieties. The estimated benefits from research and extension efforts range from US$ 16 million (for sorghum) to US$ 25 million (for pearl millet). These represent internal rates of returns of 69% and 50%. A disaggregated analysis indicates higher yield gains and higher returns from Generation 2 materials than from Generation 1 materials for both crops. Unit costs were much lower for Generation 2 materials. The major constraints cited by farmers as limiting their ability to adopt that improved materials include lack of information, lack of improved seeds, and low soil fertility. The study concludes that the breeding philosophy should be diversified to respond to the need of the changing socioeconomic environment that is related to the recent devaluation of the CFA Franc. It also recommends that efforts be made to improve the economic farming environment to enable farmers to adopt the more productive agricultural technologies necessary for rural poverty alleviation and improvement in national food security.

Akintayo I and Sedgo J. (eds.) 2001. Towards sustainable sorghum production, utilization, and commercialization in West and Central Africa: proceedings of a Technical Workshop of the West and Central Africa Sorghum Research Network, 19-22 April, 1999, Lome, Togo. Bamako, BP 320, Mali: West and Central Africa Sorghum Research Network; and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 320 pp. ISBN 92-9066-433-9. Order code: CEP 131. HDC $30.00, LDC $13.00, India Rs 400.00.

Delegates from the national agricultural research systems of Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Côte d'Ivoire, The Gambia, Ghana, Mali, Mauritania, Niger, Nigeria, Senegal, and Togo attended this technical workshop. Participants also included representatives of Comite inter-etats de lutte contre la secheresse au Sahel (CILSS), Centre de coopeeration internationale en rechereche agronomique pour le developpement (CIRAD), ICRISAT, International Fertilizer Development Center (IFDC-Africa), USAID Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL), West and Central Africa Millet Research Network (ROCAFREMI), and the United Nations Economic Commission for Africa (UNECA), together with representatives of non-governmental organizations and the private sector.

The main objectives of the workshop were to review network activities, give an opportunity to sorghum researchers and their partners to exchange views and information, and plan future activities. Sorghum production and utilization, networks and food self-sufficiency, partnerships and technology exchange, and impact evaluation were discussed during the technical sessions. Presentations are printed in the original language of submission. The Preface and a brief report of the workshop, including its recommendations, are in English.

Hall AJ, Clark N, Sulaiman V, Rasheed, Sivamohan MVS and Yoganand B. 2001. Coping with new policy agendas for agricultural research: the role of institutional innovations. NCAP Policy Brief 13. New Delhi, India: National Centre for Agricultural Economics and Policy Research (NCAP), Indian Council of Agricultural Research (ICAR). 4 pp.

Over the last four decades the policy agenda of agricultural research has evolved significantly from an initial focus on increasing food production to concerns for the environment, povery and stakeholder participation. Not only has the poverty focus become more explicit, but also the concept of poverty has expanded beyond earlier notions relating to supplies of food, to encompass wider livelihood concerns. As a result, both national and international agricultural research systems around the world are finding their output and contribution to welfare under increasing scrutiny. All too frequently agricultural research systems are struggling to accomplish new and complex tasks within the confines of institutional structures and mandates designed decades previously for a much simpler agenda. India is no exception to this global trend. To understand the challenges that this presents, it is useful to reflect on the way these agendas and institutional set ups have emerged and evolved. The global perspective provides useful lessons for India's agricultural research system. Of particular importance are new policy analysis approaches that recognize that institutional innovations are not only central to the development of more efficient research systems, but also that such developments underpin the wider process of technical and economic change. This issue of the NCAP Policy Brief Series presents food for thought for agricultural researchers world-wide, not just those in India, as they tackle the challenges ahead.

ICRISAT. 2001. Farmer participatory testing of technologies to increase sorghum and millet production in the Sahel. Progress Report 2000-2001 and Annual Work Plans and Budgets 2001-2002. Bamako, Mali: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). (Semi-formal publication, limited distribution).

Submitted to the International Fund for Agricultural Development (IFAD), Rome, Italy, this progress report highlighs achievements in the West African countries of Burkina Faso, Ghana, Mali, Niger, and Nigeria. It also covers training, work by visiting scientists, exchange visits, public awareness, and lists 10 publications by the project and its scientists. Well written and lavishly illustrated, it should prove useful to many scientists and extensionists, particularly those concerned with seed production and farmer participation in productivity trials.

Rohrbach DD and Kiriwaggulu JAB. 2001. Commercialization prospects of sorghum and pearl millet in Tanzania. Working Paper Series no. 7. PO Box 776, Bulawayo, Zimbabwe: Socioeconomics and Policy Program, International Crops Research Institute for the Semi-Arid Tropics. 28 pp.

Tanzania produces over 500,000 t of sorghum and 200,000 t of pearl millet every year, but virtually all this production is subsistence-oriented. The lack of a commercial market has limited farmer interest in improving crop management, and average sorghum and pearl millet yields have changed little over the past 15 years. This report analyzes the prospects for expanding the use of sorghum in the opaque beer brewing industry. A target of 75% substitution over the next 5 years would create an annual demand for 1800 t of high-quality white sorghum. According to industry representatives, the main constraint limiting the use of sorghum and pearl millet in animal feeds is the relative grain price. If sorghum were available at competitive prices, 5 years from now it could account for at least 5% of the grain used by the industry, i.e., 5,000 t annum^{-1}.

The potential size of the market for milled sorghum and pearl millet meal is difficult to estimate, because of uncertainty about the strength of consumer preferences for alternative grains. Nonetheless, if the milling industry set a target of replacing only 5% of the maize meal sold in Dar es Salaam with sorghum meal, it could generate an annual demand for over 20,000 t of grain.

The prospects for pearl millet are less favorable given its generally higher price and lower yields and labor productivity. However, there may be a small market niche for pearl millet based meals, particularly in communities drawn from pearl millet production zones. The milling industry could test this market with an initial throughput of 500 to 1,000 t of pearl millet grain annum^{-1}.

Wambugu FM. 2001. Modifying Africa: how biotechnology can benefit the poor and hungry, a case study from Kenya. Nairobi, Kenya, pp. 76. ISBN 9966-879-38-2. Cost $25.00.

For all concerned with rural development, there are tremendous lessons in this book. A book that will change minds. Biotechnologists have been their own worst enemies when it comes to public relations. The little press coverage biotechnology has had in Afirca has been mainly from a 'Green' or European perspective. Florence Wambugu articulates a refreshingly different version, one that sweeps away the misconceptions that surround this much-maligned science to reveal its true value. She has done a magnificient job for Kenya and for Africa.

Bashir M, Ahmad Z and Murata N. 2000. Seed-borne viruses: detection, identification and control. Islamabad, Pakistan: Pakistan Agricultural Research Council, National Agricultural Research Centre (NARC). ISBN 969-09-129-2. Rs 200.00.

An estimated 90% of all food crops are attacked by devastating seed-borne pathogens. The transfer of genetic stock on a global scale, either for utilization or for conservation, involves possible risks of widespread distribution of seed-borne viruses. Seed-borne viruses, which are often symptomless, can pose a severe threat to modern agriculture. In order to minimize such risks, knowledge about detection, identification, indexing, and mechanism of seed transmission of seed-borne viruses, as well as strategies to control these, are required to ensure that imported as well as locally produced seeds are free of such pathogens. Recent increases in germplasm exchange and advances in biotechnology have created a pressing need for an overview of existing knowledge about various aspects of seed-borne viruses.

This is the first book on seed-borne viruses in Pakistan. It was jointly produced by two Pakistani scientists (Muhammad Bashir and Zahoor Ahmad) and one from Japan (Nobuto Murata), and contains information on all aspects related to seed-borne viruses. The book has seven chapters covering characteristics of seed-borned viruses, mechanisms of seed transmission, seed health testing, serology in virus detection, quarantine and genetic resources, viruses of quarantine significance, and control of seed-borne viruses. Geographical distribution and seed transmission percentage are provided for more than 300 seed-borne viruses. Twenty-six seed-borne viruses of quarantine significance are described and, along with their symptoms, are presented in fourteen color plates. Serological techniques for detecting viruses directly from seed are illustrated and 262 references are listed. This is the first book on seed-borne viruses in Pakistan.

Send your order to: Muhammad Bashir, Crop Sciences Institute, National Agricultural Research Centre, Islamabad, Pakistan; email: bashir@drmb.isb.sdnpk.org.

Sorghum and Millet Bibliography

Abdalla AET, Stigter CJ, Mohamed HAH, Mohammed AE and Gough MC. 2001. Effects of wall linings on moisture ingress into traditional grain storage pits. International Journal of Biometeorology 45(2):75-80.

Abebe W, Mekonnen HM, Moges WM and Getachew T. 2001. Effect of concentrate supplementation and deworming on beef performance of indigenous Ethiopian zebu cattle fed on teff straw (*Eragrostis tej*). Revue de Medecine Veterinaire 152(4):307-310.

Able JA, Rathus C and Godwin ID. 2001. The investigation of optimal bombardment parameters for transient and stable transgene expression in sorghum. *In vitro* Cellular and Developmental Biology Plant 37:341-348.

Aboubacar A, Axtell JD, Huang CP and Hamaker BR. 2001. A rapid protein digestibility assay for identifying highly digestible sorghum lines. Cereal Chemistry 78(2):160-165.

Aggarwal NK, Nigam P, Singh D and Yadav BS. 2001. Process optimization for the production of sugar for the bioethanol industry from sorghum, a non-conventional source of starch. World Journal of Microbiology and Biotechnology 17(4):411—415.

Aggarwal NK, Yadav SK, Dhamija SS and Yadav BS. 2001. Optimization of enzymatic hydrolysis of pearl millet for glucose production. Starch-Starke 53(7):330-335.

Agu RC and Palmer GH. 2001. The effect of nitrogen level on the perfonnance of malting barley varieties during germination. Journal of the Institute of Brewing 107(2):93-98.

