Collaborative Sorghum Research in Asia

International Crops Research Institute for the Semi-Arid Tropics

Abstract

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The Asian Sorghum Researchers' Consultative Meeting (27-29 Sep 1993, ICRISAT Center) was attended by delegates from ICRISAT and several Asian countries. The participants reviewed collaborative sorghum research in Asia, and discussed the major production constraints and research priorities for the future. The changing role of sorghum, from a subsistence crop to a multiple-use crop (food, feed, and fodder), was recognized, as was the considerable potential for increasing demand by promoting alternative uses (e.g., in processed foods and industrial products).

The Meeting recommended that future collaborative research on sorghum be integrated into the Cereals and Legumes Asia Network (CLAN). This would create a single network covering the CLAN priority crops (sorghum, millets, groundnut, chickpea, and pigeonpea), and would strengthen collaborative research and technology and information exchange both within and outside the network.

Résumé

La recherche collaborative sur le sorgho en Asie: rapport de la Réunion consultative des chercheurs de sorgho en Asie. La Réunion consultative des chercheurs de sorgho en Asie qui a eu lieu du 27 au 29 septembre 1993 au Centre ICRISAT, en Inde, a réuni des délégués de l'ICRISAT et de plusieurs pays de l'Asie. Les participants ont fait le point sur la recherche collaborative sur le sorgho en Asie et ont examiné les contraintes majeures à la production ainsi que les priorités de recherche dans l'avenir. Le rôle changeant du sorgho—d'une culture de subsistance à une culture polyvalente (consommation humaine, aliment de bétail et fourrage)—a été reconnu, de même que le potentiel important d'augmentation de la demande en favorisant les usages alternatifs (notamment les denrées alimentaires transformées et les produits industriels).

La réunion a recommandé que la recherche collaborative future sur le sorgho soit intégrée dans le Réseau asiatique des céréales et des légumes (CLAN). Cela permettrait la mise en place d'un seul réseau comportant les cultures prioritaires du CLAN (sorgho, mils, arachide, pois chiche et pois d'Angole). En outre, le renforcement de la recherche collaborative et de l'échange d'informations et de technologie seraient facilités tant à l'intérieur du réseau qu'à l'extérieur.

Collaborative Sorghum Research in Asia

Report of the Asian Sorghum Researchers' Consultative Meeting

27-29 Sep 1993
ICRISAT Center

Edited by

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ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India

1993

Contents

Introduction

C.L.L. Gowda[1]

It gives me great pleasure to welcome all of you to the Asian Sorghum Researchers' Consultative Meeting. We have a more or less full house, with national program representatives from Australia, China, India, Iran, Myanmar, and Thailand, and a private seed industry representative from India. Invitees who were unable to attend, from other Asian countries and institutions, have nevertheless indicated their interest in collaborative research programs, and have asked to be kept informed of the outcome of this Meeting. I would like to add my special thanks to all the scientists who agreed to present the lead papers and status reports on sorghum research and development in their respective countries, and to all the Chairpersons, Moderators, and Rapporteurs for their contributions.

Some of you may recall that we had a meeting of sorghum scientists in September 1991 to consider the establishment of a sorghum research and development network for Asia. The participants at that meeting strongly endorsed the formation of such a network to 'elevate the status of sorghum from that of a .... subsistence crop to a high-value crop .... and to have the right vision at the outset—that is, to work together through a network'. Subsequent developments and the formation of a unified Cereals and Legumes Asia Network (CLAN) have resulted in changes in the organizational set up. The recommendations of the 1991 Meeting will naturally be carried forward. Dr D.E. Byth, Director of the Cereals Program at ICRISAT will discuss this issue in more detail. The important point is to maintain the momentum that has been built up by the partnership approach, and to carry forward the mission of sorghum improvement in Asia. Future collaborative research in sorghum will be facilitated by CLAN.

A collaborative agricultural research network is a group of scientists or institutions linked together by a commitment to collaborate in solving problems of mutual concern, by using existing resources more effectively. Therefore, the essence of networks is to share research responsibilities and resources to find solutions to these problems, and to exchange material, information, and technology resulting from such collaborative efforts. The CLAN Coordination Unit therefore needs the cooperation and guidance of all network members to organize effective network research. We value your suggestions on how to make this network more effective and efficient.

Once again, a hearty welcome. Late September-early October is perhaps the best time of the year to visit ICRISAT Center, and we hope that you will enjoy your stay here.

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Objectives of the Meeting

D.E. Byth[1]

I would like to add my welcome to delegates to this Asian Sorghum Researchers' Consultative Meeting. This Meeting will have a pivotal influence on the future of sorghum research in Asia, and therefore it is most encouraging to see the strong representation of so many NARS from the region. Briefly, the objectives of the Meeting are as follows:

- Review the recommendations of the Consultative Meeting (16-19 Sep 1991, ICRISAT Center) to form a sorghum research and development network for Asia, and to indicate how these may be integrated into Cereals and Legumes Asia Network (CLAN) activities;
- Discuss the contributions of member countries to network research, and members' needs and expectations from CLAN;
- Prepare a regional work plan for collaborative research on sorghum in Asia; and
- Provide the opportunity for delegates to acquaint themselves with the sorghum experimental work at ICRISAT Center and the Indian National Research Centre for Sorghum (NRCS), Hyderabad.

The background to this Meeting is perhaps well known to most here, but it justifies repetition.

At the time of the first Consultative Meeting, ICRISAT was involved in the coordination of two separate crop improvement networks impacting on Asia—the Asian Grain Legumes Network (AGLN) which was solely Asian, and the Cooperative Cereals Research Network (CCRN) which had a broader perspective extending beyond the region. The outcomes of that Meeting are outlined in Table 1.

This planning process, however, was overtaken by events. Action was taken by ICRISAT in April 1992 to form the Cereals and Legumes Asia Network (CLAN) by merging the AGLN and CCRN. The objective was to establish a unified network for technology and information exchange within Asia which involved the ICRISAT mandate crops—sorghum, millets, chickpea, pigeonpea, and groundnut:

The concept of CLAN offers advantages to all parties involved in research for the region:

- For the NARS, concerned with overall production systems, not just with the individual crops within them, it is a single window for technology development and exchange.

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- ICRISAT's research portfolio will center on the achievement of sustained increases in productivity and the introduction of improved genetic materials and management systems into specified production systems.
- The network will foster the integration of ICRISAT contributions in crop improvement and resource management research, and assist in technology exchange.
- Mentor institutions can now more readily identify opportunities for impact of their advanced research capabilities.
- Donor agencies can use CLAN to achieve a focus on impact on production in real production environments through integrated research plans derived within the region.

Clearly, the development of CLAN impacts quite fundamentally on the earlier plans regarding a sorghum research and development network for Asia. A result of

Table 1. Outcomes of the first Consultative Meeting, 16-19 Sep 1991.

Recommendation	• Formation of regional network.
Goal	• Overall, to elevate the status of sorghum from a subsistence to a high-value crop; and • Pooling of resources and expertise to achieve rapid progress in technology generation, adaptation, and adoption.
Objectives	• To exchange improved genetic material and germplasm; • To conduct cooperative research and development on sorghum production and utilization; • To upgrade research and development capabilities of the participating countries; • To support and accelerate transfer of technology to farmers and industries; and • To develop efficient databases for sharing information.
Strategy	• Steering Committee for policy making, consisting of NARS policy makers, to guide direction of the network and link it to NARS and donors; • Technical Committee to advise on technical content of network activities; and • Coordination Unit, provided by ICRISAT.
Funding	• Participating NARS to support all network activities in-country; and • Donor support to be actively sought.
Membership	• All interested Asian countries, plus Australia and Russia as resource centers linked to the region.
Proceedings	• Published by ICRISAT.

this development is the need to review the recommendations of the earlier Consultative Meeting, and to consider how an integration into CLAN activities can be achieved. A key concern will be the development of a regional work plan for sorghum. This Meeting may also wish to consider whether, given the existence of CLAN, there is a continuing need for a Sorghum Researchers' Consultative Group, which could perhaps be constituted as a crop-specific working group within the CLAN umbrella.

CLAN is submitting a proposal to the Asian Development Bank (ADB) for funding to support network activities, including sorghum research. Seven major areas of collaboration are proposed in the ADB submission.

Exchange of germplasm and breeding material among network members. The emphasis will be on; collaborative breeding research to develop cultivars adapted to local conditions, and exchange of germplasm and breeding populations with sources of resistance to major stress factors.

Working groups to address and solve high priority regional problems by collaboration among interested and committed scientists.

On-farm adaptive research to disseminate improved technology among sorghum farmers in Asia.

Information exchange to share knowledge and technology among network scientists and extension specialists.

Human resource development to strengthen the research capabilities of NARS.

Linking activities such as workshops, meetings, monitoring tours, and surveys to provide opportunities for sorghum researchers (within a country or region) to come together to interact and share information, and to prepare future work plans. This would help to share strengths, and identify areas of weakness, which can then be strengthened by collaborative work.

Closer involvement of NARS scientists in the coordination of network activities, with a view to devolve responsibility for network research and coordination to the NARS.

We need your comments, suggestions, and approval for these plans so that the recommendations of this group can be used to strengthen the funding proposal to the ADB.

With this brief introduction, I again welcome you to the Asian Sorghum Researchers' Consultative Meeting. I know we all look forward to active and open discussions over the next 2 days.

Alternative Uses of Sorghum

R.B. Somani[1] and R.B. Pandrangi[2]

Introduction

Sorghum is the primary food crop in the state of Maharashtra, India, where it occupies over 6 million ha. It is grown in both the rainy and postrainy seasons. Of the area under sorghum in the state, 50% is a *kharif* or rainy season crop, and more than 90% of this is high-yielding, photo-insensitive hybrids. The average productivity of sorghum in the Vidarbha region reached 1.79 t ha^{-1} in 1992.

Prices usually fall dramatically when production increases. Moreover, consumption of this coarse cereal as food is declining, even in remote areas, while the demand for wheat and rice is increasing. There is thus no incentive for farmers to increase sorghum production. The area under sorghum has not declined significantly, since the crop has to be grown for fodder in rainfed areas. The *kharif* crop is usually caught in the rains during its postflowering period; this results in grain becoming discolored because of grain molds. Affected grains cannot be stored for long periods, fetch low market prices, are not accepted by consumers, and their nutritive value is impaired.

To maintain attractive market prices for sorghum and encourage remunerative production, it is essential to diversify the uses of crop surpluses and mold-damaged and discolored produce. Against this background, technologies for converting sorghum into starch, sugars, alcohol, beer, and malt products are being explored.

Sugars

At present in India, maize starch is usually acid-hydrolyzed to produce liquid glucose and dextrose monohydrate.

Enzymes are substrate-specific. Sorghum grain flour has been used, since only the starch fraction of the grain is fractioned by the enzymes, thus eliminating the need for starch separation. The process for the production of liquid sugars is shown in Figure 1. The yield and quality of glucose obtained directly from whole grains are comparable to those of glucose obtained from starch hydrolysis. However, for whole-grain utilization, more stringent efforts are required to separate fats by filtering or using a centrifuge. Pentosanase enzyme (pH 5.0) was used, and incubation carried out for 15 min at 45°C. Amyloglucosidase (AMG) was replaced by dextrozyme (a mixture of pullulanase and amyloglucanase). The difficulty in agitating the gelatinized mass was

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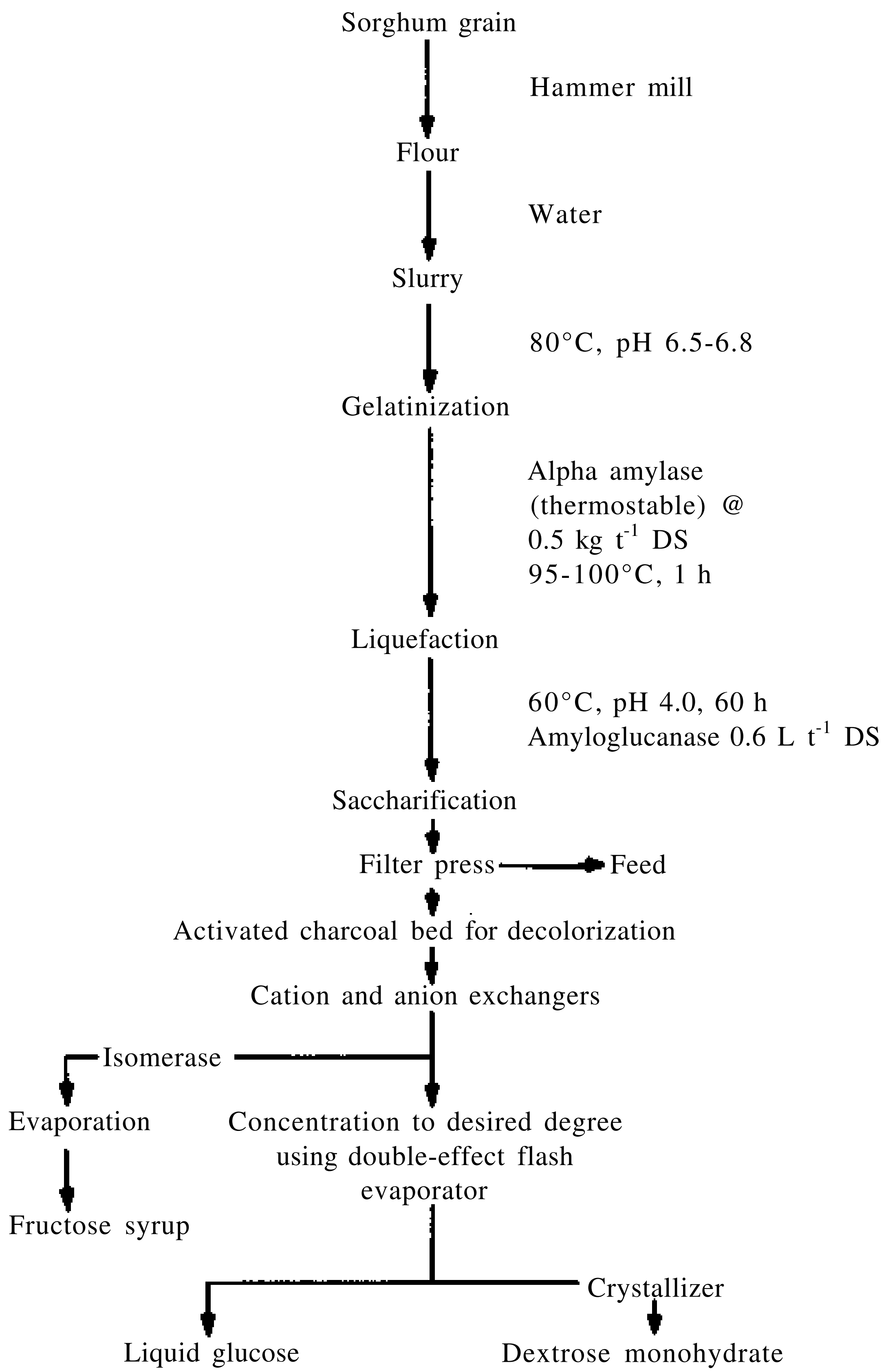

Figure 1. Production of sugars from sorghum grain.

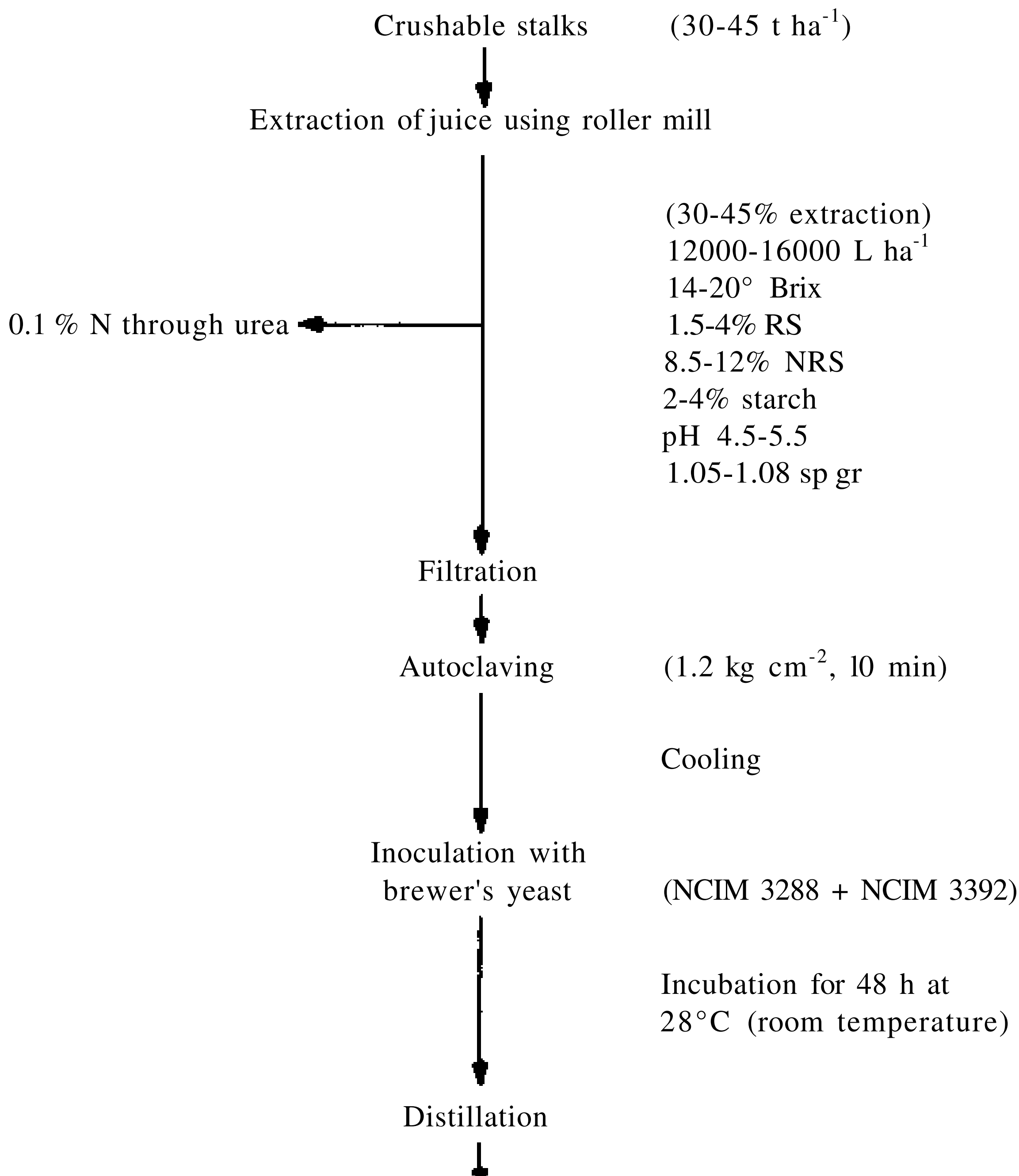

Figure 2. Alcohol production from sweet sorghum stalks.

[Alcohol yield depends on the amount of sugar available for conversion in the juice. It may roughly be calculated as: alcohol yield (L t^{-1}) = grams of sugar x 0.59. Grams of sugar L^{-1} juice = specific gravity (sp gr) of juice x (Brix°-3)] overcome by adding Termamyl® before gelatinization. Using this **process, we** obtained glucose yields equal to the theoretically obtainable values. The unconverted portion of the grain, which contains 22-26% of crude protein, can be used as livestock feed.

Alcohol

More alcohol can be produced *per* unit area of land from sweet sorghums and high-energy sorghums than from other cereals.

Stalk juice. Amongst the sweet sorghum varieties screened during 1990 and 1991, cultivars SSV 2525, SSV 84, and GSSV 148 were the best producers of ethanol from stalk juice. However, high-energy sorghums are better than sweet sorghums for total alcohol production per unit area of land. While screening strains of brewer's yeast, *Saccharomyces cerevisiae,* it was noticed that NCIM 3095 + local strain, NCIM 3288 + NCIM 3392, and NCIM 3288 + local strain were good at converting stalk juice to alcohol (Somani et al. 1992). It was also found that strains which efficiently convert sorghum stalk juice were not necessarily equally effective in converting cane juice. Acidification (pH 3.0-3.5) and boiling for 30 min gave results comparable to those obtained with autoclaving. This resulted in a considerable energy saving over earlier methods. Bagasse (the stalk remaining after juice extraction) can be used to make particle board and pulp. The process for converting stalk juice into alcohol using selected strains of brewer's yeast has been standardized and is shown in Figure 2.

Grains. The grain of commonly grown sorghum cultivars contains 65-71% starch. At present this starch is hydrolyzed to yield simple sugars, which are then fermented to yield alcohol. About 20-25% of the starch is lost during the process, as it remains bound to fiber and is difficult to extract. Whole grain utilization was therefore tried, using Termamyl-120 L® (a heat-stable alpha amylase, produced by NoVo Nordisk Als, Bangalore, India) for liquefaction and AMG-300 L® (an amyloglucosidase, also produced by NoVo Nordisk Als) for saccharification.

Of the four methods tried, simultaneous saccharification and fermentation at room temperature (28°±2°C) was the most efficient (Table 1).

A laboratory model has been made of a compact glass column that could yield 184-190° proof alcohol with 98.2% pure ethyl alcohol.

From 25-30% grain slurry, an ethanol concentration of 11-12% (v/v) was obtained, and results indicated that 384 L of ethanol could be produced from one tonne of sorghum.

Discolored grains with a threshold grain mold rating (TGMR) of 3.0 on a 1 to 5 scale, were used to produce alcohol using a method that combines saccharification and fermentation. The reduction in alcohol yield could be correlated with the loss of starch in the grains due to molds.

Table 1. Alcohol yield from sorghum grain by various methods.

Method	Alcohol yield (190° proof) L t^{-1} grain		Crude protein in spent grains on DS basis (%)	
	Normal	Blackened[1]	Normal	Blackened[1]
Enzymic liquefaction —> saccharification —> fermentation	348		24	
Enzymic liquefaction —> simultaneous saccharification and fermentation	384	310	29	24
Gelatinization —> acid hydrolysis —> fermentation	334		25	
Acid hydrolysis under pressure —> fermentation	290		26	

1. Grains showing threshold grain mold rating (TGMR) of 3 on a 1-5 scale.

Starch

Grain sorghum is similar to maize in its composition and properties. Thus the technology developed to extract starch from maize can be used for sorghum with little modification. Since sorghum costs less than maize, the profit margins in sorghum-based starch manufacture are relatively high.

Roughly 50% of starch in India is now produced from tapioca. However, tapioca cultivators are switching to rubber, and many of the tapioca starch units in Kerala state (the major producer) are on the verge of closure. The area under maize in the country is not increasing substantially, and notwithstanding increases in maize productivity, there is good scope for sorghum starch production.

Of the three extraction methods tried in the laboratory, lactic acid (1%) added during steeping gave comparatively higher starch yields. The starch extracted is white in color, with a Brabender amylograph similar to that of maize starch.

Sorghum starch can be used for a number of purposes: in the manufacture of binders, glue, and thickeners, as a functional additive in the processing of synthetic polymers, and (mixed with maize starch if necessary) in the sizing and printing of fabric. More research is required to develop these and other forms of sorghum starch utilization. Sorghum germ oil contains low levels of stearic (4%) and palmitic (10%) acids, and thus has a large potential market in the hydrogenated oil and soap industries. Other by-products such as oil cake, glutelin, and crude fiber can be used as feed.

Semolina

Semolina was prepared from sorghum grain in a commercial wheat roller flour mill. The grain was dehulled using carborundum abrasive rollers. Of the five grain-cutting machine sections of the roller mill, only three were used, and a good quality sorghum semolina was successfully produced.

Malt Products

Cleaned sorghum grains were allowed to germinate for up to 96 h, kilned, degermed, and then roasted in a hot air oven until they were brown. On cooling, the grains were coarse ground.

To prepare the beverage 'Sorgho-Vita', the following ingredients were used (w/w): malt 60%, milk powder 10%, sugar 25%, chocolate powder 1.5%, cocoa 1.5%, and minerals 2%.

To prepare beer, 50 g of malt were mixed in 450 mL of water, boiled for 2 h and then filtered. The filtrate was adjusted to an acidic pH and an inoculum of 4-5% *Saccharomyces uvarum* (NCIM 3305) was added. Fermentation was allowed to proceed for 48 h at 15°C, after which the mixture was filtered and incubated at low temperatures. No adjuncts were used in this method. The clear liquid obtained contained 5-6% alcohol. Analysis of the beer prepared by this method is in progress.

Efforts are being made to prepare non-alcoholic beverages in orange, lemon, and mango flavors using sorghum malt extract.

Conclusions

Sorghum grain and stalk have vast potentials for industrial utilization. Normal and molded grains can now be used industrially to produce sugars and alcohol. However, the quality of the end products needs to be studied in detail.

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Potential for Forage Sorghum in Asia

G.P. Lodhi[1]

Introduction

Sorghum is grown as a grain crop for human consumption and as a feed grain for animals in most of the sorghum-growing areas of the world. It also offers great potential for supplementing fodder resources, because of its wide adaptation, quick growth, high yield, and good fodder quality. Its high dry-matter content and leafiness are good for making both silage and hay. There are no available statistics on the total area and production of forage sorghum, but it is grown to a sizeable extent in USA, Australia, and some Asian countries. Forage sorghum is widely grown in the dry season, and, particularly in northern India and Pakistan, to augment fodder supplies in the monsoon season.

The role of sorghum in meeting the fodder and feed requirements of draft, milch, and beef animals in mixed farming systems is better recognized in developed countries than in most developing countries. Sorghum research in most of the semi-arid tropics has been mainly targeted at its use as a food grain; fodder aspects have always been neglected in the past. Now, realizing the increasing requirements for fodder (due to the increase in the animal population and the greater demand for milk and milk products), there is an urgent need to initiate research work to improve sorghum for forage in all sorghum-growing countries.