Ahmad Z, Gill MA and Qureshi RH. 2001. Genotypic variations of phosphorus utilization efficiency of crops. Journal of Plant Nutrition 24(8): 1149-1171.

Ajayi O and Oboite FA. 2001. Control of *Locris rubens* (Erichson) (Homoptera: Cercopidae) on sorghum in Nigeria. Journal of Sustainable Agriculture 18:85-97.

Akingbade AA, Nsahlai IV, Bonsi MLK, Morris CD and duToit LP. 2001. Reproductive performance of South African indigenous goats inoculated with DHP-degrading rumen bacteria and maintained on *Leucaena leucocephala/grass* mixture and natural pasture. Small Ruminant Research 39(l):73-85.

Allen RR and Musick JT. 2001. Deep ripping and blocked furrow effects on lower 1/3 furrow irrigation infiltration. Applied Engineering Agriculture 17:41-48.

Allouis S, Qi X, Lindup S, Gale MD and Devos KM. 2001. Construction of a BAC library of pearl millet, *Pennisetum glaucum.* Theoretical and Applied Genetics 102(8): 1200-1205.

Al Mustafa WA, Abdallah AE and Falatah AM. 2001. Assessment of five extractants for their ability to predict iron uptake and response of sorghum grown in calcareous soils. Communications in Soil Science and Plant Analysis 32(5-6):907-919.

Alobo AP. 2001. Effect of sesame seed flour on millet biscuit characteristics. Plant Foods for Human Nutrition 56(2): 195-202.

Alvey S, Bagayoko M, Neumann G and Buerkert A. 2001. Cereal/legume rotations affect chemical properties and biological activities in two West African soils. Plant and Soil 231(1):45-54.

Ambula MK, Oduho GW and Tuitoek JK. 2001. Effects of sorghum tannins, a tannin binder (polyvinylpyrrolidone) and sorghum inclusion level on the performance of broiler chicks. Asian-Australasian Journal of Animal Sciences 14(9): 1276-1281.

Amzallag GN. 2001. Maturation of integrated functions during development. 1. Modifications of the regulatory network during transition periods in *Sorghum bicolor.* Plant Cell and Environment 24(3):337-345.

Archana Sehgal S and Kawatra A. 2001. *In vitro* protein and starch digestibility of pearl millet (*Pennisetum glaucum* L.) as affected by processing techniques. Nahrung-Food 45(1):25-27.

Arockiasamy S, Prakash S and Ignacimuthu S. 2001. High regenerative nature of *Paspalum scrobiculatum* L.. an important millet crop. Current Science 80(4):496-498.

Ashkenazi V, Chani E, Lavi U, Levy D, Hillel J and Veilleux RE. 2001. Development of microsatellite markers in potato and their use in phylogenetic and fingerprinting analyses. Genome 44(I):50-62.

Assefa K, Tefera H, Merker A, Kefyalew T and Hundera F. 2001. Quantitative trait diversity in tef [*Eragrostis tef* (*Zucc.*) Trotter] germplasm from Central and Northern Ethiopia. Genetic Resources and Crop Evolution 48(1):53—61.

Azhar FM and McNeilly T. 2001. Variation in responses of *Sorghum bicolor* (L.) Moench accessions to the effect of NaCl + $CaCl_2$ and NaCl salinity. Pakistan Journal of Agricultural Sciences 38:25-28.

Babajide JM, Babajide SO and Uzochukwu SVA. 2001. Cassava-soy weaning food: Biological evaluation and effects on rat organs. Plant Foods for Human Nutrition 56(2): 167-173.

Babu RS, Poornima K and Suguna N. 2001. Mass production of vesicular arbuscular mycorrhizae using different hosts. Mycorrhiza News 13:20-21.

Bak S, Tax FE, Feldmann KA, Galbraith DW and Feyereisen R. 2001. CYP83B1, a cytochrome P450 at the metabolic branch

point in auxin and indole glucosinolate biosynthesis in Arabidopsis. Plant Cell 13(1):101-111.

Bakhoum C, Samba SAN and Ndour B. 2001. *Sterculia setigera* Del.: effects on crops. Annals of Forest Science 58(2):207-215. *(French)*

Bandyopadhyay BB. 2001. Temperature and precipitation effects on grain yield of finger millet *(Eleusine coracana)* genotypes at high hills of Garhwal Himalayas. Indian Journal of Agricultural Sciences 71(3):205-208.

Baqri QH and Bohra P. 2001. Nematodes from Rajasthan, India. 1. Six new species of Dorylaimida, Nematology 3(2): 113-127.

Barbiero L, Valles V, Regeard A and Cheverry C. 2001. Residual alkalinity as tracer to estimate the changes induced byforage cultivation in a non-saline irrigated Sodic soil. Agricultural Water Management 50(3):229-241.

Barredo Moguel LH, Rojas de Gante C and Serna Saldivar SO. 2001. Comparisons between a commercial wort and a waxy sorghum wort fermented into lager beer, wim emphasis on yeast growth and ethanol production. Journal of American Society of Brewing Chemistry 59:24-27.

Baskaran V, Mahadevamma, Malleshi NG, Jayaprakashan SG and Lokesh BR. 2001. Biological evaluation for protein quality of supplementary foods based on popped cereals and legumes suitable for feeding rural mothers and children in India. Plant Foods for Human Nutrition 56(1):37-49.

Bauder JW and Brock TA. 2001. Irrigation water quality, soil amendment, and crop effects on sodium leaching. Arid Land Research Management 15(2): 101-113.

Bean SR, Hicks C, Tuinstra M and Lookhart GL. 2001. Use of SDS to extract sorghum and maize proteins for free zone capillary electrophoresis (FZCE) analysis. Cereal Chemistry 78(I):84-87.

Bearden BN. 2001. Influence of arbuscular mycorrhizal fungi on soil structure and soil water characteristics of Vertisols. Plant and Soil 229(2):245-258.

Beaujean A, Issakidis Bourguet E, Catterou M, Dubois F, Sangwan RS and Sang wan Norreel BS. 2001. Integration and expression of sorghum C-4 phospho-enolpyruvate carboxylase and chloroplastic NADP(+)-malate dehydrogenase separately or together in C-3 potato plants. Plant Science 160(6): 1199-1210.

Benabdelmouna A, Shi Y, Abirached Darmency M and Darmency H. 2001. Genomic *in situ* hybridization (GISH) discriminates between the A and the B genomes in diploid and tetraploid *Setaria* species. Genome 44(4):685-690.

Ben Hammouda M, Ghorbal H, Kremer RJ and Oueslati O. 2001. Allelopathic effects of barley extracts on germination and seedlings growth of bread and durum wheats. Agronomie 21(1): 65-71.

Bennett PV, Hada M, Hidema J, Lepre AM, Pope LC, Quaite FE, Sullivan JH, Takayanagi S, Sutherland JC and Sutherland BM. 2001. Isolation of high molecular length DNA: alfalfa, pea. rice, sorghum, soybean, and spinach. Crop Science 41(1):167-172.

Beta T and Corke H. 2001. Noodle quality as related to sorghum starch properties. Cereal Chemistry 78(4):417-420.

Beta T, Corke H, Rooney LW and Taylor JRN. 2001. Starch properties as affected by sorghum grain chemistry. Journal of the Science of Food and Agriculture 81(2):245-251.

Beta T, Corke H, Taylor JRN and Rooney LW. 2001. Effect of steeping treatment on pasting and thermal properties of sorghum starches. Cereal Chemistry 78(3):303-306.

Bhalerao EB, Laware SL, Vaidya RR and Dhumal KN. 2001. Effect of *Aspidium cicutarium* rhizome extract on seed germination and seedling growth of jowar and bajara. Proceedings of the National Seminar on the Frontiers of Research and Development in Medicinal Plants, Lucknow, India, 16-18 September 2000 (Sushil Kumar, Hasan SA, Dwivedi S, Kukreja AK, Sharma A, Singh AK, Sharma S and Tewari R, eds.). Journal of Medicinal and Aromatic Plant Sciences 22-23:499-501.

Bhau BS and Wakhlu AK. 2001. Effect of some antibiotics on the *in vitro* morphogenetic response from callus cultures of *Coryphantha elephantidens.* Biologia Plantarum 44(1): 19-24.

Bidinger FR, Chandra S and Raju DS. 2001. Genetic variation in grain-filling ability in dwarf pearl millet [*Pennisetum glaucum* (L.) R. Br.) restorer lines. Theoretical and Applied Genetics 102(2-3):387-391.

Bielders CL, Alvey S and Cronyn N. 2001. Wind erosion: the perspective of grass-roots communities in the Sahel. Land Degradation and Development 12(1):57-70.

Bock CH, Songa J and Julian AM. 2001. Survey of sorghum pests and pathogens in eastern Kenya. Tropical Science 41:16-22.

Borrell A, Hammer G and van Oosterom E. 2001. Stay-green: a consequence of the balance between supply and demand for nitrogen during grain filling? Annals of Applied Biology 138(1): 91-95.

Brahmbhatt SR, Fearnley R, Brahmbhatt RM, Eastman CJ and Boyages SC. 2001. Study of biochemical prevalence indicators for the assessment of iodine deficiency disorders in adults at field conditions in Gujarat (India). Asia Pacific Journal of Clinical Nutrition 10:51-57.

Bressan W, Siqueira JO, Vasconcellos CA and Purcino AAC. 2001. Mycorhizal fungi and phosphorus on growth, yield and nutrition of intercropped grain sorghum and soybean. Pesquisa Agropecuaria Brasileira 36(2):315-323. *(Portuguese)*

Buerkert A, Bationo A and Piepho HP. 2001. Efficient phosphorus application strategies for increased crop production in sub-Saharan West Africa. Field Crops Research 72(1):1—15.

Buerkert A, Moser M, Kumar AK, Furst P and Becker K. 2001. Variation in grain quality of pearl millet from Sahelian West Africa. Field Crops Research 69(1): 1-11.