Production Constraints and Possible Solutions

The most important constraints limiting forage sorghum production are:

- Lack of emphasis and planning for improvement and management;
- Shortage of quality seed;
- Production of forage sorghum on poor soils with poor management;
- Susceptibility to insect pests and diseases;
- Price fluctuation and lack of adequate fodder marketing facilities;
- Limited conservation of surplus fodder; and
- Inadequate transfer of improved production technology.

Herbage, dry fodder, and seed—the major yield traits in forage sorghum—are governed by a complex interplay of several factors, and fodder and seed yields are negatively correlated. Hence, a proper balance between these characters should be

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maintained in forage sorghum improvement, in addition to breeding for fodder quality traits and resistance to insect pests and diseases. Forage sorghum cultivars should be fast-growing and responsive to inputs and management conditions, in order to increase the yield and nutritive value of fodder. The seed yield of varieties, and hybrid seed production, should be given high priority because of the higher seed requirement for forage types.

Biotic and Abiotic Stresses

Sorghum is attacked by a large number of insect pests and diseases. In the case of forage sorghum, foliar diseases and such pests as shootfly *(Atherigona soccata)* and stem borer *(Chilo partellus),* are important, as these adversely affect both fodder yield and quality (Chirangeevi and Tripathi 1976, Gandhi et al. 1980, Singh et al. 1989, Het Ram and Lodhi 1990). Although sorghum is reasonably tolerant of abiotic stresses, fodder yield and quality are drastically reduced by drought and adverse soil conditions.

Current Research and Future Priorities

The present research program for the improvement of forage sorghum in India focuses on breeding varieties and hybrids with high forage yield, better quality, good seed yield, and resistance to insect pests and diseases, and on the development of improved production technology.

Considering the extent of developments in grain sorghum that have taken place to date in various sorghum-growing countries, relatively limited work has been done on the improvement of forage sorghum, particularly in Asia. However, some useful results have been obtained in India.

Twelve varieties for single cut and two varieties and three hybrids for multicut have been recommended for cultivation in all Indian sorghum-growing areas. These were found to be 30-40% superior in fodder yield, and 25-30% better in quality than currently used varieties. Breeding work on a limited scale is also in progress in other Asian countries including Pakistan, the former Soviet Union, Japan, and the Philippines; and forage sorghum cultivars are being grown in these countries. Extensive work on forage sorghum improvement is in progress in Australia and USA for green chopping, silage, and grazing, with the result that Sudan grass varieties and forage sorghum hybrids now account for much of the area occupied by sorgos in USA. Forage hybrids are mostly sorghum x Sudan grass and Sudan grass x Sudan grass combinations.

A considerable amount of genetic variability and heterosis exists for various forage yield and quality characters. Promising sorghum lines with good combining ability for different agronomic characters have been identified (Paroda and Lodhi 1981, Lodhi 1992). Plant height, leaf number, and leaf size are the component traits of dry-matter yield. Protein content has a high direct effect on the digestibility of fodder, while tannin content is negatively associated with digestibility. The genetics of forage yield, its quality characters, and resistance to major insect pests and foliar diseases have been investigated (Lodhi and Dangi 1981, Grewal et al. 1987, Het Ram and Lodhi 1992).

Several findings of practical importance to forage sorghum management have been obtained, and can be used to increase forage sorghum production. These relate to sowing time, seed rate, fertilizer requirement, weed management, insect pests, and foliar diseases, management of hydrocyanic acid (HCN), harvesting, mixed cropping, and crop rotations (Lodhi and Grewal 1988).

Future Research Needs

Attention should be paid to stability in production of biomass and nutrient content through resistance breeding. While improvement in yield and quality of both single and multicut cultivars through breeding and management should receive attention, more emphasis is needed on maintaining the fodder yield potential of current varieties. This can be achieved through the incorporation of resistance to biotic factors, improved tillering capacity, and quick growth to meet the multiple demands of sorghum as a fodder, silage, hay, and stover crop. At the same time, reasonable seed yields should be assured to meet the demands of farmers and the seed industry. The identification and development of male-sterile lines and restorers suitable for forage sorghum hybrid production are also important, as is a detailed study of the relationship between midrib color and fodder quality. Forage sorghum improvement programs are beset with lack of information on variability and useful genetic stocks for various traits. Therefore, concerted and planned efforts are needed to collect, evaluate, catalog, and maintain germplasm exclusively for forage sorghum. Attention also needs to be focused on breeding dual-purpose cultivars for food, feed, and forage.

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Potential for Sweet Sorghum in Asia

A.D. Karve[1]

Introduction

Most Asian countries already have sugar industries, based either on sugarcane *(Saccharum* spp) or sugarbeet *{Beta vulgaris).* With the exception of those in equatorial regions, the factories operate only for 4 to 6 months in a year, generally beginning operations in the first week of November. In both the tropical and subtropical regions of Asia, it is possible to cultivate sweet sorghum from May to October. In tropical Asia, this period coincides with the rainy season; in the subtropical region, this is the only period of the year that is warm enough for successful sorghum production. The long days during summer promote good vegetative growth with tall stalks. The crop matures during September and October, offering factories the chance to work for 2 more months each year, and to dramatically improve their profits.

Sweet Sorghum Characteristics

Freshly harvested sweet sorghum stalks contain about 70% moisture, 15% soluble solids, and 15% nonsoluble matter. Sugars constitute about 80% of the soluble solids. The ratio of sucrose to reducing sugars (glucose and fructose) ranges from about 10:1 in high-sucrose types to about 3:1 in low-sucrose varieties. The non-sucrose impurities consist of phenolic compounds, starch, proteins, photosynthetic pigments, waxes, organic acids, and salts. Freshly harvested mature stalks of high-sucrose varieties normally contain about 10% sucrose. The juice is rather acidic (pH 5.0-5.5) due to the presence of aconitic acid.

The stalks have an outer rind, formed by thick-walled, lignified, silicified cells. Many of the impurities such as phenolic compounds, pigments, waxes, and some protein are contributed by this rind. Sugar is stored in the parenchymatous cells of the pith, along with organic acids, starch, and salts.

Processing Sweet Sorghum

A well-grown crop of sweet sorghum, harvested at physiological grain maturity, yields about 1-2 t ha^{-1} of grain, 10-15 t ha^{-1} of fresh leaves, and 40-50 t ha^{-1} of stripped

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stalks. Juice can be extracted from the stalks using roller mills or with a diffuser. After extraction, the juice is subjected to liming, followed by carbonation or sulphitation, and filtration. The clarified juice is then boiled under vacuum to remove water. A rule of thumb in sugar technology states that every unit of nonsucrose impurity in the juice reduces recovery by 0.4 units. The dissolved solids in sweet sorghum juice contain 70-75% sucrose and 25-30% nonsucrose impurities. Although mature stalks contain about 10% sucrose, the impurities in the juice allow only 7-8% sucrose to be recovered. In comparison to recovery of 11-12% in sugarcane and 13-14% in sugarbeet, crystalline sugar recovery from sweet sorghum is quite poor.

In the case of sweet sorghum, the rind of the stalks and the leaf sheaths that remain adhering to the stalk, contribute significantly to the impurities in the juice. The rind contains phenolic compounds, photosynthetic pigments, and waxes, while the leaf sheaths are rich in photosynthetic pigments, soluble proteins, and starch. When whole stalks are subjected to the extraction process, the impurities in the rind and the leaf sheaths are extracted along with the sugars. If the pith could be separated from the rind and juice extracted only from the pith, the load of impurities in the juice would automatically be reduced. Such a process would not only reduce processing costs but would also improve the recovery percentage of crystalline sugar.

Messrs Four Eyes Research (P) Limited, a commercial firm in Pune, India, has developed a prototype for a sweet sorghum pith separator. A stalk entering the separator is split longitudinally into two halves, which are driven by a set of rollers over high-velocity scraper wheels, which scrape out the pith. The rind and leaf sheaths are thrown out intact. The pith scrapings can either be fed into a diffuser, or they can be passed through a roller tandem that extracts the juice they contain. The prototype can separate pith from about 10-12 tonnes of stalks per hour.

On the whole, it is cheaper and easier to produce syrup from sweet sorghum than to prepare crystalline sugar. Such a product may not be accepted by household consumers, but it should be acceptable to bulk users of sugar like bakeries and manufacturers of confectionery, soft drinks, jams, etc. Depending on the process used, the syrup can have reducing and nonreducing sugars in the same proportion as that in the stalk (high-sucrose syrup), only glucose and fructose in equal proportions (inverted sugar syrup), or a higher proportion of fructose than glucose (high-fructose syrup). At the same total sugar content, the inverted sugar would be 1.25 times and the high-fructose syrup twice as as sweet as high-sucrose syrup.

To produce a commercially acceptable product, the syrup would have to be treated with ion-exchange resins (to remove salts) and with active charcoal (to decolorize and deodorize it). These processes are used in modern sugar factories to upgrade the quality of molasses.

With a few, relatively minor modifications, any sugar factory can process sweet sorghum.

Alternatively, the juice can be fermented to produce alcohol. But because the alcohol yield is only about half that of sugar, this alternative would be economically viable only if the price of alcohol were to be twice that of sugar.

Syrup Production as a Cottage Industry

The strategy of extending the working period of existing sugar factories by 2 months appears economically quite attractive, but it would require sweet sorghum to be sown on about 5 000 to 10 000 ha in the vicinity of the factory. This may not always be possible. One should, therefore, also think seriously of encouraging syrup production on a smaller scale. All over the tropical regions of Asia, so-called noncentrifugal sugar is produced from sugarcane or palm sap in small plants that process about 10-20 t day^{1}. These same facilities could be used to produce syrup from sweet sorghum. A plantation of just 20 to 40 ha could keep such a plant running for 2 months.

In addition to tropical Asian countries, village-level production of sorghum syrup could also have good potential in Sahelian Africa. Many sub-Saharan countries do not have their own sugar industry, and have to depend on imported sugar. However, they may be able to produce short-duration sweet sorghum as a rainfed crop. It is suggested that syrup, or noncentrifugal sugar made from sweet sorghum juice would at least partially satisfy the demand for sugar in these countries. Such a program would also boost the rural economy of these countries, which today are among the poorest in the world.

Research Needs

Apart from standardizing process technology for syrup production, a great deal also needs to be done on the plant breeding front, and efforts are needed to improve juice purity. This might be done by combining tan plant type with the bloomless character and a higher degree of resistance to stem borers. Loose leaf sheaths and stronger stalks that do not break during stripping would make harvesting easier.

In the tropical parts of Asia, sweet sorghum stems turn dry and pithy if harvesting is delayed, while in subtropical regions, they remain juicy for several weeks after maturity. Breeders and agronomists in tropical areas need to look into this problem because under a tropical monsoon climate, large areas are sown simultaneously, depending on the rains, but they cannot all be harvested simultaneously.

Research-Production-Market Linkages in Sorghum—Future Needs for Asia

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Introduction

Alarm bells have been ringing for the past decade in sorghum production and trading centers around the world. World sorghum production, which increased steadily during the 1960s and 1970s, slowed down in the 1980s. Trading in grain sorghum has similarly levelled off (Kelley et al. 1991).

Total sorghum production in Asia has been stagnant during the last 30 years at about 20 million t (Table 1). Productivity has increased marginally, but this has been offset by a decrease in area under sorghum cultivation.

Table 1. Production and consumption of sorghum in selected Asian countries and Australia, 1986-88 (from Kelley et al. 1991).

Country	Production ('000 t)	Consumption ('000 t)
India	9 489	9 555
China	5 495	5 445
Australia	1 432	710
Yemen (Arab Republic)	542	542
Thailand	265	127
Pakistan	222	221
Taiwan	109	705
Israel	3	360
Japan	0	4 040
Total (Asia + Australia)	17 557	21 705

India (54%) and China (31%) shared the bulk of Asian sorghum production about 5 years ago. By the turn of this century, they are expected to contribute about 69% and 20%, respectively. Thus, India is not only a present major producer in Asia, but will play an even more significant role in the near future.

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Future Needs

Projections for Asia indicate that 7 years from now, significant growth in production is expected from India alone. However, a marginal increase in the total Asian sorghum production is expected. The gap between projected consumption and production is expected to be about 6.7 million tonnes, largely due to deficits in Japan, Taiwan, and China (Table 2). The projected consumption pattern in 2000 AD indicates that these three countries will be importing sorghum grain for livestock feed rather than for food.

Table 2. Projected sorghum production and consumption in 2000 AD in selected Asian countries and Australia (from Kelley et al. 1991).

Country	Projected production ('000 t)	Growth in production[1]	Projected consumption ('000 t)			Surplus (+)/ Deficit (-)
			Food	Feed	Total	
India	13 743	+	10 468	1 339	11 807	+ 1 936
China	4 085	-	1 799	5 107	6 906	-2 821
Australia	1 045	-	29	854	883	+ 162
Thailand	377	+	30	119	149	+ 228
Taiwan	265	+	24	1 288	1 312	-1 047
Yemen (Arab Republic)	212	-	816	NA	816	-604
Pakistan	187	-	222	0	222	- 35
Israel	0	-	52	158	210	-210
Japan	0	NA[2]	NA	4 325	4 325	-4 325
Total (Asia + Australia)	19914	+	13 440	13 190	26 630	-6 716

1. + = positive; - = negative.
2. NA = not available.

With this as a background, we can ask the following specific questions about the future of sorghum grain supplies in the Asian region:

- How do we arrest the declining trends in production?
- How do we improve supplies in order to meet the demand in 2000 AD?
- How do we increase the production, and handle the increased production in individual countries?
- How do we develop research - crop production - marketing linkages to sustain and absorb the increased production?

As with any other commodity, sorghum production is a function of demand (either for internal consumption or for export). The economics of production determine the extent to which increases in production and consumption can be achieved and sustained. Price can be a powerful driving force. The 'Yellow Revolution' of oilseed production in India, driven mainly by increased support prices and improved technology, is a good example of what price policy can do to increase production.

Taking India as an example, we notice that the following sections of society are involved in nurturing and furthering the cause of sorghum.

Stage	Activity	Institutions	Stake
Research	Technology and information generation	NARS, IARCs, SAUs	Philanthropic, non-profit
		Private sector	Commercial
Development	Technology transfer	Government departments, SAUs	Philanthropic, non-profit
	Input supply	Seed and other input industries	Commercial
Production	Production	Individual farmers	Food for consumption and sale
Trading	Storage and transfer	Small and large traders, government agencies	Commercial
Conversion sector	Conversion to consumable forms	Private and public sector industries	Commercial
Consumption	Consumption	People	Satisfy food needs
		Animals	Conversion through animals

I believe that if the sorghum supply is to be increased and absorbed, all these links in the sorghum chain have to be strengthened.

The following areas may need specific attention to encourage higher sorghum supply in future, especially from India.

Export market servicing. India has the potential to become the leading sorghum exporter in Asia. However, to realize this potential, export market servicing needs to be strengthened. The export market requires feed grains; red sorghums particularly are internationally acceptable. The cultivation of suitable varieties must be promoted over large areas. Most feed-type sorghums are dwarf and early hybrids. These could be grown in areas where early-maturing local sorghums are currently being replaced by such other early-maturing crops as sunflower and minor oilseed and pulse crops, which have a price advantage. The involvement of both public and private trading and export agencies is essential to successfully absorb the exportable surplus.

Alternative uses. Local consumption of sorghum, both as direct human food and in altered forms, could be increased by encouraging the development of alternative uses. Maize is a good example: the grain is consumed in several forms in India; the processing industry is well established, and in some areas organizes contract cultivation of varieties suitable for conversion to specific forms.

Sorghum in animal feed. Sorghum grain is cheaper than maize grain; production for animal feed could therefore be increased. However, sorghum's only disadvantage is that the carotene levels in its endosperm are lower than those of maize. As a poultry feed for layers, carotene is important for the development of egg yolk color. Yellow endosperm sorghum varieties with higher levels of vitamin A than white endosperm varieties should be developed.

Price support. Higher support price, and the inclusion of sorghum in the Public Distribution System could encourage higher local consumption. This would ensure that sorghum, a coarse cereal, reaches that section of society which normally consumes coarse grains, but is not presently doing so because rice and wheat are available at lower prices through the Public Distribution System.

***Sorghum** Development Association.* Maize in India is an excellent example of a situation where total production has increased without an associated increase in area grown, and the entire production is being absorbed. Alternative uses of maize grain have been popularized, and all the links in the maize chain—producers, industry, and consumers—meet and share experiences. Organizing an effective forum for sorghum development could nurture the cause of sorghum in India (and elsewhere), act as a catalyst to increase sorghum supply and, more importantly, ensure that excess production is absorbed. Such a forum should involve sorghum researchers, sorghum grain producers, traders, seed and other input industries, representatives of industries involved in developing alternative uses, government agencies, feed manufacturers, etc.

Seed Industry in India—New Policies

In 1990/91, the seed industry had a total turnover of about Rs. 7 billion (US$ 225 million), a mere 0.7% of total agricultural production. The potential market for sorghum seed in India is expected to be about 120 000 t in 2000 AD and the total seed business is valued at Rs. 20 billion (US$ 645 million). A large number of public, private, and cooperative sector organizations are involved in production and distribution. The seed industry is now at the take-off stage, and private sector participation in all aspects—research, development, and marketing—is on the increase.

The new Policy on Seed Development announced by the Government of India in October 1988 was developed to encourage seed-related activities in crops other than wheat and rice, where the 'green revolution' was catalysed by improved seed. The initiatives under this policy included liberalization of seed import, improved access of Indian researchers to imported germplasm, and incentives to seed producers.

The new policy has given the country good imported sunflower and maize hybrids, and more recently fodder sorghums. Progress has been slow in grain sorghum, because Indian food quality requirements do not match those of the grain types of sorghum hybrids popular in other countries.

Future Research Needs

The following areas in sorghum seed research production and marketing need improvement.

Hybrid improvement. CSH 9 is the best hybrid available today in India. However, two areas of seed improvement need researchers' attention; improving the stability of the female line across environments, and improvement of female line seed quality to improve storability.

Hybrid suitability. In areas where hybrids are not yet popular, studies are required to establish the proper criteria for determining the suitability of a hybrid; the highest-yielding hybrids may not necessarily be the most suitable. Perhaps the decline in sorghum area could be arrested by encouraging the cultivation of suitable hybrids in different environments.

Seed production areas. In the years following excess seed production, sorghum seed production areas are often lost to other crops. There is a need to make sorghum seed production more remunerative and competitive with the seed production of other crops, to retain sorghum seed production areas even in years of glut.

Seed bowls. Sorghum 'seed bowls' need to be developed—for example, the Nandyal belt in Andhra Pradesh for 296A-based hybrids, the Bellary tract in Karnataka for 2077A-based hybrids, Marathwada for CK60A-based hybrids, and the Nizamabad area in Andhra Pradesh for fodder sorghum hybrids. These 'seed bowls' require specific development plans to improve and sustain sorghum seed production, so that seed can be cultivated on larger areas in these tracts in future.

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Overview of ICRISAT's Research on Sorghum

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Introduction

Sorghum research at ICRISAT Center forms just one part of the global sorghum research activities of the Institute. Major contributions also come from regional sorghum research programs in western Africa (Nigeria and Mali), eastern Africa (Kenya), southern Africa (Zimbabwe), and Latin America (Mexico). These programs mainly conduct applied and adaptive research targeting the problems of their regions, and conduct strategic research in areas of comparative advantage. ICRISAT Center conducts strategic research on problems of global significance and also serves as a regional center addressing applied and adaptive research problems of particular concern to Asia. The approach is multidisciplinary, and stresses collaboration and complementation-with national agricultural research systems.

This paper summarizes sorghum research at ICRISAT Center, a very large part of which is undertaken in collaboration with the Indian Council for Agricultural Research (ICAR), and cites examples of recent progress.

Varietal Improvement

The main theme of varietal improvement at ICRISAT Center is germplasm enhancement. By this we mean prebreeding activities that aim to transfer traits of interest into intermediate breeding products that will be of greater interest to plant breeders than the original sources. Depending on the trait under consideration, its inheritance, and the extent and success of previous breeding work, this might involve transfer from nonimproved landraces into partially improved lines, from partially improved into more improved lines, or from landraces directly into improved lines. As the majority of characteristics of concern are quantitatively inherited, the first two approaches predominate. For the same reason, population breeding is used extensively to supplement pedigree breeding efforts. The traits that we are targeting in this way include resistance to: insects (shootfly, *Atherigona soccata,* stem borer, *Chilo partellus,* midge, *Contarinia sorghicola,* and head bug, *Calocoris angustatus)*, diseases (grain mold, downy mildew, *Perenosclerospora sorghi,* anthracnose, *Colletotrichum graminicola,* leaf blight, *Helminthosporium turcicum,* and rust *Puccinia purpurea),* and *Striga,* and to agronomically important traits (bold grain, tillering, and earliness). A large part of our program involves the transfer of resistance traits into

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male-sterile lines for use in the breeding of resistant grain sorghum hybrids. We are using similar approaches in breeding forage sorghums (in collaboration with ICAR).

Entomology

We conduct research on host-plant resistance, and its mechanisms and inheritance, for shootfly, stem borer, midge, and head bug. We also study the population dynamics of these pests, and their management.

Recent work on shootfly has shown that leaf surface wetness of the unexpanded leaf in the whorl of sorghum seedlings is associated with resistance; cultivars with low levels of wetness are resistant, and those with high wetness levels are susceptible. The moisture on the leaf surface has been shown to come from within the plant rather than from the atmosphere; it varies in quantity with soil and plant water status, but is consistently less in resistant genotypes (Nwanze et al. 1992).

For midge resistance, pollination of male-sterile lines with pollen from resistant lines has been shown to result in slightly lower levels of midge emergence than pollination with pollen from susceptible lines. When the male-sterile lines were not pollinated, significantly fewer midges emerged than when they were pollinated. The level of midge emergence on midge-resistant maintainer lines was much lower than on their corresponding male-sterile lines, whether the latter were pollinated or not. These results suggest that pollen influences ovipositional behavior and/or larval development of midge (Sharma 1993).

Integrated pest management is an area in which we have recently increased our activity. The interactions of host-plant resistance to midge and predation by natural enemies have been studied, and results indicate that there is no adverse effect of host-plant resistance on predation levels. Studies of tritrophic interactions in sorghum and short-duration pigeonpea intercrops suggest that movement of beneficial insects from the sorghum crop can lead to enhanced levels of predation on *Helicoverpa armigera,* the most devastating pest of pigeonpea.

Pathology

The diseases on which we focus research include anthracnose, downy mildew, grain mold, leaf blight, and rust. Disease pressure at ICRISAT Center is generally low, but reliable techniques for artificial inoculation and management of humidity have recently been developed to permit greenhouse and field screening for anthracnose, leaf blight, and rust. The greenhouse techniques have been used to study the inheritance of anthracnose and leaf blight for which single dominant genes were implicated in the ICRISAT breeding lines used as sources. For leaf blight, different genes appeared to be present in two resistant source lines (Sifuentes et al. 1993).

For grain mold, a petri dish method that permits screening for resistance to the major pathogens involved in the mold complex, either individually or in mixtures, is under evaluation. Initial results suggest that resistance to individual pathogens is available in germplasm, and that the technique is suitable for screening photoperiod-sensitive germplasm accessions that have not previously been tested for resistance (Singh and Prasada Rao 1993).

Materials generated in breeding for downy mildew resistant seed parents have been used to study the inheritance of resistance originating from QL 3 (IS 18757). A seedling inoculation technique carried out in a greenhouse was used, and indicated that two dominant genes with epistatic and complementary interactions were involved in determining resistance (Reddy et al. 1992).

Physiology

Studies concentrate on: evaluation methodologies to capture physiological traits in ways that permit their use in breeding programs, growth studies, classification of environments by their effects on phenology of diverse germplasm, and studies of the photoperiodic responses of sorghum. Traits that have been studied include secondary root development, seedling vigor, ability of seedlings to emerge in low-moisture conditions, and staygreen.

Research at Other ICRISAT Locations

Substantial research activities are conducted at other ICRISAT locations. The results, in some cases, would be applicable to Asian conditions, and therefore of interest to CLAN members. These research programs focus on:

- Low-temperature tolerance at flowering;
- Adaptation to high altitudes;
- Malting quality;
- Sooty stripe resistance; and
- Improvement of guinea sorghums.

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Sorghum Research in China

Chen Yue[1] and Shi Yuxue[2]

Introduction

Sorghum has been long cultivated in China and is still one of the most important cereals in the semi-arid parts of the northern, northwestern, and northeastern regions, comprising Hebei, Shanxi, Liaoning, Jilin, and Helongjiang provinces. Most of these areas are populated by ethnic minorities, whose standards of living are below the national average; sorghum is their staple crop. Sorghum grain use in China is divided almost equally between food, alcohol manufacture, and in livestock feed. Stover is used for fodder as well as a building or fencing material. The cropped area, production, and productivity of sorghum in China are shown in Table 1. The highest yields obtained to date are 12.99 t ha^{-1} on experimental plots in 1988, and 9.35 t ha^{-1} on 207 ha of farmland in 1990.

Over the years, sorghum cultivation has gradually moved from semi-humid regions with fertile soils to semi-arid regions with low soil fertility. This is attributed to the

Table 1. Area, production, and productivity of sorghum in China, 1980-92.

Year	Area (million ha)	Production (million tons)	Yield (t ha^{-1})
1980	2.7	6.8	2.5
1981	2.6	6.7	2.6
1982	2.8	6.9	2.5
1983	2.7	8.4	3.1
1984	2.5	7.7	3.2
1985	1.9	5.6	2.9
1986	1.9	5.4	2.9
1987	1.9	5.4	2.9
1988	1.8	5.8	3.3
1989	1.6	4.5	2.8
1990	1.5	5.7	3.7
1991	1.4	4.9	3.6
1992	1.3	4.7	3.6

Source: Agriculture Yearbook of China (1993).

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increase in the maize-growing area, and to improved living standards and a consequent change in food preferences from sorghum to rice and maize.