Bugusu BA, Campanella O and Hamaker BR. 2001. Improvement of sorghum-wheat composite dough Theological properties and bread making quality through zein addition. Cereal Chemistry 78(1):31-35.

Bunce JA. 2001. Direct and acclimatory responses of stomatal conductance to elevated carbon dioxide in four herbaceous crop species in the field. Global Change Biology 7(3):323-331.

Bunce JA. 2001. Effects of prolonged darkness on the sensitivity of leaf respiration to carbon dioxide concentration in C-3 and C-4 species. Annals of Botany 87(4):463-468.

Burd JD, Shufran KA, Elliott NC, French BW and Prokrym DA. 2001. Recovery of imported hymenopterous parasitoids released to control Russian wheat aphids in Colorado. Southwestern Entomologist 26:23-31.

Burke JJ. 2001. Identification of genetic diversity and mutations in higher plant acquired thermotolerance. Physiologia Plantarum 112(2):167-170.

Callison SL, Firkins JL, Eastridge ML and Hull BL. 2001. Site of nutrient digestion by dairy cows fed com of different particle sizes or steam-rolled. Journal of Dairy Science 84(6): 1458—1467.

Campbell AW, Griffin WB, Burritt DJ and Conner AJ. 2001. The importance of light intensity for pollen tube growth and embryo survival in wheat x maize crosses. Annals of Botany 87(4):517-522.

Carrari F, Perez Flores L, Lijavetzky D, Enciso S, Sanchez R, Benech Arnold R and Iusem N. 2001. Cloning and expression of a sorghum gene with homology to maize vp1. Its potential involvement in pre-harvest sprouting resistance. Plant Molecular Biology 45(6):631-640.

Celenza JL. 2001. Metabolism of tyrosine and tryptophan-new genes for old pathways. Current Opinion in Plant Biology 4(3):234-240.

Chantereau J, Trouche G, Rami JF, Deu M, Barro C and Grivet L. 2001. RFLP mapping of QTLs for photoperiod response in tropical sorghum. Euphytica 120(2): 183-194.

Chattopadhyay PS and Pandey KP. 2001. Impact cutting behaviours of sorghum stalk using a flail-cutter-a mathematical model and its experimental verification. Journal of Agricultural Engineering Research 78(4):369-376.

Chauhan SS, Dighe JM and Sharma RA. 2001. Studies on utilization of available nutrients by sorghum genotypes in black cotton soils of Indore, M.P. Crop Research Hisar 21:268-270.

Chavan JK, Deshmukh RA and Dalvi US. 2001. Pearling treatment of discoloured sorghum grains. Journal of Food Science and Technology 38(3):263-265.

Chen CC, Hunag CT and Cheng KJ. 2001. Improvement of phytase thermostability by using sorghum liquor wastes supplemented with starch. Biotechnology Letters 23(5):331-333.

Chiduza C. 2001. Comparative performance of maize, sorghum and pearl millet under low input in a dry region of Zimbabwe. Research on Crops **2:1-7.**

Chiduza C. 2001. Comparative performance of maize, sorghum and pearl millet under high input management in a dry region of Zimbabwe. Research on Crops 2:8-16.

Chiduza C. 2001. Performance of maize, sorghum and pearl millet cultivars in a dry region of Zimbabwe. Crop Research Hisar 21:1-10.

Childs KL, Klein RR, Klein PE, Morishige DT and Mullet JE. 2001. Mapping genes on an integrated sorghum genetic and physical map using cDNA selection technology. Plant Journal 27(3):243-255.

Chittapur BM, Hunshal CS and Shenoy H. 2001. Allelopathy in parasitic weed management: Role of catch and trap crops. Allelopathy Journal 8(2): 147-159.

Choudhury BJ. 2001. Modeling radiation- and carbon-use efficiencies of maize, sorghum, and rice. Agricultural and Forest Meteorology 106(4): 317-330.

Conley MM, Kimball BA, Brooks TJ, Pinter PJ, Hunsaker DJ, Wall GW, Adam NR, La Morte RL, Matthias AD, Thompson TL, Leavitt SW, Ottman MJ, Cousins AB and Triggs JM. 2001. CO_2 enrichment increases water-use efficiency in sorghum. New Phytologist 151(2):407—412.

Cordeiro GM, Casu R, McIntyre CL, Manners JM and Henry RJ. 2001. Microsatellite markers from sugarcane (*Saccharum* spp.) ESTs cross transferable to erianthus and sorghum. Plant Science 160(6): 1115-1123.

Cousins AB, Adam NR, Wall GW, Kimball BA, Pinter PJ, Leavitt SW, La Morte RL, Matthias AD, Ottman MJ, Thompson TL and Webber AN. 2001. Reduced photorespiration and increased energy-use efficiency in young $C0_2$-enriched sorghum leaves. New Phytologist 150(2):275-284.

Cox WJ and Cherney DJR. 2001. Row spacing, plant density, and nitrogen effects on corn silage. Agronomy Journal 93(3):597-602.

Craufurd PQ and Qi A. 2001. Photothermal adaptation of sorghum (*Sorghum bicolor*) in Nigeria. Agricultural and Forest Meteorology 108:199-211.

Cueto Wong JA, Guldan SJ, Lindemann WC and Remmenga MD. 2001. Nitrogen recovery from N^{15}-labeled green manures: I. Recovery by forage sorghum and soil one season after green manure incorporation. Journal of Sustainable Agriculture 17(4):27-42.

Cueto Wong JA, Guldan SJ, Lindemann WC and Remmenga MD. 2001. Nitrogen recovery from N^{15}-labeled

green manures: II. Recovery by oat and soil two seasons after green manure incorporation. Journal of Sustainable Agriculture 17(4):43-55.

Cupina B and Eric P. 2001. Effect of sowing mode on sorghum and Sudan grass forage yield and yield components. [Uticaj nacina setve na prinos i komponente prinosa krme sirka i sudanske trave.] Journal of Scientific Agricultural Research. Arhiv za poljoprivredne nauke 62:133-141. *(Serbo-croat)*

Daba S and Zewedie E. 2001. Evaluation of the residual value of phosphorus fertilizer for sorghum *(Sorghum tricolor* L.) grown on a Vertisol. Bodenkultur 52(2): 175-181.

Dabney SM, Delgado JA and Reeves DW. 2001. Using winter cover crops to improve soil and water quality. Communications in Soil Science and Plant Analysis 32(7-8): 1221-1250.

Daniells IG, Holland JF, Young RR, Alston CL and Bernardl AL. 2001. Relationship between yield of grain sorghum (*Sorghum bicolor*) and soil salinity under field conditions. Australian Journal of Experimental Agriculture 41 (2):211-217.

Davis MA and Bockus WW. 2001. Evidence for a *Pythium* sp. as a chronic yield reducer in a continuous grain sorghum field. Plant Disease 85(7):780-784.

Defoor PJ, Cole NA, Galyean ML and Jones OR. 2001. Effects of grain sorghum planting density and processing method on nutrient digestibility and retention by ruminants. Journal of Animal Science 79(1): 19-25.

Devi KU , Padmavathi J, Sharma HC and Seetharama N. 2001. Laboratory evaluation of the virulence of *Beauveria bassiana* isolates to the sorghum shoot borer *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) and their characterization by RAPD-PCR. World Journal of Microbiology and Biotechnology 17(2):131-137.

Dhankhar JS, Kuhad MS, Narender Singh, Sharma JC and Bhandari DK. 2001. Response of balanced fertilizer use in different crops. Annals of Biology 17:57-60.

Diagne O, Ingleby K, Deans JD, Lindley DK, Diaite 1 and Neyra M. 2001. Mycorrhizal inoculum potential of soils from alley cropping plots in Senegal. Forest Ecology and Management 146:35-43.

Domitruk DR, Duggan BL and Fowler DB. 2001. Genotype x environment interaction of no-till winter wheat in western Canada. Canadian Journal of Plant Science 81(1):7-16.

Draye X, Lin YR, Qian XY, Bowers JE, Burow GB, Morrell PL, Peterson DG, Presting GG, Ren SX, Wing RA and Paterson AH. 2001. Toward integration of comparative genetic, physical, diversity, and cytomolecular maps for grasses and grains, using the sorghum genome as a foundation. Plant Physiology 125(3): 1325-1341.

Duponnois R, Plenchette C, Thioulouse J and Cadet P. 2001. The mycorrhizal soil infectivity and arbuscular mycorrhizal fungal spore communities in soils of different aged fallows in Senegal. Agriculture, Ecosystem and Environment 17:239-251.

Ebenebe AA, van den Berg J and van der Linde TC. 2001. Farm management practices and farmers' perceptions of stalk-borers of maize and sorghum in Lesotho. International Journal of Pest Management 47(1):41-48.

Ebenebe A A, van den Berg J and van der Linde TC. 2001. The incidence of *Dorylus helvolus* (Linnaeus) (Hymenoptera: Formicidae) and parasitoids (Hymenoptera: Braconidae) as mortality factors of *Busseola fusca* Fuller (Lepidoptera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) in Lesotho. African Entomology 9(1):77-84.

Eckard RJ, Salardini AA, Hannah M and Franks DR. 2001 The yield, quality and irrigation response of summer forage crops suitable for a dairy pasture renovation programme in north-western Tasmania. Australian Journal of Experimental Agriculture 41(1):37-44.

Elaskar SA, Godoy LA, Mateo D and Seeber G. 2001. An experimental study of the gravity flow of sorghum. Journal of Agricultural Engineering Research 79(1):65-71.

Elkhalil EAI, El-Tinay AH, Mohamed BE and Elsheikh EAE. 2001. Effect of malt pretreatment on phytic acid and *in vitro* protein digestibility of sorghum flour. Food Chemistry 72(I):29-32.

Ellstrand NC. 2001. When transgenes wander, should we worry? Plant Physiology 125(4): 1543-1545.

Eneje LO, Obiekezie SO, Aloh CU and Agu RC. 2001. Effect of milling and mashing procedures on millet (*Pennisetum maiwa*) malt wort properties. Process Biochemistry 36(8-9):723-727.