Abiotic Stress Factors

Drought. In the semi-arid zones of China, the predominant factor that limits sorghum production is a shortage of soil moisture. Three important drought periods are recognized: 'spring drought' that occurs during seed germination and seedling establishment; 'Qiabozi' drought (*qiabozi* = to strangle), that prevents panicle exsertion in the pre-flowering stage; and 'autumn drought' in the post-flowering stage. Among these three, spring drought is the most important yield-limiting factor.

Varieties or hybrids which are suitable for drought-prone conditions may escape the effects of drought by combinations of three mechanisms: avoidance, tolerance, and recovery resistance. Considering the necessity to stabilize and optimize yield under drought conditions, it is essential to develop effective, rapid, and reliable screening techniques for drought-resistance breeding. These efforts, if they are successful, will permit the development of early-maturing hybrids that could be used in drought years.

Yield losses occur on a large scale during drought years (Table 2). Research on drought resistance has been focused mainly on breeding. Sorghum can tolerate

Table 2. Biotic and abiotic constraints to sorghum production in China.

Constraint	Importance rating[1]	Yield loss (%)	Approximate value of annual yield loss (million US$)
Biotic stresses			
Asian corn borer (*Ostrinia furnaculis*)	2	10	52.74
Aphids (*Melanaphis sacchari* and *Sipha flava*)	1	10-15	52.74-79.11
Armyworm (*Spodoptera* sp)	4	4	21.10
All leaf diseases	3	5	26.37
Head smut (*Sphacelotheca reiliana*)	1	8-10	42.19-52.74
Abiotic stresses			
Drought	1	10	52.74
Salinity	4	3	15.82
Low temperature	3	5	26.37

1. 1= very important, 5 = least important.

wilting after emergence better than other crops. Some measures for increasing emergence rates in water-limited areas, methods to identify suitable genotypes, and an index for crop drought resistance have been suggested (Shun Lun and Guo Likun 1984). New cytoplasmic male-sterile lines and restorers are being developed. From among 6 877 germplasm accessions collected in China, 773 have been identified as drought-tolerant.

Low temperature damage. This is an important stress factor, especially in northeastern China. Extended periods of low temperature, which occur every 3-5 years, cause significant reductions in yield. Some cold-tolerant landraces and varieties have been identified using a low-temperature seedling treatment. Yiang Liguao et al. (1992) studied the relationship between plant biochemistry and tolerance to low temperature, and found that seed tannin contents have a significant negative correlation with low temperature tolerance, and a significant positive correlation with the relative emergence rates of different genotypes. The effects of low temperature on panicle differentiation and seed set have also been studied. Among 9 076 sorghum germplasm accessions evaluated to date, 920 were found to have good low-temperature tolerance.

Biotic Stress Factors

Sorghum aphids. There are two major kinds of sorghum aphids, the sugarcane aphid, *Melanaphis sacchari* and the yellow sugarcane aphid, *Sipha flava,* which together cause yield losses above 20% in years of epidemics. One major gene with incomplete dominance controls resistance to these aphids, (Tan Wenqing et al. 1985). Variation between genotypes in organic acid content and pH can be used as standards to identify resistance to aphids (He Fugang et al. 1991). The biological basis of resistance to aphids has been studied, and it was found that most Chinese sorghums lack the gene for resistance to aphids. Among 3 799 accessions evaluated in the field, only one—8432 (that contained the resistance gene from TAM 428)—showed high resistance to aphids. Several new restorers with high degrees of resistance have now been developed by the Sorghum Research Institute, Shenyang, Liaoning Province.

Asian corn borer. *Ostrinia fumaculis* is an important pest of sorghum; it reduces yields by about 10-15% in most years, and by more than 20% in epidemic years. He Fugang et al. (1991) indicated that the Asian corn borer differs from the European corn borer, *O. nubilalis* in its choice of egg-laying sites. The second generation of *O. fumaculis* is more damaging than the first. In order to manage the pest by resistance breeding, germplasm accessions should be screened intensively to identify sources of resistance. The mechanisms of resistance should be studied, and methods of comprehensive protection from the Asian corn borer must be developed.

Sorghum head smut. This disease, caused by *Sphacelotheca reiliana,* is of major importance in China. The pathogen occurs as three different physiological races (designated numbers 1, 2, and 3). Resistance to head smut is controlled by both quantitative and qualitative genes. Among 10 083 germplasm accessions studied, 39 showed immunity to race number 2. Only three accessions have shown resistance to race number 3.

Other diseases. A wide range of sorghum diseases occurs in China. If a susceptible hybrid is sown in an environment conducive to disease development, some of these diseases including leaf blight, sooty stripe, zonate leaf spot, grey leaf spot, oval leaf spot, and anthracnose could cause substantial (about 10%) yield losses. Leaf diseases are a serious problem in some provinces. Hybrids and/or lines should have resistances incorporated, and be evaluated under natural disease pressure.

Prospects for the Future

To increase yield potential and stability under stress environments and insect pest and disease pressure, it is necessary to develop genotypes that withstand these stresses. The main tasks for sorghum researchers in China are:

- Strengthening collaboration among scientists from different disciplines working in different countries and international organizations, so as to exchange information and germplasm resources;
- Speeding up collection, evaluation, and identification of resistant sorghum germplasm resources, especially for stress environments and insect pests and diseases;
- Development of short-statured hybrids/varieties with resistance to lodging;
- Developing hybrids and/or lines that can withstand stress environments, and insect pest and disease pressure. Individual traits could be improved by backcrossing, and multiple resistance developed by population improvement on several traits;
- Studying the mechanism of tolerance and/or resistance of different traits, and strengthening the infrastructure for sorghum breeding; and
- Expanding research on various agronomic practices suitable for different regions, with different stresses and pressures.

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Sorghum Production and Utilization in India

U.R. Murty[1] and B.S. Rana[2]

Present Status and Potential

Sorghum was the most important grain crop in India until the Green Revolution, and is still third among foodgrains in terms of cropped area and production. During 1990/91, 11.68 million t were produced on 14.5 million ha with a productivity of 0.82 t ha^{-1} (Table 1). An examination of the changes in area, production, and productivity of sorghum from 1960 to date reveals that the annual requirement for sorghum grain in India is of the order of 12 to 14 million t. At present, this grain is being produced from 14 to 15 million ha whereas, in 1950, 9 million t were obtained from 18 million ha. This increased productivity has effectively released some sorghum area to other crops. Farm incomes could be further elevated by releasing more of the land presently under sorghum to more remunerative crops by increasing productivity and producing the same amount of grain from a reduced area. To achieve this objective, technology that is already available needs to be transferred to the grassroots level. There is a skewed distribution in the transfer of technology in different states.

Table 1. Area, production, and productivity of sorghum in India during 1980-92.

Year	Area (million ha)	Production (million t)	Yield (t ha^{-1})
1980/81	15.81	10.43	0.66
1981/82	16.60	12.06	0.73
1982/83	16.38	10.77	0.66
1983/84	16.43	11.92	0.73
1984/85	15.94	11.41	0.72
1985/86	16.10	10.20	0.63
1986/87	15.95	9.19	0.58
1987/88	15.65	11.85	0.76
1988/89	14.85	10.52	0.71
1989/90	14.95	12.91	0.86
1990/91	14.36	11.68	0.82
1991/92	12.59	8.36	0.66

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In Maharashtra, the adoption of high-yielding varieties (HYVs) is almost 100% during the rainy season *(kharif)* with the result that sorghum farmers in the state achieved average yields of 1.8 t ha^{-1} during 1990-93. If this type of change could be brought about in other areas, 14 million t of sorghum could be produced from 8 million ha. Net incomes for sorghum farmers from improved technology could be Rs. 1250 ha^{-1} while traditional technology yields only Rs. 485 ha^{-1}. In addition, research should attempt to further increase productivity in marginal areas.

Present Production and Future Projections

The total demand for grain sorghum in India will be of the order of 12 to 14 million t for a few more years to come, judging from the production figures of the last decade. By projecting the amount of dry fodder obtained from the realized grain yield, the demand for the dry fodder can be approximately estimated to be of the order of 30 to 40 million t. Although statistics for green fodder from sorghum are not available, the demand for it will also increase. Presently, green fodder is being produced under irrigation exclusively in the northern Indian states from an area of 2.6 million ha. The demand for green fodder is likely to increase in other states. For grain sorghum, the Directorate of Millets Development projected a production of 13 million t from an area of 15.2 million ha for 1994/95. A more pragmatic estimate indicates that production figures may remain static, but cropped area will decrease and productivity will increase in both rainy *(kharif)* and postrainy *(rabi)* seasons.

Abiotic Stresses

Sorghum in India is widely affected by drought (especially terminal drought) in both its growing seasons. The drought is much more severe during *rabi* than *kharif.* Extreme (either high or low) temperatures do not normally affect sorghum to any great extent.

Biotic Stresses

Pests. Shootfly *(Atherigona soccata),* stem borer *(Chilo partellus),* midge *(Contarinia sorghicola),* earhead bug *(Calocoris angustatus),* shoot bug, earhead worms, aphids *(Rhopalosiphum* sp), and mites *(Oligonychus indicus)* are the insect pests of sorghum (see Table 2).

Diseases. Grain molds (complex of fungi) and downy mildew *(Perenosclerospora sorghi)* during *kharif,* and ergot *(Sphacelia sorghi)* and charcoal rot *(Macrophomina phaseolina)* during *rabi* are the major diseases. *Striga* occurs in endemic areas, especially in light soils under drought conditions. Losses due to these stresses are not

Table 2. Biotic and abiotic constraints to sorghum production in India.

Constraints	Importance rating[1]	Yield loss (%)	Approximate value of annual yield loss (in million US$)
Abiotic stresses			
Drought	1	40	390.3
Salinity	3	5	48
Acidity	5	-	
Temperature	4	2	19.6
Pests			
Shoot fly *(Atherigona soccata)*	1	30	292.7
Stem borer *(Chilo partellus)*	3 grain	15	19.6
	2 fodder	20	
Head bug *(Calocoris angustatus)*	2.5	12	
	3	10	
Aphids (*Rhopalosiphum maidis)*	4	5	48.8
Armyworm *(Mythimna separata)*	4	2	19.6
Major diseases			
Grain molds (complex of fungi)	1 *(kharif)*	30	292.7
Downy mildew *(Perenosclerospora sorghi)*	4	5	48.8
Charcoal rot *(Macrophomina phaseolina)*	1 *(rabi)*	15	146.4
Anthracnose *(Colletotrichum graminicola)* (fodder)	2 (forage)	20	48.8
Anthracnose *(Colletotrichum graminicola)* (grain)	5		
Leaf blight *(Helminthosporium turcicum)*	4	2	19.6
Other diseases			
Ergot *(Sphacelia sorghi)*	3.5	5	48
Sorghum stripe	5	1	9.8
Stalk rot/root rot	5	1	9.8
Striga	3 *(kharif)*	5	48.8

1.1 = very important, 5 = least important.

normally heavy since they are managed by farmers with improved practices and chemical control measures. Damage reduces grain yields and fodder quality, although farmers are usually able to meet their fodder requirements (in terms of quantity) even when damage does occur. Data on losses caused by various stresses do not exist, and are not recorded by any agency. The possible extent of damage due to specific stresses can only be estimated (Table 2). It should be noted that severe damage only occurs in endemic pockets, and that too on a very small scale.

Current Research Thrusts

The national program is meant to deliver end products, mostly through applied research. At present, the Indian national program gives top priority to the following four objectives:

- Development of *rabi* hybrids;
- Development of multicut forage hybrids;
- Development of early-maturing dual-purpose hybrids for *kharif;* and
- Alternative uses of grain and stalks.

Future research will continue along the same lines.

Availability of Scientific Staff

The National Research Centre for Sorghum (NRCS) has two components. One is the resident research at headquarters, and the other an All India Coordinated Sorghum Improvement Project (AICSIP) at 16 cooperative research centers located in ten agricultural universities in eight states of India.

At present 93 scientific staff work on sorghum (34 at NRCS, and 59 at AICSIP centers).

India's Contribution to CLAN

The Indian NARS have considerable experience in sorghum research. Information developed over 25 years was presented during the first collaborative meeting held at ICRISAT Center in September 1991, and during subsequent meetings. Elite released and notified material from the national program is always available to CLAN members for research purposes. The Indian national program has a powerful system for yield testing, and for screening, testing, and selection for stable and reproducible traits for a variety of stresses. This multilocational testing mechanism could be made available to a limited extent to CLAN members. The national program can thus contribute human resources (expertise), germplasm, and elite material. In addition it can also also provide 'hot spot' locations for screening germplasm and breeding material.

India's Needs and Expectations from CLAN

The expectations of the Indian national program from CLAN are essentially exchange of information and material (germplasm, genetic stocks, and elite material), and collaborative research directed towards overcoming the plateau in yields, and identifying resistance factors in good agronomic backgrounds. These exchanges can be monitored/executed through regular workshops and group meetings. The necessary funding should be arranged by ICRISAT through international agencies.

Collaborative research on modern methods of crop improvement (gene mapping, transformation) should be supported entirely by ICRISAT. Conventional techniques have not resulted in any quantum jumps in levels of resistance in elite backgrounds in the case of either shootfly or grain molds. Modern methods of biotechnology need to be utilized, using resources and expertise through CLAN. It is expected that techniques will be standardized, and procedures developed and utilized at ICRISAT Center.