Eric P and Cupina B. 2001. Effect of different nitrogen levels on sorghum forage yield and yield components.[Uticaj primene razlicitih doza azota na prinos i komponente prinosa krme sirka.] Journal of Scientific Agricultural Research. Arhiv za poljoprivredne nauke 62:143-150. (*Serbo-croat*)

Esse PC, Buerkert A, Hiernaux P and Assa A. 2001. Decomposition of and nutrient release from ruminant manure on acid sandy soils in the Sahelian zone of Niger, West Africa. Agriculture Ecosystems and Environment 83(I-2):55-63.

Fan TWM, Lane AN, Shenker M, Bartley JP, Crowley D and Higashi RM. 2001. Comprehensive chemical profiling of gramineous plant root exudates using high-resolution NMR and MS. Phytochemistry 57(2):209-221.

Fang C, Radosevich M and Fuhrmann JJ. 2001. Atrazine and phenanthrene degradation in grass rhizosphere soil. Soil Biology and Biochemistry 33:671-678.

Fang C, Radosevich M and Fuhrmann JJ. 2001. Characterization of rhizosphere microbial community structure in five similar grass species using FAME and BIOLOG analyses. Soil Biology and Biochemistry 33:679-682.

Firdous R and Gilani AH. 2001. Changes in chemical composition of sorghum as influenced by growth stage and cultivar. Asian-Australasian Journal of Animal Sciences 14(7):935-940.

Fitzgerald MS, Shakirov EV, Hood EE, McKnight TD and Shippen DE. 2001. Different modes of *de novo* telomere formation by plant telomerases. Plant Journal 26:77-87.

Flinn M, Smith CM, Reese JC and Gill B. 2001. Categories of resistance to greenbug (Homoptera: Aphididae) biotype I in *Aegilops tauschii* germplasm. Journal of Economic Entomology 94(2):558-563.

Focher B, Palma MT, Canetti M, Torn G, Cosentino C and Gastaldi G. 2001. Structural differences between non-wood plant celluloses: evidence from solid state NMR, vibrational spectroscopy and X-ray diffractometry. Industrial Crop Production 13:193-208.

Freeling M. 2001. Grasses as a single genetic system. Reassessment 2001. Plant Physiology 125(3): 1191-1197.

French BW, Elliott NC, Kindler SD and Arnold DC. 2001. Seasonal occurrence of aphids and natural enemies in wheat and associated crops. Southwestern Entomologist 26:49-61.

Gandikota M, de Kochko A, Chen L, Ithal N, Fauquet C and Reddy AR. 2001. Development of transgenic rice plants expressing maize anthocyanin genes and increased blast resistance. Molecular Breeding 7(1):73-83.

Garrido MJ and Trujillo GE. 2001. Three sorghum cultivars differentiating sorghum yellow banding virus in Venezuela. Journal of Plant Pathology 83:70.

Gerard B, Hiernaux P, Muehlig Versen B and Buerkert A. 2001. Destructive and non-destructive measurements of residual crop residue and phosphorus effects on growth and composition of herbaceous fallow species in the Sahel. Plant and Soil 228(2):265-273.

Girish AG, Singh SD, Chakrabarty SK, Rao RDVJP, Surender A, Varaprasad KS and Bramel PJ. 2001. Seed microflora of five 1CR1SAT mandate crops. Seed Science and Technology 29:429-443.

Goldwasser Y and Yoder JL 2001. Differential induction of *Orobanche* seed germination by *Arabidopsis thaliana.* Plant Science 160(5):951-959.

Gomez Cordoves C, Bartolome B, Vieira W and Virador VM. 2001. Effects of wine phenolics and sorghum tannins on tyrosinase activity and growth of melanoma cells. Journal of Agricultural and Food Chemistry 49(3): 1620-1624.

Goyal V, B ansal P, Goel A and Bishnoi NR. 2001. Effect of terminal drought stress on different pigments of various genotypes of pearl millet. Crop Research Hisar 21:271-273.

Grenier C, Bramel-Cox PJ and Hamon P. 2001. Core collection of sorghum. I. Stratification based on eco-geographical data. Crop Science 41(1):234-240.

Grenier C, Hamon P and Bramel-Cox PJ. 2001. Core collection of sorghum. II. Comparison of three random sampling strategies. Crop Science 41 (1):241-246.

Grewal KS, Yadav PS, Mehta SC and Oswal MC. 2001. Direct and residual effect of flyash application to soil on crop yields and soil properties. Crop Research Hisar 21:60-65.

Gu H, Cao A and Walter GH. 2001. Host selection and utilisation of *Sonchus oleraceus* (Asteraceae) by *Helicoverpa armigera* (Lepidoptera: Noctuidae): a genetic analysis. Annals of Applied Biology 138:293-299.

Guadagnuolo R, Savova Bianchi D and Felber F. 2001. Gene flow from wheat (*Triticum aestivum* L.) to jointed goatgrass *(Aegilops cylindrica* Host.), as revealed by RAPD and microsatcllite markers. Theoretical and Applied Genetics 103(1): 1 - 8 .

Hada M, Hino K and Takeuchi Y. 2001. Development of UV defense mechanisms during growth of spinach seedlings. Plant and Cell Physiology 42(7):784-787.

Hadimani NA, Muralikrishna G, Tharanathan RN and Malleshi NG. 2001. Nature of carbohydrates and proteins in three pearl millet varieties varying in processing characteristics and kernel texture. Journal of Cereal Science 33(1): 17-25.

Haile A and Hofsvang T. 2001. Survey of lepidopterous stem borer pests of sorghum, maize and pearl millet in Eritrea. Crop Protection 20(2): 151-157.

Haque N, Saraswat ML and Sahoo A. 2001. Methane production and energy balance in crossbred male calves fed on rations containing different ratios of green sorghum and wheat straw. Indian Journal of Animal Sciences 71(8):797-799.

Hash CT, Abdu Rahman MD, Bhasker Raj AG and Zerbini E. 2001. Molecular markers for improving nutritional quality of crop residues for ruminants. Pages 203-217 *in* Molecular breeding of forage crops: Proceedings of the 2nd International Symposium. Lome and Hamilton. Victoria, Australia, 19-24 November 2000. (Spangenberg G, ed). Shrub Oak. New York, USA: Agritech Publications.

Hatfield JL, Sauer TJ and Prueger JH. 2001. Managing soils to achieve greater water use efficiency: a review. Agronomy Journal 93(2):271-280.

Haussmann BIG, Hess DE, Reddy BVS, Mukuru SZ, Kayentao M, Welz HG and Geiger HH. 2001. Quantitative-genetic parameters of sorghum growth under *Striga* infestation in Mali and Kenya. Plant Breeding 120(1):49-56.

Havrlentova M, Farago J and Nestakova M. 2001. Regeneration of immature inflorescences of barley *in vitro.* Biologia Plantarum 44(1): 157-159.

Hicks C, Bean SR, Lookhart GL, Pedersen JF, Kofoid KD and Tuinstra MR. 2001. Genetic analysis of kafirins and their phenotypic correlations with feed quality traits, *in vitro* digestibility, and seed weight in grain sorghum. Cereal Chemistry 78(4):412-416.

Hill Ambroz KL and Weeks JT. 2001. Comparison of constitutive promoters for sorghum [*Sorghum bicolor* (L.) Moench] transformation. Cereal Research Communications 29(1-2): 17-24.

Hirohashi T, Hase T and Nakai M. 2001. Maize non-photosynthetic ferredoxin precursor is missorted to the inter-membrane space of chloroplasts in the presence of light. Plant Physiology 125:2154-2163.

Hovny MR A, El Menshawi MM and El Nagouly OO. 2001. Combining ability and heterosis in grain sorghum [*Sorghum bicolor* (L.) Moench]. Bulletin of Faculty of Agriculture, Cairo University 52:47-60.

Ignjatovic-C upina A. 2001. The effect of various grains on morphometric properties, life cycle and reproductive capacity of angoumois grain moth *(Sitotroga cerealella* Oliv). Novi Sad (Yugoslavia). 203 pp.

Igyor MA, Ogbonna AC and Palmer GH. 2001. Effect of malting temperature and mashing methods on sorghum wort composition and beer flavour. Process Biochemistry 36(11): 1039-1044.

Ishaq M, Hassan A, Saeed M, Ibrahim M and Lal R. 2001. Subsoil compaction effects on crops in Punjab, Pakistan. 1. Soil physical properties and crop yield. Soil and Tillage Research 59(I-2):57-65.

Ishaq M, Ibrahim M, Hassan A, Saeed M and Lal R. 2001. Subsoil compaction effects on crops in Punjab, Pakistan. II. Root growth and nutrient uptake of wheat and sorghum. Soil and Tillage Research 60(3-4): 153-161.

Jain NK, Poonia BL and Singh RP. 2001. Response of pearl millet (*Pennisetum glaucum)* to zinc fertilization in flood-prone eastern plains zone of Rajasthan. Indian Journal of Agricultural Sciences 71(5):339-340.

Jasvir Singh, Yadav KK and Mandal AB. 2001. Feeding plane of milch Murrah buffaloes in its native breeding tract. Buffalo Journal 17:1-12.

Ji SN and linger PW. 2001. Soil water accumulation under different precipitation, potential evaporation, and straw mulch conditions. Soil Science Society of America Journal 65(2):442-448.

Jideani VA, Nkama I, Agbo EB and Jideani IA. 2001. Survey of Fura production in some northern states of Nigeria. Plant Foods for Human Nutrition 56(I):23-36.

Jondreville C, van den Broecke J, Gatel F, Grosjean F, van Cauwenberghe S and Seve B. 2001. Ileal digestibility of aminoacids and estimates of endogenous amino acid losses in pigs fed wheat, triticale, rye, barley, maize and sorghum. Animal Research 50(2): 119-134.

Jones ES, Breese WA and Shaw DS. 2001. Inoculation of pearl millet with the downy mildew pathogen, *Sclerospora graminicola:* chilling inoculum to delay zoospore release and avoid spray damage to zoospores. Plant Pathology 50(3):310-316.

Jones P and Vogt T. 2001. Glycosyl transferases in secondary plant metabolism: tranquilizers and stimulant controllers. Planta 213(2): 164-174.

Kabore BK, Couture L, Dostaler D and Bernier L. 2001. Phenetic variability of *Colletotrichum graminicola* from sorghum. Canadian Journal of Plant Pathology 23:138-145.

Kalbande VH and Chainpure AH. 2001. Effect of feeding bypass protein with urea treated jowar kadbi (sorghum straw) on performance of cross bred (HF x DEONI) calves. Asian-Australasian Journal of Animal Sciences 14(5):651-654.

Kebede H, Subudhi PK, Rosenow DT and Nguyen HT. 2001. Quantitative trait loci influencing drought tolerance in grain sorghum [*Sorghum bicolor* (L.) Moench]. Theoretical and Applied Genetics 103:266-276.

Kidd PS and Proctor J. 2001. Why plants grow poorly on very acid soils: are ecologists missing the obvious? Journal of Experimental Botany 52(357):791-799.

Kindler SD, Harvey TL, Wilde GE, Shufran RA, Brooks HL and Sloderbeck PE. 2001. Occurrence of greenbug biotype K in the field. Journal of Agricultural and Urban Entomology 18(I):23-34.

Klein RR, Klein PE, Chhabra AK, Dong J, Pammi S, Childs KL, Mullet JE, Rooney WL and Schertz KF. 2001. Molecular mapping of the *rfl* gene for pollen fertility restoration in sorghum (*Sorghum bicolor* L.). Theoretical and Applied Genetics 102(8): 1206-1212.

Klein RR, Rodriguez-Herrera R, Schlueter JA, Klein PE, Yu ZH and Rooney WL. 2001. Identification of genomic regions that affect grain-mould incidence and other traits of agronomic importance in sorghum. Theoretical and Applied Genetics 102(2-3):307-319.

Krauter PC, Sansone CG and Heinz KM. 2001. Assessment of Gaucho (R) seed treatment effects on beneficial insect abundance in sorghum. Southwestern Entomologist 26(2): 143-146.

Kung L and Ranjit NK. 2001. The effect of *Lactobacillus buchneri* and other additives on the fermentation and aerobic stability of barley silage. Journal of Dairy Science 84(5): 1149-1155.

Lakshmi KA and Lakshmi TVR. 2001. A non-enzymatic method of embryo sac isolation in *Pennisetum glaucum* (L.) R. Br. Phytomorphology 51:71-77.

Lale NES and Alaga KA. 2001. Exploring the insecticidal, larvicidal and repellent properties of *Piper guineense* Schum. et Thonn. seed oil for the control of rust-red flour beetle *Tribolium castaneum* (Hcrbst) in stored pearl millet *Pennisetum glaucum* (L.) R. Br. Zeitschrift fur Pflanzenkrankheiten und Pflanzenschutz. Journal of Plant Diseases and Protection 108(3):305-313.

Lale NES and Yusuf BA. 2001. Potential of varietal resistance and *Piper guineense* seed oil to control infestation of stored millet seeds and processed products by *Tribolium castaneum* (Herbst). Journal of Stored Products Research 37(1):63-75.

Lawrence PR, Gerard B, Moreau C, Lheriteau F and Buerkert A. 2001. Design and testing of a global positioning system-based radiometer for precision mapping of pearl millet total dry matter in the Sahel. Agronomy Journal 93(1):262.

Lema M, Felix A, Salako S, Cebert E and Bishnoi U. 2001. Nutrient content and *in vitro* dry matter digestibility of silages made from various grain sorghum cultivars. Journal of Applied Animal Research 19(2): 129-136.

Lezama-Gutierrez R, Hamm JJ, Molina-Ochoa J, Lopez-Edwards M, Pescador-Rubio A, Gonzalez-Ramirez M and Styer EL. 2001. Occurrence of entomopathogens of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Mexican states of Michoacan, Colima, Jalisco and Tamaulipas. Florida Entomologist 84(1):23-30.

Liebig MA, Varvel G and Doran J. 2001. A simple performance based index for assessing multiple agroecosystem functions. Agronomy Journal 93:313-318.

Lopez-Martinez N, Gonzalez-Gutierrez J and de Prado R. 2001. Propanil activity, uptake and metabolism in resistant *Echinochloa* spp. biotypes. Weed Research41(2):187-196.

Lukens L and Doebley J. 2001. Molecular evolution of the teosinte branched gene among maize and related grasses. Molecular Biology and Evolution 18(4):627-638.

Machado S and Paulsen GM. 2001. Combined effects of drought and high temperature on water relations of wheat and sorghum. Plant and Soil 233(2): 179-187.

Manisegaran S, Manimegalai M, Venkatesan S and Mohammed SEN. 2001. Effect of intercropping on the incidence of shoot webber *Antigastra catalaunalis* in sesame. Annals of Plant Protection Sciences 9:131-133.

Marley PS, Elemo KA, Aba DA, Onu I and Akintayo I. 2001. Reactions of sorghum genotypes to anthracnose and grey leaf spot diseases under Sudan and Sahel savanna field conditions of Nigeria. Journal of Sustainable Agriculture 18(2—3): 105—116.

Marley PS, Thakur RP and Ajayi O. 2001. Variation among foliar isolates of *Colletotrichum sublineolum* of sorghum in Nigeria. Field Crops Research 69(2): 133-142.

Marra MC and Kaval P. 2001. The relative profitability of sustainable grain cropping systems: a meta-analytic comparison. Journal of Sustainable Agriculture 16(4): 19-32.

Mbuya OS, Nkedi Kizza P and Boote KJ. 2001. Fate of atrazine in sandy soil cropped with sorghum. Journal of Environmental Quality 30(I):71-77.

McIntyre BD, Bouldin DR, Urey GH and Kizito F. 2001. Modeling cropping strategies to improve human nutrition in Uganda. Agricultural Systems 67(2): 105-120.

McKeown AW and Potter JW. 2001. Yield of 'Superior' potatoes (*Solatium tuberosum*) and dynamics of root lesion nematode (*Pratylenchus penetrans*) populations following 'nematode suppressive' cover crops and fumigation. Phytoprotection 82:13-23

McLaren NW. 2001. [Important diseases occuring on sorghum leaves]. SA Grain (South Africa) 2(I):35-36. *(Africaans*)

McLaren NW. 2001. [Root rot in sorghum detrimental to crop yields]. SA Grain (South Africa) 2(2):41-43. (*Africaans*)

Meagher RL. 2001. Collection of soybean looper and other noctuids in phenylacetaldehyde-baited field traps. Florida Entomologist 84(1): 154-155.

Mertz O, Lykke AM and Reenberg A. 2001. Importance and seasonality of vegetable consumption and marketing in Burkina Faso. Economic Botany 55(2):276-289.

Mishra NS, Mallick BN and Sopory SK. 2001. Electrical signal from root to shoot in *Sorghum bicolor:* induction of leaf opening and evidence for fast extracellular propagation. Plant Science 160(2):237-245.

Misra AK, Chaturvedi OH, Mishra AS, Tripathi MK, Verma DL and Karim SA. 2001. Nutrient intake and utilization in sheep fed urea supplemented diets containing mustard straw and other roughage. Indian Journal of Small Ruminants 7:8-13.

Miyake H, Nishimura M and Takeoka Y. 2001. Immunogold labeling of rubisco in C4 plant leaves for scanning electron-microscopy. Plant Production Science 4(1):41-49.

Mochida K and Tsujimoto H. 2001. Production of wheat doubled haploids by pollination with Job's tears (*Coix lachryma-jobi* L.). Journal of Heredity 92(I):81-83.

Moguel LHB, de Gante CR and Saldivar SOS. 2001. Comparisons between a commercial wort and a waxy sorghum wort fermented into lager beer, with emphasis on yeast growth and ethanol production. Journal of the American Society of Brewing Chemists 59(1):24-27.

Mohapatra S and Ortiz R. 2001. Safeguarding the future of food security in the semi arid tropics: the role of ICRISAT's genetic resource collection. Entwicklung und Landlicher Raum 35:29-31. (*German*)

Molina-Ochoa J, Hamm JJ, Lezama-Gutierrez R, Lopez-Edwards M, Gonzalez-Ramirez M and Pescador-Rubio A. 2001. A survey of fall army worm (Lepidoptera: Noctuidae): parasitoids in the Mexican states of Michoacan, Colima, Jalisco, and Tamaulipas. Florida Entomologist 84(1):31-36.

Moore KJ and Jung HJG. 2001. Lignin and fiber digestion. Journal of Range Management 54(4):420-430.

da Motta S and Soares LMV. 2001. Survey of Brazilian tomato products for alternariol, alternariol monomethyl ether, tenuazonic acid and cyclopiazonic acid. Food Additives and Contaminants 18(7):630-634.

Mulatu E and Belete K. 2001. Participatory varietal selection in lowland sorghum in eastern Ethiopia: impact on adoption and genetic diversity. Experimental Agriculture 37(2):211-229.

Munamava M and Riddoch I. 2001. Response of three sorghum [*Sorghum bicolor* (L.) Moench) varieties to soil moisture stress at different developmental stages. South African Journal of Plant and Soil 18:75-79.

Munene CN, Kampen WH and Njapau H. 2001. Economic feasibility of co-producing bioethanol and glycerol from grain and cane molasses fermentations. International Sugar Journal 103:264-268.

Mutanal SM, Prabhakar AS and Nadagoudar BS. 2001. Compatability of sorghum (*Sorghum bicolor*) in teak (*Tectona grandis*)-*based* agroforestry system. Indian Journal of Agricultural Sciences 71(3): 197-200.

Muthukrishnan S, Liang GH, Trick HN and Gill BS. 2001. Pathogenesis-related proteins and their genes in cereals. Plant Cell Tissue and Organ Culture 64(2-3):93-I 14.