Sorghum Research in Iran

Abbas Almodares[1] and Asghar Vaez Zadeh[2]

Introduction

Iran is a hot, dry country with an annual average rainfall of 220 mm or less. With the exception of the northern areas, the country does not receive any summer rainfall. Winter rain and snowfall cannot be used effectively by farmers, because the low temperatures do not allow any cropping during winter. However, the climatic conditions permit a potential grain yield of up to 10-12 t ha^{-1} under irrigated conditions during summer.

Sorghum in Iran

Sorghum is cultivated for several uses. These are, in decreasing order of importance: forage, feed (especially poultry), industry (e.g., sweet sorghum for the manufacture of crystalline or liquid sugar), and human consumption, mainly as composite flour.

Forage sorghum. Forage is the most important use of sorghum in Iran, especially during summer when other fodder perennial grasses are not available. The area under forage sorghum has increased from 4 000 ha in 1980 to 10 000 ha in 1993 (Table 1). Farmers are interested in multicut forage varieties.

Sweet sorghum. Sugarbeet and sugarcane are the major sugar crops in Iran. However, in many areas, sugarbeet (which needs large amounts of water and fertilizer, expensive labor, and therefore government subsidies) and sugarcane (which is sensitive to the saline conditions prevailing in southern Iran) can be replaced by sweet sorghum. A number of lines have been screened, and a few with high sugar levels (>15% Brix value) and >70% purity have been identified for potential commercial cultivation. The purities at sugar factories are 86% for sugarbeet, 81% for sugarcane, and 70-75% for sorghum.

Grain sorghum. Currently a very limited area is sown to grain sorghum because bird damage problems prevent successful grain sorghum production in most areas. Some local brown-seeded varieties suffer relatively less bird damage, but the new

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Table 1. Cropped area, production, and productivity of green fodder sorghum in Iran, 1980-93.

Year	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})
1980	4.0	192	48
1981	4.2	206	49
1982	4.5	225	50
1983	4.6	230	50
1984	5.0	250	50
1985	5.8	320	55
1986	6.0	330	55
1987	6.5	360	56
1988	7.5	440	59
1989	8.0	450	56
1990	9.0	480	53
1991	9.8	600	62
1992	10.0	650	65
1993	10.0	700	70

white-grained lines suffer heavily. At present grain sorghum production is at very low levels; but it is now planned, with government funding, to set up demonstration plots with the intention of introducing grain sorghum cultivation to different parts of the country. Varietal evaluation at the University of Isfahan has identified several early- and medium-maturing sorghum lines from trials supplied by ICRISAT; these have yield potentials of 5-6 t ha^{-1} in Iran. White-grained sorghum can be used in: leavened bread (25% sorghum + 75% wheat flour); poultry feed (100% as a replacement for maize); and for the industrial production of starch and glucose, where it can replace wheat and maize.

Production Constraints

The most important constraint is the shortage of hybrid seed, the majority of which is currently imported from Australia. Hybrid seed production in the country is insufficient to meet demand.

Another important constraint to the cultivation of forage sorghum is a lack of appropriate machinery for harvesting and chopping. Conventional maize choppers are not suitable for broadcast or hand-sown sorghum. Most land in Iran is presently under wheat or barley. There is a need for early-maturing sorghum cultivars which can be sown after the wheat/barley harvest.

The occurrence of different biotic and abiotic stresses and the extent of losses they cause are presented in Table 2.

Table 2. Abiotic and biotic constraints to sorghum production in Pakistan.

Constraints	Importance[1]	Yield loss (%)	Yield loss value per year ('000 US$)
Abiotic stresses			
Drought	3	15	200
Salinity	4	5	40
Acidity	5	NA[2]	NA
Temperature	4	5	40
Pests			
Shootfly *(Atherigona soccata)*	5	NA	NA
Stem borer *(Chilo partellus)*	5	NA	NA
	5	NA	NA
Midge *(Contarinia sorghicola)*	5	NA	NA
Aphids *(Rhopalosiphwn maidis)*	4	5	40
Armyworm *(Mythimna separata)*	5	NA	NA
Major diseases			
Grain molds (complex of fungi)	5	NA	NA
Downy mildew *(Perenosclerospora sorghi)*	4	5	40
Charcoal rot *(Macrophomina phaseolina)*	5	NA	NA
Anthracnose *(Colletotrichum graminicola)*	5	NA	NA
Leaf blight *(Helminthosporium turcicum)*	5	NA	NA
Other diseases	5	NA	NA
Ergot *(Sphacelia sorghi)*	5	NA	NA
Sorghum stripe	5	NA	NA
Stalk rot/root rot	5	NA	NA
Striga	5	NA	NA
Others (birds)	NA	NA	NA

1.1 = most important, 5 = least important.
2. NA - data not available.

Abiotic stresses. Most of the sorghum grown in summer is irrigated wherever water is available, and hence drought (though it occurs in several areas) is not a major problem. Soil acidity and salinity are not important constraints. Neither is temperature; high yields have been obtained even in hot regions.

Biotic stresses. Bird damage is a constraint to both seed and grain production. Other stresses are not very important as the new hybrids have shown good resistance to diseases, and except for aphids, insect pests do not cause much damage.

Current Research Thrusts

Sorghum research is conducted at 30 stations of the Seed and Plant Improvement Institute, Tehran, and Isfahan University. Major areas of research include:

- Evaluation of varieties and hybrids (grain, forage, and sweet-stalk) for suitability in different areas;
- Agronomic research to determine optimum sowing time, plant density, and water and nutrient requirements for different sorghums; and
- Genetic and breeding research to investigate combining ability, develop male-steriles and restorers, and to produce hybrids for commercial cultivation.

The Ministry of Agriculture, in collaboration with an Australian seed company, has obtained a license to produce A, B, and R lines for a forage sorghum hybrid. These lines are multiplied locally to produce hybrid seed in the country.

Using bulk and pedigree selection among populations of crosses, more than 40 pure lines, some of which are early and productive for both forage and grain, have been selected for multilocational evaluation.

Research Personnel

There are about 30 scientists involved in sorghum research. More people need to be trained at such research institutions as ICRISAT and those in Australia.

Future Plans

- Local production of sufficient hybrid seed to meet all the seed requirements of the country; and
- Expansion of grain sorghum cultivation to other areas in the country by providing good quality varieties/hybrids with bird resistance.

Contribution to CLAN

Iran's contribution is minimal to date because it joined the network only recently. Contributions to the network in future will include exchange of germplasm (especially landraces), and information exchange through publications and visits by CLAN scientists. CLAN's assistance in improving research capabilities is sought; specifically in breeding for fodder quality and productivity in forage and grain sorghums (the latter for poultry and animal feed), and in germplasm exchange and information on suitable technologies for sorghum research and development.

Sorghum Research and Development in Myanmar

Thu Kha[1]

Introduction

Sorghum is an important cereal crop in Myanmar, and covers the second largest area after rice. Over 50% of the sorghum grain produced in the country is for human consumption; it is the staple food in the rice-deficient central dry zone. Sorghum is also a major feed and forage crop for livestock. Sorghum is grown mainly in central Myanmar, in the Sagaing, Mandalay, and Magway divisions. Area, production, and yield during 1982-92 are given in Table 1.

Table 1. Cropped area, production, and productivity of sorghum in Myanmar, 1982-92.

Year	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})
1982	186	85	0.58
1983	189	100	0.57
1984	259	282	1.19
1985	232	165	0.80
1986	217	216	1.08
1987	220	231	1.14
1988	192	156	0.91
1989	177	113	0.73
1990	187	116	0.66
1991	184	138	0.78
1992	190	119	0.67

Production Constraints

Details of abiotic and biotic constraints to sorghum production in Myanmar are given in Table 2. The most important constraints are the slow adoption of improved exotic varieties by local farmers, and the use of marginal soils coupled with inadequate use of organic and inorganic fertilizers. Only about 25% of the total sorghum area is under

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Sorghum Research in Pakistan

Muhammad Naeem[1] and Abdul Shakoor[2]

Area, Production, and Yield

Sorghum is a minor crop in Pakistan compared to such other cereals as rice and wheat. Sorghum area, production, and yield during 1980-92 are given in Table 1.

Table 1. Cropped area, production, and productivity of sorghum in Pakistan, 1980-92.

Year	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})
1980	423	249	0.59
1981	394	230	0.58
1982	393	225	0.57
1983	390	222	0.57
1984	391	222	0.57
1985	395	230	0.58
1986	372	219	0.59
1987	399	236	0.59
1988	320	181	0.57
1989	431	248	0.58
1990	440	262	0.60
1991	417	239	0.57
1992	383	225	0.59

Abiotic *Stresses*

Most of the sorghum-producing areas in Pakistan are warm and semi-arid (Kohat, Kark, Bannu, Attock, Mianwali, Sargogha, and Jhang), or hot and arid (Multan, Muzaffargarh, D.I. Khan, D.G. Khan, Bahawalnagar, Bahawalpur, Rahim yar Khan, Sukkur, Jaccobabad, Khairpur, Nawabshah, Sangarh, Dadu, Hyderabad, Tharparker, Loralai, Nasirabad, Sibbi, Kachchhi, Kalat, Chaghi, and Lasbella). Drought, coupled

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with extremely high temperatures (up to 50°C) can cause severe damage to the crop in these areas.

Biotic Stresses

Insects. Shootfly *(Atherigona soccata)* and stem borer (Chilo *partellus)* are the most important insects, and cause severe damage to the sorghum crop. The head bug *(Calocoris angustatus),* sorghum midge *(Contarinia sorghicola),* aphid *(Rhopalosiphum maidis)* and armyworm *(Mythimna separata)* also occur.

Diseases. Leaf blight *(Helminthosporium turcicum)* is the most serious disease. Anthracnose *(Colletotrichum graminicola),* ergot *(Sphacelia sorghi),* and bacterial leaf stripe (*Pseudomonas andropogoni)* also occur (Table 2).

Table 2. Abiotic and biotic constraints to sorghum production in Pakistan.

Constraint	Importance rating[1]	Yield loss (%)
Abiotic stresses		
Drought	1	25
Salinity	5	5
Acidity	5	5
Temperature	1	30
Pests		
Shootfly *(Atherigona soccata)*	1	30
Stem borer *(Chilo partellus)*	2	15
Head bug *(Calocoris angustatus)*	3	5
Midge (*Contarinia sorghicola)*	3	5
Aphids (*Rhopalosiphum maidis)*	3	5
Armyworm (*Mythimna separata)*	3	5
Major diseases		
Grain molds (complex of fungi)	4	10
Downy mildew (*Perenosclerospora sorghi)*	5	5
Charcoal rot *(Macrophomina phaseolina)*	5	5
Anthracnose *(Colletotrichum graminicola)*	3	10
Leaf blight *(Helminthosporium turcicum)*	2	20
Other diseases		
Ergot *(Sphacelia sorghi)*	3	5
Bacterial leaf stripe (*Pseudomonas andropogoni)*	3	10

1. 1* very important, 5 = least important.

Current Research Thrusts

- Development of sorghum varieties for different areas;
- Collection, evaluation, and conservation of local sorghum germplasm;
- Testing of international and national germplasm for adaptation and yield;
- Studies on weed control, most appropriate sowing dates, fertilizer use, and optimum plant population for newly developed sorghum varieties; and
- Dissemination of improved production technology to farmers through on-farm research.

Future Plans

- Screening of local and exotic germplasm, and segregating generations of crosses for tolerance to drought, heat, and salinity, and emergence through crusted soil surfaces;
- Breeding for resistance to major diseases (leaf blight) and insects (shootfly and stem borer); and
- Mechanization of sorghum production with regard to tillage operations, in sowing, harvesting, and threshing.

Staff for Research and Technology Exchange

The Pakistan Agricultural Research Council has a Coordinated Sorghum and Millet Programme located at the National Agricultural Research Centre, Islamabad. Four Provincial Cooperating Units are associated with this program: Maize and Millet Research Institute, Yousafwala, Sahiwal, Punjab; Agricultural Research Institute, D.I. Khan, North West Frontier Province; Agricultural Research Station, Sariab, Quetta, Baluchistan; and Agricultural Research Station, Dadu, Sindh.

The functioning of these units is hampered to varying degrees by shortages of scientific staff; three units (at Sariab, D.I. Khan, and Dadu) are currently operating without a permanent senior scientist responsible for sorghum.

Pakistan's Contribution to CLAN

Pakistan can contribute to CLAN by mutual exchange of germplasm, literature, and joint research projects in the fields of drought, heat, disease, and insect tolerance.

Pakistan's Needs and Expectations from CLAN

Strong linkages with CLAN could benefit Pakistan by providing:

- Access to elite germplasm, particularly in the form of Regional Adaptation Trials, nurseries, and donors for drought, heat, disease, and insect pest tolerance;
- Screening techniques for various biotic and abiotic stresses, particularly drought, high temperatures, shootfly, and stem borer;
- Technical assistance through cooperative research projects, e.g., a joint project on breeding for drought tolerance in such drought-prone locations as Tharparker;
- Training and continuous improvement of scientific skills in sorghum research and production; and
- Access to current research literature for the National Agricultural Research Centre and its provincial Cooperating Units.