Mwikya SM, van Camp J, Rodriguez R and Huyghebaert A. 2001. Effects of sprouting on nutrient and anti nutrient composition of kidney beans (*Phaseolus vulgaris* var. Rose coco). European Food Research and Technology 212(2): 188-191.

Nagarajan S, Dijkema C and van As H. 2001. Metabolic response of roots to osmotic stress in sensitive and tolerant cereals qualitative in vivo [31P] nuclear magnetic resonance study. Indian Journal of Biochemistry and Biophysics 38:149-152.

Nanda SS, Alim MA, Santra GH and Dash B. 2001. Biofertilizer use in economizing nitrogen in fodder sorghum (*Sorghum bicolor*). Environment and Ecology 19:5-8.

Nandini CD and Salimath PV. 2001. Carbohydrate composition of wheat, wheat bran, sorghum and bajra with good chapati/roti (Indian flat bread) making quality. Food Chemistry 73(2): 197-203.

Ndabikunze BK, 2001. The nutritional value of togwa with different types of ingredients and some implications for their use as a weaning food. Aas, Norway: Norges Landbruskshoegskole, NLH. 34 pp

Nelson LA. 2001. Nebraska grain sorghum hybrid tests, 2000. Lincoln, Nebraska, USA: University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources, Agricultural Research Division, Cooperative Extension. 19 pp.

Neves Piestun BG and Bernstein N. 2001. Salinity-induced inhibition of leaf elongation in maize is not mediated by changes in cell wall acidification capacity. Plant Physiology 125(3): 1419-1428.

Ngugi HK, King SB, Holt J and Julian AM. 2001. Simultaneous temporal progress of sorghum anthracnose and leaf blight in crop mixtures with disparate patterns. Phytopathology 91(8):720-729.

Nielsen JK, Hansen ML, Agerbirk N, Petersen BL and Halkier BA. 2001. Responses of the flea beetles *Phyllotreta nemorum* and *P. cruciferae* to metabolically engineered *Arabidopsis thaliana* with an altered glucosinolate profile. Chemoecology 11:75-83.

Nnaji AO. 2001. Forecasting seasonal rainfall for agricultural decision-making in northern Nigeria. Agriculture for Meteorology 107(3): 193-205.

Nnam NM. 2001. Chemical, sensory and Theological properties of porridges from processed sorghum (*Sorghum bicolor*), bambara groundnut [*Vigna subterranea* (L.) Verde] and sweet potato (*Ipomoea batatas*) flours. Plant Foods for Human Nutrition 56(3):251-264.

Nnam NM. 2001. Comparison of the protein nutritional value of food blends based on sorghum, bambara groundnut and sweet potatoes. International Journal of Food Sciences and Nutrition 52(1):25-29.

Ockerby SE, Midmore DJ and Yule DF. 2001. Leaf modification delays panicle initiation and anthesis in grain sorghum. Australian Journal of Agricultural Research 52(1): 127-135.

Ockerby SE, Midmore DJ and Yule DF. 2001. Timing and height of defoliation affect vegetative growth and floral development in grain sorghum. Australian Journal of Agricultural Research 52(8):801-808.

Odunfa SA, Adeniran SA, Teniola OD and Nordstrom J. 2001. Evaluation of lysine and methionine production in some lactobacilli and yeasts from Ogi. International Journal of Food Microbiology 63(1-2): 159-163.

Oldach KH, Morgenstern A, Rother S, Girgi M, O'Kennedy M and Lorz H. 2001. Efficient *in vitro* plant regeneration from immature zygotic embryos of pearl millet [*Pennisetum glaucum* (L.) R. Br.] and *Sorghum bicolor* (L.) Moench. Plant Cell Reports 20(5):416-421.

Omokawa H and Ryoo JH. 2001. Enantioselective response of rice and barnyard millet on root growth inhibition by optically active alpha-methylbenzyl phenylureas. Pesticide Biochemistry and Physiology 70(1): 1-6.

van Oosterom EJ, Carberry PS, Hargreaves JNG and O'Leary GJ. 2001. Simulating growth, development, and yield of tillering pearl millet. II. Simulation of canopy development. Field Crops Research 72(1):67-91.

van Oosterom EJ, Carberry PS and Muchow RC. 2001. Critical and minimum N contents for development and growth of grain sorghum. Field Crops Research 70(1):55—73.

van Oosterom EJ, Carberry PS and O'Leary GJ. 2001. Simulating growth, development, and yield of tillering pearl millet. I. Leaf area profiles on main shoots and tillers. Field Crops Research 72(1):51-66.

Orak A. 2001. The effect of different sowing dates on yield and yield components of hybrid sorghum [*Sorghum bicolor* (L.) Moench.] in dryland conditions. Cereal Research Communications 29(1-2):183-187.

Ottman MJ, Kimball BA, Pinter PJ, Wall GW, Vanderlip RL, Leavitt SW, La Morte RL, Matthias AD and Brooks TJ. 2001. Elevated CO_2 increases sorghum biomass under drought conditions. New Phytologist 150(2):261-273.

Ouedraogo E, Mando A and Zombre NP. 2001. Use of compost to improve soil properties and crop productivity under low imput agricultural system in West Africa. Agriculture, Ecosystems and Environment 84:259-266.

Pandey RK, Maranville JW and Bako Y. 2001. Nitrogen fertilizer response and use efficiency for three cereal crops in Niger. Communications in Soil Science and Plant Analysis 32(9-10): 1465-1482.

Parani M, Rajesh K, Lakshmi M, Parducci L, Szmidt AE and Parida A. 2001. Species identification in seven small millet species using polymerase chain reaction-restriction fragment length polymorphism of trnS-psbC gene region. Genome 44(3):495-499.

Patil SL and Sheelavantar MN. 2001. Effect of in-situ moisture conservation practices and integrated nutrient management on nutrient availability and grain yield of rabi sorghum (*Sorghum bicolor)* in the Vertisols of semi-arid tropics of South India. Indian Journal of Agricultural Sciences 71(4):229-233.

Pazoutova S. 2001. The phylogeny and evolution of the genus *Claviceps.* Mycological Research 105: 275-283.

Pedersen JF and Toy JJ. 2001. Germination, emergence, and yield of 20 plant-color, seed-color near-isogenic lines of grain sorghum. Crop Science 41(1): 107-110.

Pedersen JF and Toy JJ. 2001. Registration of N313, N314, and N315 sorghum germplasm lines. Crop Science 41 (2):600-601.

Pedersen JF and Toy JJ. 2001. Registration of N316-N320 sorghum nuclear male-sterility genetic stocks. Crop Science 41(2):607.

Pedersen JF and Toy JJ. 2001. Registration of N321-N340 sorghum seed color/plant color genetic stocks. Crop Science 41(2):607.

Peixoto PHP, Cambraia J, Sant-Anna R, Mosquim PR and Moreira MA. 2001. Aluminum effects on fatty acid composition and lipid peroxidation of a purified plasma membrane fraction of root apices of two sorghum cultivars. Journal of Plant Nutrition 24(7): 1061-1070.

Perez M, Henke SE and Fedynich AM. 2001. Detection of aflatoxin-contaminated grain by three granivorous bird species. Jounal of Wildlife Disease 37(2):358-361.

Petersen BL, Andreasson E, Bak S, Agerbirk N and **Halkier BA.** 2001.Characterization of transgenic *Arabidopsis thaliana* with metabolically engineered high levels of p-hydroxybenzyl-glucosinolate. Planta 212(4):612-618.

Qiu-Wen Ping, Scholthof KBG and Qiu WP. 2001. Genetic identification of multiple biological roles associated with the capsid protein of satellite panicum mosaic virus. Molecular Plant Microbe Interactions 14(1):21—30.

Raiger HL and Prabhakaran VT. 2001. A study on the performance of a few non parametric stability measures using pearl millet data. Indian Journal of Genetics and Plant Breeding 61:7-11.

Rajendra Prasad, Saukhyan SK. Karim SA and Jakhmola RC. 2001. Nutrient utilization by grower rabbits fed various energy supplements in complete feed. Indian Journal of Small Ruminants 7:14-18.

Ramirez-Cano F, Ramos-Quirarte A, Faix O, Meier D, Gonzalez-Alvarez V and Zuniga-Partida V. 2001. Slow-release effect of N-functionalized kraft lignin tested with sorghum over two growth periods. Bioresource Technology 76(1):71-73.

Rao MVSSTS and Muralikrishna G. 2001. Non-starch polysaccharides and bound phenolic acids from native and malted finger millet (ragi, *Eleusine coracana,* Indaf-15). Food Chemistry 72(2): 187-192.

Rao SVR, Sunder GS, Reddy MR, Praharaj NK, Raju MVLN and Panda AK. 2001. Effect of supplementary choline on the performance of broiler breeders fed on different energy sources. British Poultry Science 42:362-367.

Raskar BS, Bhoi PG and Shinde SH. 2001. Productivity and economics of rabi sorghum (*Sorghum bicolory-summer* vegetables cropping sequences under irrigated conditions. Indian Journal of Agricultural Sciences 71(1):9-11.

Rattunde HFW, Zerbini E, Chandra S and Flower DJ. 2001. Stover quality of dual-purpose sorghums: genetic and environmental sources of variation. Field Crops Research 71 (1):1-8.

Ravindran V, Selle PH, Ravindran G, Morel PCH, Kies AK and Bryden WL. 2001. Microbial phytase improves performance, apparent metabolizable energy, and ileal amino acid digestibility of broilers fed a lysine-deficient diet. Poultry Science 80(3): 338-344.

Repellin A, Baga M, Jauhar PP and Chibbar RN. 2001. Genetic enrichment of cereal crops via alien gene transfer: New challenges. Plant Cell Tissue and Organ Culture 64(2-3): 159-183.

Ribeiro ES, Dias LE, Alvarez VH, Mello JWV and Daniels WL. 2001. Dynamics of sulfur fractions in Brazilian soils submitted to consecutive harvests of sorghum. Soil Science Society of America Journal 65(3):787-794.

Rillig MC, Wright SF, Kimball BA, Pinter PJ, Wall GW, Ottman MJ and Leavitt SW. 2001. Elevated carbon dioxide and irrigation effects on water stable aggregates in a sorghum field: a possible role for arbuscular mycorrhizal fungi. Global Change Biology 7(3):333-337.

Roche D, Chen Z, Hanna WW and Ozias-Akins P. 2001. Non-Mendelian transmission of an apospory-specific genomic region in a reciprocal cross between sexual pearl millet (*Pennisetum glaucum)* and an apomictic F_1 *(P. glaucum* x *P. squamulatum).* Sexual Plant Reproduction 13(4):217-223.

Rohrbach DD and Kiriwaggulu JAB. 2001. Commercialization prospects for sorghum and pearl millet in Tanzania. Working Paper Series No. 7. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi Arid Tropics (ICRISAT). 28 pp.

Romero Zalamea C. 2001. Biomass production. [Produccion de biomasa.] Agricultura, Revista Agropecuaria 70:364-366. *Italian*

Ryley MJ. 2001. Location and activity of hyphae of the downy mildew, *Peronosclerospora noblei* (Family Peronosporaceae), and its relationship to symptom expression on wild sorghum *(Sorghum leiocladum).* Australian Journal of Botany 49(4):487-492.

Saadalla MM and Refay YA. 2001. Genotypic response, correlations, and path coefficients in grain sorghum as affected by contrasting water regimes. Bulletin of Faculty of Agriculture, Cairo University 52:207-224.

Saneoka H, Ishiguro S and Moghaieb REA. 2001. Effect of salinity and abscisic acid on accumulation of glycine betaine and betaine aldehyde dehydrogenase mRNA in sorghum leaves *(Sorghum bicolor).* Journal of Plant Physiology 158(7):853-859.

Sanni AI, Asiedu M and Ayernor GS. 2001. Influence of processing conditions on the nutritive value of Ogi-baba, a Nigerian fermented sorghum gruel. Plant Foods for Human Nutrition 56(3):217-223.

Sene M, Dore T and Gallet C. 2001. Relationships between biomass and phenolic production in grain sorghum grown under different conditions. Agronomy Journal 93(I):49-54.

Sene M, Gallet C and Dore T. 2001. Phenolic compounds in a Sahelian sorghum *(Sorghum bicolor)* genotype (Ce (145-66)) and associated soils. Journal of Chemical Ecology 27(1):81-92.

Shailasree S, Sarosh BR, Vasanthi NS and Shetty HS. 2001. Seed treatment with beta-aminobutyric acid protects *Pennisetum glaucum* systemically from *Sclerospora graminicola.* Pest Management Science 57(8):721-728.

Shapiro CA, Holshouser DL, Kranz WL, Shelton DP, Witkowski JF, Jarvi KJ, Echtenkamp GW, Lunz LA, Frerichs RD, Brentlinger RL, Lubberstedt MA, McCluskey MM and Stroup WW. 2001. Tillage and management alternatives for returning Conservation Reserve Program land to crops. Agronomy Journal 93:850-862.

Sharma HC and Franzmann BA. 2001. Host-plant preference and oviposition responses of the sorghum midge, *Stenodiplosis sorghicola* (Coquillett) (Dipt., Cecidomyiidae) towards wild relatives of sorghum. Journal of Applied Entomology-Zeitschrift fur Angewandte Entomologie 125(3): 109-114.

Sharma OP and Gupta AK. 2001. Comparing the feasibilities of pearl millet-based intercropping systems supplied with varying levels of nitrogen and phosphorus. Journal of Agronomy and Crop Science-Zeitschrift fur Acker und Pflanzenbau 186(2):91-95.

Shayo NB, Laswai HS, Tusekwa BPM, Nnko SAM, Gidamis AB and Njoki P. 2001. Evaluation of nutritive value and functional qualities of sorghum subjected to different traditional processing methods. International Journal of Food Sciences and Nutrition 52(2): 117-126.

Shetty HS and Kumar VU. 2001. Biological control of pearl millet downy mildew: present status and future prospects. Biocontrol Potential and Its Exploitation in Sustainable Agriculture 1:251-265.

Shetty HS, Vasanthi NS, Sarosh BR and Kini KR. 2001. Inheritance of downy mildew resistance, beta-l,3-glucanases and peroxidases in pearl millet *[Pennisetum glaucum* (L.) R.Br.] crosses. Theoretical and Applied Genetics 102(8): 1221-1226.

Silberbush R. 2001. Potassium influx to roots of two sorghum genotypes grown under saline conditions. Journal of Plant Nutrition 24(7):1035-1045.

Sinclair TR and Muchow RC. 2001. System analysis of plant traits to increase grain yield on limited water supplies. Agronomy Journal 93(2):263-270.

Song JQ, Dong FG, Lilly JW, Stupar RM and Jiang JM. 2001. Instability of bacterial artificial chromosome (BAC) clones containing tandemly repeated DNA sequences. Genome 44(3):463-169.

Soyelu LO, Ajayi SA, Aluko OB and Fakorede MAB. 2001. Varietal differences in development of maize (*Zea mays* L.) seedlings on compacted soils. Journal of Agronomy and Crop Science-Zeitschrift fur Acker und Pflanzenbau 186(3): 157-166.

Steadman KJ, Burgoon MS, Lewis BA, Edwardson SE and Obendorf RL. 2001. Minerals, phytic acid, tannin and rutin in buckwheat seed-milling fractions. Journal of the Science of Food and Agriculture 81(11):1094-1100.

de Stefano G, Piacquadio P and Sciancalepore V. 2001. Effect of selected processing variables on sensory attributes of extrudates. Italian Journal of Food Science 13(2):229-232.

Stone PJ, Wilson DR. Reid JB and Gillespie RN. 2001. Water deficit effects on sweet corn. 1. Water use, radiation use efficiency, growth, and yield. Australian Journal of Agricultural Research 52(1):103-113.

Stratford S, Barnes W, Hohorst DL, Sagert JG, Cotter R, Golubiewski A, Showalter AM, McCormick S and Bedinger P. 2001. A leucine rich repeat region is conserved in pollen extensin like (Pex) proteins in monocots and dicots. Plant and Molecular Biology 46:43-56.

Su G, Suh SO, Schneider RW and Russin JS. 2001. Host specialization in the charcoal rot fungus, *Macrophomina phaseolina.* Phytopathology 91(2): 120-126.

Sujava IN, Amachi S, Yokota A, Asano K and Tomita F. 2001. Identification and characterization of lactic acid bacteria in ragitape. World Journal of Microbiology and Biotechnology 17(4):349-357.

Sun Qing, Ao Yong Hua, Ge Wen and Cao Yu Rui. 2001. Research on production of protein feed from the residue of sweet sorghum stalks. [Tian gaoliang jinggan canza shengchan danbai siliao de yanjiu.] Scientia Agricultura Sinica 34:61-65. (*Chinese*)

Swarts J. 2001. [Quelea control]. SA Grain (South Africa) 2(2):32. (*Africaans*)

Taiwo OE and Osinowo FAO. 2001. Evaluation of various agro-wastes for traditional black soap production. Bioresource Technology 79(1):95-97.

Tarafdar JC, Yadav RS and Meena SC. 2001. Comparative efficiency of acid phosphatase originated from plant and fungal sources. Journal of Plant Nutrition and Soil Science-Zeitschrift fur Pflanzenernahrung und Bodenkunde 164(3):279-282.

Taylor JRN and Dewar J. 2001. Developments in sorghum food technologies. Advances in Food and Nutrition Research 43:217-264.

Teniola OD and Odunfa SA. 2001. The effects of processing methods on the levels of lysine, methionine and the general acceptability of ogi processed using starter cultures. International Journal of Food Microbiology 63(1-2): 1-9.

Thakur RP, Rai KN, Rao VP and Rao AS. 2001. Genetic resistance of pearl millet male-sterile lines to diverse Indian pathotypes of *Sclerospora graminicola.* Plant Disease 85(6): 621-626.

Thompson CA. 2001. Winter wheat and grain sorghum production as influenced by depth of soil water, tillage and cropping system. Journal of Soil and Water Conservation 56(I):56-63.

Tonani FL, Ruggieri AC, Queiroz AC and Andrade P. 2001. Ruminal *in situ* degradability of dry matter and neutral detergent fiber of sorghum (*Sorghum bicolor* L.) silages with different harvesting times. [Degradabilidade ruminal *in situ* da materia seca e da fibra em detergente neutro em silagens de hibridos de sorgo colhidos em diferentes epocas.] Arquivo Brasileiro de Medicina Veterinaria e Zootecnia 53:100-104. (*Portugese*)

Tooley PW, Goley ED, Carras MM, Frederick RD, Weber EL and Kuldau GA. 2001. Characterization of *Claviceps* species pathogenic on sorghum by sequence analysis of the beta-tubulin gene intron 3 region and EF-1 alpha gene intron 4. Mycologia93(3):541-551.

Tsubo M, Walker S and Mukhala E. 2001. Comparisons of radiation use efficiency of mono-/inter-cropping systems with different row orientations. Field Crops Research 71 (1): 17-29.

Tunstall V, Teshome A and Torrance JK. 2001. Distribution, abundance and risk of loss of sorghum landraces in four communities in North Shewa and South Welo, Ethiopia. Genetic Resources and Crop Evolution 48(2): 131-142.

Unger PW. 2001. Alternative and opportunity dryland crops and related soil conditions in the southern Great Plains. Agronomy Journal 93(1):216-226.

Unger PW. 2001. Paper pellets as a mulch for dryland grain sorghum production. Agronomy Journal 93(2):349-357.

Uozumi S, Kurokawa S and Yoshimura Y. 2001. Effects of night temperature treatments on the panicle initiation and the final leaf number of sorghum [*Sorghum hicolor* (L.) Moench] inbred strain 932233B. Grassland Science 47:145-150.