Sorghum Research and Development in Thailand

Nipon Iamsupasit[1]

Introduction

Sorghum has been grown in Thailand for several decades. The cropped area, production, and productivity during 1980-92 are shown in Table 1. The overall mean grain yields for this period were between 1.0 and 1.3 t ha^{-1}. Yields from farmers' fields are lower than on research stations. Many constraints contribute to these low yields. Sorghum research in Thailand covers almost all disciplines in attempts to eliminate these constraints. More than 50% of the sorghum research budget goes to breeding work, while cultural practices, pathology, entomology, and seed technology make up the rest.

Table 1. Area, production, and productivity of sorghum in Thailand, 1980-92.

Year	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})
1980	247	237	1.01
1981	280	274	1.02
1982	245	236	1.00
1983	265	327	1.31
1984	294	374	1.32
1985	310	404	1.39
1986	194	211	1.15
1987	177	192	1.20
1988	180	215	1.24
1989	187	231	1.30
1990	194	237	1.26
1991	197	250	1.30
1992[1]	200	264	1.32

1. Estimated

Source: Agricultural Statistics of Thailand, Crop Year 1991/92.

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Constraints

Farmers usually sow sorghum late in the rainy season (August-September) as a second crop following maize or soybean. A high proportion of grain production (approximately 60%, and mostly red grain) is exported, and the remainder is used in the local feed industry. The mean grain yield on farmers' fields is low because of: low-yielding varieties, inappropriate cultural practices, disease and insect damage, low and erratic distribution of rainfall, and poor returns compared to other crops. Information on some of these constraints is given in Table 2.

Table 2. Abiotic and biotic constraints to sorghum production in Thailand.

Constraint	Importance rating[1]
Abiotic stresses	
	2
Salinity	3
Acidity	3
Pests	
Shootfly (*Atherigona soccata*)	1[2]
Stem borer (*Chilo partellus*)	4
Head bug (*Calocoris angustatus*)	4
Aphids (*Rhopalosiphum maidis*)	4
Armyworm (*Mythimna separata*)	4
Major diseases	
Grain molds (complex of fungi)	1
Charcoal rot (*Macrophomina phaseolina*)	5
Anthracnose (*Colletotrichum graminicola*)	5
Leaf blight (*Helminthosporium turcicum*)	5
Other diseases	
Ergot (*Sphacelia sorghi*)	3
Stalk rot (*Fusarium moniliforme*)	5
Loose kernel smut (*Sphacelotheca cruenta*)	5

1.1 = very important, 5 = least important.
2. causes yield losses of 50-75%.

Current Research Activities

Basic and applied research has been conducted on the problems listed above. New technologies have been developed, including high-yielding varieties, improved cultural practices, and pest control.

Varieties. Pure line varieties are developed mainly by the Department of Agriculture (DOA) sorghum breeding program, whereas both hybrids and pure line varieties are developed at the Kasetsart University (KU) sorghum breeding program. New high-yielding varieties, including UThong 1, Suphan Buri 60, and KU 439, have been released and recommended by both programs. The DOA program (Iamsupasit et al. 1993) has the following objectives: high yield, dual purpose, disease and insect resistance (specifically to grain mold and shootfly), and environmental stress tolerance (specifically to drought and salinity).

Most activities, at present, emphasize the first two objectives. Some high-yielding lines are now in on-farm trials. Suphan Buri 1, a dual-purpose sorghum variety, has been released. Only limited research efforts are directed towards the last two objectives. Kasetsart University (Pothisoong et al. 1993) is working on breeding high-yielding grain hybrids and forage sorghums. KU 8501 is a recommended grain sorghum hybrid, and Klang Dong 1 has been released as a forage sorghum variety.

Cultural practices. Much research has been done on grain sorghums, and new technologies have been recommended. These relate to land preparation, sowing methods, fertilizer use, and weeding. These technologies, however, are yet to be widely adopted by farmers due to the low price of sorghum grain and the high cost of inputs. Research is now emphasizing low-input practices with high returns, and the introduction of suitable cropping systems. For dual-purpose sorghum, research is now in progress, and some preliminary recommendations have been made.

Disease and insect control. In Thailand, shootfly and grain mold are recognized as major constraints. Breeding programs to combat these constraints have now been initiated using parental sources obtained from ICRISAT (Boon-Long et al. 1991, Iamsupasit et al. 1993). Alternative control methods, such as the selection of the optimum sowing time to avoid damage, are now recommended. Even though chemical control is the most effective control method, it is recommended only as a last resort.

Future Activities

Research work is limited by the availability of trained sorghum researchers. However, future work plans at the Suphan Buri Field Crops Research Center aim to:

- Develop hybrids;
- Use effective screening techniques to select varieties resistant to major diseases and insects, and to drought and salinity;
- Learn more about molecular biology for sorghum breeding; and
- Increase the emphasis on on-farm adaptive research.

Four research organizations, DOA, KU, Khon Kaen University, and the Department of Livestock Development, are now forming a working group to study various aspects of dual-purpose sorghum.

Thailand's Projected Contribution to CLAN

Technology or information exchange usually comes from CLAN/ICRISAT (in the form of breeding materials, training, workshops, etc.) to the national programs. These interactions can strengthen national projects. However, Thai contributions to the network have not been insubstantial. Trials from CLAN/ICRISAT have been conducted in Thailand since 1975. International sorghum yield trials have been conducted each year, and sorghum shootfly nurseries have been tested in some years. Other trials have been requested. Thailand will continue to contribute to CLAN by acting as a testing location as well as a collaborative research partner to study dual-purpose sorghums.

Needs and Expectations from CLAN

Apart from the exchange of germplasm and breeding materials, training, technology exchange, and some essential equipment are needed from CLAN to strengthen the Thai national program. Specifically, training is required in: hybrid development; screening techniques for grain mold resistance, shootfly resistance, and drought and salinity tolerance; and molecular biology techniques for sorghum breeding. However, further discussions with CLAN/ICRISAT scientists are required before such training/research programs are initiated.

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Grain Sorghum in Australia

R.G. Henzell[1]

Area, Production, and Yield

Sorghum area and production in Australia varied little during the 1980s but have declined rapidly during the 1990s (Table 1). This decline is due to prolonged dry conditions, the crop being grown almost exclusively under rainfed conditions. Production is expected to return to at least the 1980s level upon the return to normal rainfall conditions, because sorghum is an important component of the cropping system and has an established market. Grain sorghum produced in Australia is used only as a stock feed for cattle, pigs, and poultry, and in pet food. This market includes a rapidly expanding cattle feed lot industry and an export market of at least 1 million tonnes.

Table 1. Area, production, and productivity of sorghum in Australia, 1980-92.

Year	Area ('000 ha)	Production ('000 t)	Yield (t ha^{-1})
1980	516	916	1.77
1981	656	1198	1.83
1982	641	1308	2.04
1983	698	1419	2.03
1984	681	1416	2.08
1985	722	1369	1.90
1986	729	1416	1.94
1987	813	1419	1.74
1998	745	1677	2.25
1989	547	1662	1.94
1990	492	969	1.97
1991	437	860	1.97
1992	396	865	2.18

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Abiotic Stresses

The major constraint to production is lack of water (Table 2). Removing this constraint would result in at least a tripling of yield (the additional production would be worth US$ 200 million), but more likely quadrupling it to an average of 8 t ha^{-1}. Work aimed at increasing water-use efficiency under water-limited conditions therefore has a potentially high benefit/cost ratio.

Salinity is not a major problem in the sorghum areas, although there is a suggestion that in some circumstances salt accumulation in deeper layers may prevent root penetration. The extent of this possible problem is not known. There is no acidity problem because most sorghum soils are neutral or slightly alkaline.

Table 2. Abiotic and biotic constraints to sorghum production in Australia.

Constraints	Importance rating[1]	Yield loss (%)	Approximate value of annual yield loss (million US$)
Abiotic stresses			
Drought	1.	66	200
Salinity	4	NA	NA
Acidity	5	NA	NA
Temperature	4	NA	NA
Soil nutrition	2	NA	NA
Pests			
Midge (Contarinia sorghicola)	3	NA	10
Aphids (Rhopalosiphum maidis)	5	NA	NA
Armyworm (Mythimna separata)	5	NA	NA
Helicoverpa/Head caterpillar	2	20	30
Major diseases			
Grain mold	4	0.5	0.5
Charcoal rot/Stalk rot/Root rot/lodging	3	10	10
Anthracnose (Colletotrichum graminicola)	5	0.1	0.1
Leaf blight (Helminthosporium turcicum)	4	0.5	0.5
Other diseases	4	0.1	0.1
Sorghum stripe virus	4	0.5	0.5

1.1 = very important, 5 = least important.
NA = data not available

The effects of temperature are suspected not to be large, as maximum temperatures do not exceed 30-40°C in central Queensland. There is occasionally a low temperature effect on crop establishment in southern Queensland and northern New South Wales when farmers sow too early.

Poor soil nutrition is becoming an increasingly important abiotic stress in Australia since it results in lower yields (or higher costs of production) and lower grain protein contents. Work on soil nitrogen and plant nitrogen-use efficiency is given high priority.

Biotic Stresses

The major biotic constraint in Australia is the plant death/stalk and root rot/lodging complex. This is a problem caused by the combined effects of water deficit, plant death, and stalk rot infection; the major form of lodging occurs when plant death and stalk rot development result from water deficits during grain filling. Work in this area is given high priority. Other diseases, e.g., head smut (*Sphacelotheca reiliana)* rust *(Puccinia purpurea)*, leaf blight *(Helminthosporium turcicum),* and anthracnose *(Colletotrichum)*, are of minor importance. Downy mildew *(Perenosclerospora sorghi),* ergot *(Sphacelia sorghi),* and *Striga* do not occur in Australia.

The sorghum midge *(Contarinia sorghicola)* and the head caterpillar group *(Helicoverpa, Crytoblabes, Conoqethes)* are the major insect pests. Work in this area is given high priority.

Shootfly *(Atherigona soccata),* stem borer *(Chilo partellus)* and head bug or greenbug *(Calocoris angustatus)* do not occur in Australia.

Areas of Research

There is a current major program of research aimed at the genetic improvement of grain sorghum in Australia. This program comprises the following projects.

Core breeding. This program aims to develop germplasm for use by other breeders, e.g., those in the private sector. Current specific objectives include breeding for midge resistance and staygreen (a drought-resistance trait). Progress has been made in enhancing both these traits. Materials have been bred that sustain no economic midge damage under Australian conditions, and that have a level of staygreen such that they rarely lodge. More than 50% of sorghum grown by farmers has a level of midge resistance.

Osmotic adjustment and grain yield. The contribution of osmotic adjustment (OA) to sorghum grain yield will be examined in different production environments.

A set of recombinant inbred lines (RILs) from two crosses, TAM 422/QL 27 and TX2813/QL 27, have been developed. These vary in OA, and will be tested in a sample of environments. Results (plus long-term weather and soils data) will then be input to the sorghum model, QSORG, so that the overall magnitude of the effect of OA across the sorghum-growing environment can be calculated.

Development of molecular markers. Molecular markers are potentially important tools for breeding work. A search is on for molecular markers linked to the partly dominant osmotic adjustment gene in TAM 422 and for the recessive OA gene in TX2813. The closest linkage found so far (20 cM) has been for the TAM 422 gene. A set of recombinant inbred lines has been developed from the cross QL 39/QL 41. They vary in staygreen (e.g., QL 41) and midge resistance (e.g., QL 39). During the next two seasons the phenotype of these with respect to staygreen and midge resistance will be determined, after the OA work detailed above.

Staygreen character. This project will focus on physiological assessment of the genetic variation in the staygreen character. The aim is to determine the association between staygreen and yield and components of yield (i.e., water transpired, transpiration-use efficiency, and harvest index) in 16 hybrids, varying in staygreen character, under varying levels of water supply.

Nitrogen-use efficiency. This study will assess the scope for genetic improvement of grain sorghum in water-limited environments by maximizing nitrogen-use efficiency. Specifically, it will quantify genotypic differences in:

- Nitrogen uptake and dry matter production during pre- and post-anthesis;
- Leaf area index, specific leaf area, and specific leaf nitrogen at anthesis and maturity;
- Grain yield and components, grain moisture content, harvest index, and grain protein content at maturity;
- Nitrogen-use efficiency in biomass production, grain yield, and grain protein;
- Mobilization of leaf nitrogen to grain during grain filling, comparing maintenance of leaf area with maintenance of leaf nitrogen and leaf dry matter; and
- Leaf area, dry matter, and nitrogen content of senescent leaves.

Transpiration efficiency. This small project, involving screening for improved transpiration efficiency, aims to assess whether there is genetic variation in sorghum for carbon isotope discrimination; and whether this variation is theoretically associated with transpiration efficiency.

Midge resistance in native sorghums. There are 17 species of sorghum 'native' to Australia, all of which are in subgenera other than *Eusorghum.* They are potential sources of useful genes. This project aims to test six native sorghums for midge resistance.

Crop improvement using native sorghums. Native sorghum can be used as a genetic resource for grain sorghum improvement. The current aim of this project is to develop methods for transferring genes from wild sorghums into *Sorghum bicolor.*

Genetic engineering for improved insect pest resistance. This project involves transformation studies, e.g., with *Agrobacterium* and microprojectiles, in grain sorghum. The protocol for transformation using *Agrobacterium* has been developed. The current project aims to further refine this technique and to attempt transformation using microprojectiles.

Genotype* x *environment interaction. Assessment of the different genotype x environment (G x E) interactions can help improve the efficiency of breeding research. The aim of this project is to rationalize yield testing by better quantifying target environments and G x E interactions, and to assess the potential value of genetic variation in plant traits. The project relies heavily on the use of the sorghum growth model, QSORG, and long-term weather and soils data.

Helicoverpa. In addition to these projects, there are several others relating to the biological control of *Helicoverpa.*

Australia's Contribution to CLAN

This could be achieved by exchange of technology (including germplasm) in areas of interest and by assistance in human resource development. Of interest here is a proposal for international collaboration on sorghum research and development and generic G x E interaction/adaptation research involving Australia, ICRISAT, and the Indian Council of Agricultural Research (ICAR). This proposal will be put to the Australian Centre for International Agricultural Research (ACIAR) and the Grain Research and Development Corporation (GRDC), two Australian funding bodies. The following broad areas are of mutual interest:

- Transformation (genetic engineering);
- Traits and molecular markers for postrainy season sorghum in India and rainfed sorghum in Australia. Traits of interest would include midge resistance, osmotic adjustment, staygreen, and water-use efficiency;
- Modeling to identify target environments, and assess adaptive traits;
- Pyramiding insect resistance genes (including genes from wild sorghum and *Bacillus thuringiensis* (Bt) genes; and
- Pre-emptive screening for resistances to downy mildew, shootfly, and stem borer, which are prevalent in Southeast Asia but not yet in Australia.

If this proposal is approved, it would have positive implications for other members of CLAN.

Benefits to Australia from CLAN

Collaboration with international sorghum improvement programs would benefit Australia in several ways:

- Provide access to wider sources of genetic material for traits of interest;
- Facilitate pre-emptive screening for important insect pests and diseases;
- Provide leverage for additional resources (possibly from ACIAR and GRDC) for modeling and G x E interaction work to assess target environments and identify adaptive traits; and
- Identification of molecular markers for quantitative trait loci.

Recommendations

The participants formed two groups for discussions. Group I (Co-moderators: R.G. Henzell and J.W. Stenhouse) discussed aspects related to crop improvement and protection, while Group II (Co-moderators: R.B. Somani and N. Seetharama) deliberated on alternative uses, production, and market linkages. These recommendations are based on the group discussion reports presented at the recommendations session.

Asian Network Proposal

The group thanked ICRISAT for its foresight and initiative in planning a network of Asian researchers, and ratified the proposal to merge sorghum research and development in Asia with the Cereals and Legumes Asia Network (CLAN). The group suggested that emphasis on alternative uses and linkages with industries and mentor institutions should be included in the draft CLAN funding proposal to the Asian Development Bank (ADB).

The group also endorsed the proposed collaborative sorghum research project between Indian Council of Agricultural Research, Australian Grain Research and Development Corporation, and ICRISAT.

Goals and Objectives for Collaboration on Sorghum Research in Asia

The goal, as stated in the 1991 Meeting Report, was modified to recognize that sorghum research and development in the region reflects the changing production and utilization needs of the crop. Sorghum's role as a food source is diminishing, although it will continue to be important. Alternative uses, such as for animal feed (grain and forage), alcohol, crystalline sugar, glucose, starch, etc., are becoming increasingly important.

The following objectives of the sorghum component of the network, as stated in the 1991 Meeting Report, were found to be appropriate:

- To exchange improved genetic material and germplasm;
- To conduct cooperative research and development on sorghum production and utilization;
- To upgrade and develop capabilities of the participating countries;
- To support and accelerate transfer of technology to farmers and industries; and
- To develop efficient databases and sharing of information.

Production Systems and Constraints

The group recognized the need to treat each production system in the Asian region separately for the purposes of research planning and collaboration. The different production systems in the Asian region and constraints in those systems are summarized in Table 1.

Table 1. Production systems, constraints, and research needs for sorghum in Asia.

Production Systems	Constraints	Utilization research/extension
1. Rainy season sorghums		
India: High rainfall areas	Grain mold, competition with other crops	Alternate uses of grain, especially molded grain, whole-plant utilization
India: Low rainfall areas	Drought, low inputs	Food grains, dry fodder
Laos	Unknown	On-farm popularization trials
Myanmar	Low productivity	On-farm trials, for food and fodder
Pakistan	Drought	Fodder; less emphasis on feed
Thailand	Drought, poor soils	Feed and fodder
2. Postrainy winter sorghums		
India	Drought, shoot fly, cold	Food grains and dry fodder
3. Summer sorghums		
Iran	Lack of appropriate varieties	Forage, feed, syrup, sugar, and particle board
4. Rice fallow sorghums		
Philippines	Crop establishment and drought	Feed
Indonesia	Crop establishment and drought	Feed
5. Cool, temperate sorghums		
China	Insufficient productivity	Feed, liquor, and minor alternate uses
Commonwealth of Independent States (CIS)	Insufficient productivity	Feed

Development of Working Groups

The group considered that the development of working groups to address specific problem areas was an appropriate way to conduct sorghum research and development in CLAN.

As a first step in the development of working groups, the production constraints in individual countries were updated (Table 2). There were no major changes in regional priority. As a result of this analysis the following Working Groups were set up and Technical Coordinators identified:

Working Group	Technical Coordinator
Drought	H.F.W. Rattunde
Shoot Pests	H.C. Sharma
Grain Mold	J.W. Stenhouse
Forage Sorghum	G.P. Lodhi

Table 2. Priority of sorghum production problems in individual countries.

Problem	China	India	Indo-nesia	Iran	Myan-mar	Nepal	Philip-pines	Thai-land	Viet-nam	Asia Region	Aus-tralia
Abiotic											
Seedling emergence	2[1]	5	2	3	4	4	3	3	1	2	3
Drought	2	1	2	4	1	2	1	1	2	1	1
Soil nutrition	3	3	2	4	1	1	4	2	4	2	2
Soil toxicity	4	3	3	4	5	3	4	2	3	4	5
Biotic											
Shootfly	5	1	3	5	2	2	2	1	2	1	5
Stem borer	2	4	4	3	3	1	2	2	2	1	5
Midge	5	3	5	5	5	3	4	5	2	5	2
Striga		3	5	5	2	5	3	5	5	5	5
Storage insects	-	3	1	2	5	1	2	3	2	2	4
Leaf diseases	3	4	3	4	5	5	2	3	3	4	3
Stalk rot	4	1	3	4	5	4	2	4	3	3	2
Grain mold	5	1	2	5	2	3	1	1	2	1	4
Panicle diseases	1	5	4	3	5	5	2	2	3	2	4
Aphids	1	3	-	3	3	-	-	5	-	-	4
Others											
Quality/ Quality seed	4	1	2	1	2	1	1	3	2	1	5
Marketing	4	1	2	3	5	1	1	1	2	1	5

1.1 = very important; 5 = least important.

It was suggested that the role of the Technical Coordinators is to develop detailed work plans for their respective Groups in collaboration with national program scientists, and to follow up on the agreed work plans in consultation with the CLAN Coordination Unit.

The involvement of each country in working groups and potential contributions from members to the Group were identified.

Drought Working Group

Involvement in research by country and discipline are given in Table 3.

Potential contributions will be:

- Australia • drought physiology, agronomy, germplasm, modeling for target environment and trait analysis, staygreen, earliness.
- India • germplasm, testing material.
- ICRISAT • germplasm, modeling for target environment, physiology, staygreen, earliness, stand establishment, testing.
- China • germplasm, testing.
- Thailand • germplasm, testing.
- Iran • germplasm (collection of local types), testing.

The remaining countries to contribute by testing material and providing results.

Shoot Pests (Shootfly and Stem Borer) Working Group

Involvement in research by country and discipline are given in Table 3.

Potential contributions:

- ICRISAT/India • germplasm, methodology, chemical control for both pests, and integrated pest management.
- China • germplasm for stem borer resistance (different species from India).

Other countries to contribute by testing materials and providing information.

Grain Mold Working Group

Involvement in research by country and discipline are given in Table 3.

Table 3. Involvement of collaborators in sorghum working groups.				
Country	Drought	Shoot pests	Grain mold	Forage sorghums
Australia	B, M. Ph, A[1]	-	–	B
Bangladesh	-	-	-	-
China	B,A	B,E	B	B
ICRISAT	B, M. Ph, A	B, E	B, Pa	B, Pa
India	B, Ph, A	B, E	B, Pa	B, Pa
Indonesia	-	-	-	-
Iran	A	-	-	-
Laos	A	-	-	-
Myanmar	A	-	-	-
Nepal	-	-	-	-
Pakistan	B,A	B, E	-	B, Pa
Philippines	A	-	-	-
Sri Lanka	-	-	-	-
Thailand	B,A	B	B	B
Vietnam	A	-	-	-

1. B = Breeding; M = Modeling; Ph = Physiology; A = Agronomy, Pa = Pathology; E = Entomology research.

Potential contributions:

India/ICRISAT • germplasm, screening methodology, breeding for resistance.

Where appropriate, other countries will contribute by conducting tests/trials and providing information.

Forage Sorghum Working Group

Involvement in research by country and discipline are given in Table 3.

Potential contributions to network will be supply of germplasm by India, ICRISAT, Australia, and Pakistan.

Where appropriate, other countries will contribute by conducting tests/trials and providing information.

Other Working Groups

In addition to these Working Groups, the participants recommended a 'Study Group' to prepare a status report and work plan on alternative uses of sorghum. Umaid Singh and T.G. Kelley (ICRISAT) were requested to take lead roles.

Bilateral collaboration was suggested for head smuts (Australia and China), and *Striga* (India and Myanmar).

Specific End-uses:

Feed. The group felt that there is enough research information available on utilization of sorghum as animal feed. However, limited additional research on poultry feed is called for. Advanced lines should be screened for carotene, low fiber, and low tannin levels. ICRISAT Center should compile and circulate a methodology for screening for feed quality so that all members of the network can follow the same procedure. Some screening work to reduce the number of lines for poultry feed testing should be carried out by ICRISAT.

Punjabrao Krishi Vidyapeeth (PKV), Akola, India will be a lead center for feed quality evaluation, and will explore liaison with the feed industry.

Fodder. As sufficient information is available on fodder quality traits, only screening of suitable materials is required. However, the group is concerned with the consequences of incorporation of disease resistance genes on fodder quality, as many of these genes may change the levels of secondary metabolites. Evaluation of the brown midrib trait in breeding for forage yield and quality is another area needing some additional research.

Haryana Agricultural University (HAU), Hisar, India will take the lead role in conducting and coordinating research on forage sorghums.

Industrial uses. Priority should be given to liaison with industry to exploit the available information and technology, rather than to conduct basic investigations. The group recognizes the urgent need for appropriate policy changes.

PKV, Akola, India will take the lead in exploring prospects for industrial collaboration. Isfahan University, Iran, will further explore the prospects for making particle boards from sorghum straw.

Non-traditional foods. The group recognizes that considerable work has been done in this area in Maharastra, India. Therefore, Marathwada Agricultural University (MAU), Parbhani, India was requested to take the lead role in popularizing technologies for the preparation of pops, flakes, and grits; and PKV, Akola, India, was requested to popularize sorghums for making syrup and crude sugar. Isfahan University, Iran, will take the lead role in further exploring the use of composite flour to make bread.

Role of Mentor Institutions

The group felt that the following topics might be suitable for research, technology exchange, and extension by mentor institutions:

- Malting;
- Brewing;

- Extending the crushing season;
- Harvesting and processing of sweet stalks;
- Utilization of sorghum starch; and
- Novel techniques for incorporating genes to increase quality or accumulation of specific end-products.

Information and Technology Exchange

The group was satisfied with the information flow from ICRISAT and appreciated ICRISAT's initiative in publishing the Sorghum and Millet Newsletter from ICRISAT Center. The provision ICRISAT has made for joint publication with national program scientists was also appreciated.

Meetings

Regular meetings of network participants are useful and provide opportunities for interactions, and exchange of information and research results among members. Such meetings could be organized by the Coordination Unit at ICRISAT Center or sponsored by national programs. Greater emphasis should be placed on the utilization of expertise within the network (including ICRISAT Center, where the critical mass of expertise is available).

Funding

It is understood that network activities should rely heavily on the internal resources of member countries. However, opportunities for suitable external funding should be keenly sought where appropriate, to hasten collaborative research among the members of the network.

Policy Research

Economic analysis of sorghum production, consumption, and trade in Asia is urgently called for. The group felt that ICRISAT economists should play a lead role in this area, and urged active collaboration with such national programs as those of Thailand and Indonesia.

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About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the semi-arid tropics. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is one of 18 nonprofit, research and training centers funded through the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is an informal association of approximately 50 public and private sector donors; it is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the World Bank, and the United Nations Development Programme (UNDP).

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