Uozumi S, Yoshimura Y and Kurokawa S. 2001. Effects of night temperature treatments on the panicle initiation and final leaf number of some sorghum [*Sorghum bicolor* (L.) Moench] varieties. Grassland Science 47:139-144.

Ventelon M, Deu M, Garsmeur O, Doligez A, Ghesquiere A, Lorieux M, Rami JF, Glaszmann JC and Grivet L. 2001. A direct comparison between the genetic maps of sorghum and rice. Theoretical and Applied Genetics 102(2-3):379-386.

Vikrant and Rashid A. 2001. Direct as well as indirect somatic embryogenesis from immature (unemerged) inflorescence of a minor millet *Paspalum scrohiculatum* L. Euphytica 120(2): 167-172.

Villenave C, Bongers T, Ekschmitt K, Djigal D and Chotte JL. 2001. Changes in nematode communities following cultivation of soils after fallow periods of different length. Agriculture, Ecosystem and Environment 17(1):43-52.

Watling JR and Press MC. 2001. Impacts of infection by parasitic angiosperms on host photosynthesis. Plant Biology 3(3):244-250.

Wenzel WG, van-Loggerenberg M and Ordon F. 2001. Quick screening methods for sorghum quality traits. Journal of Applied Botany-Angewandte Botanik 75(1-2):43-45.

Wesley RA, Elmore CD and Spurlock SR. 2001. Deep tillage and crop rotation effects on cotton, soybean, and grain sorghum on clayey soils. Agronomy Journal 93(1): 170-178.

Weston LA and Czarnota MA. 2001. Activity and persistence of sorgoleone, a long chain hydroquinone produced by *Sorghum bicolor.* Journal of Crop Production 4:363-377.

Wharton PS, Julian AM and O'Connell RJ. 2001. Ultrastructure of the infection of *Sorghum bicolor* by *Colletotrichum sublineolum.* Phytopathology 91 (2): 149-158.

Wilde GE, Shufran RA, Kindler SD, Brooks HL and Sloderbeck PE. 2001. Distribution and abundance of insecticide-resistant greenbugs (Homoptera: Aphididae) and validation of abioassay to assess resistance. Journal of Economic Entomology 94(2):547-551.

Williams DG, Gempko V, Fravolini A, Leavitt SW, Wall GW, Kimball PA, Pinter PJ and La Morte R. 2001. Carbon isotope discrimination by *Sorghum bicolor* under CO_2 enrichment and drought. New Phytologist 151(2):551+.

Williams DG, Gempko V, Fravolini A, Leavitt SW, Wall GW, Kimball BA, Pinter PJ, La Morte R and Ottman M. 2001. Carbon isotope discrimination by *Sorghum bicolor* under CO_2 enrichment and drought. New Phytologist 150(2):285-293.

Wilson JP, Gates RN and Pan war MS. 2001. Dynamic multiline population approach to resistance gene management. Phytopathology 91 (3):255-260.

Winkel T, Payne W and Renno JF. 2001. Ontogeny modifies the effects of water stress on stomatal control, leaf area duration and biomass partitioning of *Pennisetum glaucum.* New Phytologist 149(I):71-82.

Winter SR and Unger PW. 2001. Irrigated wheat grazing and tillage effects on subsequent dryland grain sorghum production. Agronomy Journal 93(3):504-510.

Wu J, Ransom MD, Kluitenberg GJ, Nellis MD and Seyler HL. 2001. Land-use management using a soil survey geographic database for Finney County, Kansas. Soil Science Society of America Journal 65(1): 169-177.

Yadav OP and Bhatnagar SK. 2001. Evaluation of indices for identification of pearl millet cultivars adapted to stress and non-stress conditions. Field Crops Research 70(3):201-208.

Yadav RS and Yadav OP. 2001. The performance of cultivars of pearl millet and cluster bean under sole cropping and intercropping systems in arid zone conditions in India. Experimental Agriculture 37(2):231-240.

Yoneyama K, Takeuchi Y and Yokota T. 2001. Production of clover broomrape seed germination stimulants by red clover root requires nitrate but is inhibited by phosphate and ammonium. Physiologia Plantarum 112(1):25-30.

Yousif NE and El Tinay AH. 2001. Effect of fermentation on sorghum protein fractions and *in vitro* protein digestibility. Plant Foods for Human Nutrition 56(2): 175-182.

Zeng Ren Sen, Luo Shi Ming, Shi Yue Hong, Shi Mu Biao and Tu Cong Yong. 2001. Physiological and biochemical mechanism of allelopathy of secalonic acid F on higher plants. Agronomy Journal 93:72-79.

van Zyl H and Setser CS. 2001. Measuring characteristics of frankfurters extended with sorghum flour. Journal of Food Quality 24(1):37-52.

Information for ISMN Contributors

Publishing objectives

The International Sorghum and Millets Newsletter (ISMN) is published annually by the Sorghum Improvement Conference of North America (SICNA) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). It is intended as a worldwide communication link for all those interested in the research and development of sorghum [*Sorghum bicolor* (L.) Moench], pearl millet [*Pennisetum glaucum* (L.) R. Br.), and minor millets, and their wild relatives. Though the contributions that appear in ISMN are reviewed and edited, it is expected that the work reported will be developed further and formally published in refereed journals.

What to contribute?

- Contributions should be current, scholarly and well justified on the grounds of new information.
- Results of recently concluded experiments, newly released varieties, recent additions to germplasm collections, registration notes for newly developed trait-specific breeding lines/germplasm. etc.
- Genome maps and information on probe-availability and sequences, and populations synthesized for specific traits being mapped.
- Short reports of workshops, conferences, symposia, field days, meetings, tours, surveys, network activities and recently launched or concluded projects.
- Details of recent publications, with full bibliographic information and 'mini reviews' whenever possible.
- Personal news (new appointments, awards, promotions, change of address, etc.).

Deadline for submission to Vol. 46 : 15 August 2005

How to format contributions

- Keep the items brief up to **6 pages (double-spaced) including data tables and figures.**
- Table should be separated from the text and placed upright (not landscape). Supply only the essential information; round off the data-values to just one place of decimal; use suitable units to keep the values small (eg, tons instead of kg).
- Keep the list of references short - not more than five references, all of which should have been seen in the original by the author. Provide all the details including author/s, year, title of the article, full title of the journal, volume, issue and page numbers (for journal articles), and place ol publication and publishers (for books and conference proceedings) for every reference. **Cite references as in this issue.**
- Black-and-white photographs are welcome. Send disk-files whenever you submit line figures and maps.
- Express all quantities only in SI units. Spell out in full every acronym you use.
- Give Latin name of every crop, pest, or pathogen at the first mention.
- Submit one hard copy of the manuscript in the correct format to the Scientific Editor of the respective region at the address given below. Also send the manuscript MS Word file as email attachment.
- Include full address of all authors, and provide telephone, fax and e-mail of the **corresponding** author.

ISMN will carefully consider all submissions and will accept only those that conform to its scientific standard and requirements. The language of the Newsletter is English, but we will do our best to translate articles submitted in other languages. **Authors should closely follow the format and style of the articles in this issue to prepare the manuscripts.**

Contributions and requests for inclusion in the mailing list should be mailed to:

Africa and Asia

ISMN Scientific Editor
ICRISAT
Patancheru 502 324
Andhra Pradesh. India
Fax +91 40 30713074
E-mail newslettcr@cgiar.org
Phone +91 40 30713071

Americas, Europe and Oceania

ISMN Scientific Editor
National Grain Sorghum Producers
4201 N Interstate 27
Lubbock, TX 79403. USA
Fax +1 806 749 9002
E-mail jeff@sorghumgrowers.com
Phone +1 806 749 3478

SICNA

Sorghum Improvement Conference of North America

National Grain Sorghum Producers

4201 N Interstate 27, Lubbock, TX 79403, USA

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political, international organization for science-based agricultural development. ICRISAT conducts research on sorghum, pearl millet, chickpea, pigeonpea and groundnut - crops that support the livelihoods of the poorest of the poor in the semi-arid tropics encompassing 48 countries, ICRISAT also shares information and knowledge through capacity building, publications and information and communication technologies (ICTs). Established in 1972. it is one of 15 Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

Contact information :

ICRISAT-Patancheru (Headquarters)
Patancheru 502 324
Andhra Pradesh, India
Tel +91 40 30713071
Fax +91 40 30713074/75
icrisal©cgiar.org

Liaison Office
CG Centers Block
NASC Complex
Dev Prakash Shastri Marg
New Delhi 110 012. India
Tel +91 11 25849552/25842553
Fax +91 11 25841294

ICRISAT-Nairobi (Regional hub ESA)
PO Box 39063. Nairobi. Kenya
Tel +254 20 7224550
Fax +254 20 7224001
icrisat-nairobi@cgiar.org

ICRISAT-Niamey (Regional hub WCA)
BP 12404
Niamey. Niger (Via Paris)
Tel +227 722529, 722725
Fax +227 734329
icrisatsc@cgiar.org

ICRISAT-Bamako
BP 320
Bamako, Mali
Tel +223 2223375
Fax +223 2228683
icrisat-w-mali@cgiar.org

ICRISAT-Bulawayo
Matopos Research Station
PO Box 776
Bulawayo, Zimbabwe
Tel +263 83 8311 to 15
Fax +263 83 8253/8307
icrisatzw@cgiar.org

ICRISAT-Lilongwe
Chitedze Agricultural Research Station
PO Box 1096
Lilongwe, Malawi
Tel +265 1 707297/071/067/057
Fax +265 1 707298
icrisat-malawi@cgiar.org

ICRISAT-Maputo
c/o INIA, Av. das FPLM No 2698
Caixa Postal 1906
Maputo, Mozambique
Tel +258 1461657
Fax +258 1461581
icrisatmoz@panintra.com

Visit us at www.icrisat.org

ISSN 1023 - 487 X

152-2005