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CFC Technical Paper No. 34

Alternative Uses of Sorghum and Pearl Millet in Asia

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Proceedings of the Expert Meeting
ICRISAT, Patancheru
Andhra Pradesh, India
1-4 July 2003

ICRISAT

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Abstract

Both sorghum and pearl millet are staple food crops for the poor people in the semi-arid tropics (SAT). However, during the last two decades both crops are becoming less important as staple foods in SAT countries. Demand for coarse cereals (such as sorghum and pearl millet) as human food is decreasing in many countries, due to increased production and availability of preferred cereals (such as rice and wheat) at subsidized prices. The poor farmers in rainfed SAT cannot grow other crops, and are economically impacted negatively, as they do not get reasonable price for their produce. However, possibilities of alternative uses of sorghum and pearl millet are creating new opportunities that have potential to increase market demand and income to farmers.

An Expert Meeting on "Alternative Uses of Sorghum and Pearl Millet in Asia" was organized to: (i) synthesize the available information and assess the future outlook for increasing the demand and expanding market opportunities for alternative uses of sorghum and pearl millet with special reference to alternative novel food products, livestock feed, starch and brewing/distilling industries; (ii) assess existing and improved sorghum and pearl millet cultivars for suitability of alternative uses mentioned above; and (iii) identify potential players and opportunities for stimulating the institutional alliances among public, private, industry and NGO sectors to enhance alternative uses and market demand. Sixty participants from China, India, Indonesia, Pakistan, Thailand, USA and ICRISAT discussed the various aspects (mentioned above) to enhance the utilization of sorghum and pearl millet that would lead to sustained market demand for these crops. This, in turn, would ensure increased income and better livelihoods for the resource-poor sorghum and pearl millet farmers in the SAT countries.

The proceedings document the 22 papers presented at the expert meeting to serve as a valuable reference book on alternative uses of sorghum and pearl millet.

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Alternative Uses of Sorghum and Pearl Millet in Asia

Proceedings of the Expert Meeting

ICRISAT, Patancheru
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Foreword

In a joint undertaking by the Common Fund for Commodities, FAO and ICRISAT, an "Expert Meeting on Alternative Uses of Sorghum and Pearl Millet in Asia" was held in Patancheru, India, from 1 to 4 July 2003, financed by the Common Fund for Commodities.

The meeting brought together international experts on sorghum and pearl millet processing, food, feed, alcohol and brewing and other industrial and alternative uses. The experts analyzed current and future demand and identified constraints to various uses of sorghum and pearl millet, including high quality grain and fodder, food and feed processing, as well as new product developments and marketing.

About 50 representatives from governments, industry and research institutes from China, India, Indonesia, Pakistan, the Philippines, Thailand, the United Kingdom, the United States of America and international organizations attended the meeting, which concentrated on:

- (i) the identification of development issues for sorghum and pearl millet;
- (ii) the priorities for the development of sorghum and pearl millet; and
- (iii) the formation of proposals for interventions on the basis of the identified development priorities.

The meeting noted that sorghum and pearl millet offered considerable opportunities in the context of poverty reduction and food security in Asia. However, sorghum and pearl millet were facing increasing competition from other industrially produced grain crops from temperate regions, which could lead to marginalization of producers in semi-arid tropic areas. The development of alternative uses and new products from sorghum and pearl millet would be among the most effective mechanisms to maintain and improve the economic base of farmers in the semi-arid tropics of Asia.

The expert meeting is an example of the Common Fund's commitment to assist commodity producers in marginal areas in developing countries to maintain their source of income and to successfully participate in an increasingly integrated world economy. It is hoped that the meeting and its proceedings will contribute to the sustainable development of the semi-arid tropic regions in Asia.

Dr. Rolf W.Boehnke
Managing Director
Common Fund for Commodities

Acknowledgments and Disclaimer

The Common Fund for Commodities (CFC) and the Intergovernmental Group on Grains of the Food and Agriculture Organization (FAO) would like to acknowledge the hospitality of the Government of India and the assistance and logistical support of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to the organization of this Expert Meeting.

Special thanks go to all those who prepared presentations and chaired sessions of the Expert Meeting. The kind support provided by Effem India Private Limited and some seed companies based at Hyderabad, India is also gratefully acknowledged. The Meeting benefited from the organizational support provided by Drs CLL Gowda, Farid Waliyar, Belum VS Reddy, KN Rai of ICRISAT and PS Dravid of JK Agri-Genetics; and acknowledges the technical editing by Drs CLL Gowda, Belum VS Reddy, KN Rai, P Parthasarathy Rao and Farid Waliyar.

Special thanks go to Mr P Rama Krishna for his considerable assistance in coordinating the review process between the authors and editors. Several individuals from ICRISAT's support services also contributed to the success of the workshop. Ms Sheila Vijayakumar has provided invaluable assistance by editing the proceedings. Special thanks go also to M/s P Rama Krishna, SR Venkateswarlu, SB Stanley and Ms K Sai Lakshmi for their valuable secretarial and organizational support.

Welcome Address

WD Dar[1]

Exploring alternative uses of sorghum and pearl millet in Asia

Guests and colleagues from ICRISAT, good morning. Allow me to welcome all of you to this "Expert Meeting on Alternative Uses of Sorghum and Pearl Millet in Asia". This will go on from today (1 July) until 4 July 2003.

First of all, I would like to thank the Common Fund for Commodities (CFC) for its financial support and for jointly organizing this workshop with ICRISAT. The same thanks also go to the Intergovernmental Group on Grains, FAO, Rome, for its support. My special thanks are also due to Mr Andrey Kuleshov of CFC and Mr Myles Mielke of FAO for all their whole-hearted support to this initiative. I would also like to thank Dr Guy Spielberger, Managing Director of Effem India for their financial support. Effem India is another new partner of ICRISAT, further broadening our partnership with the private sector.

This is just one aspect of ICRISAT's total research program, which is guided by our new vision: "improved well being of the poor of the semi-arid tropics through agricultural research for impact." To attain this, we are committed with our mission "to help the poor of the semi-arid tropics through science with a human face and partnership-based research and development to increase agricultural productivity and food security, reduce poverty and protect the environment in SAT production systems."

ICRISAT's vision is guided by the seven planks of the new CGIAR vision and strategy. This is also anchored on our core competencies and thematic comparative advantages, strategic analysis of opportunities in the semi-arid tropics and potential impacts on the livelihoods of the poor. In order to pursue our vision and mission, we have mapped out six global research themes which form the core of our research strategy. These are:

1. Harnessing biotechnology for the poor
2. Crop improvement, management and utilization for food security and health

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3. Water, soil and agro-diversity management for ecosystem health
4. Sustainable seed supply systems for productivity
5. Enhancing crop-livestock productivity and systems diversification
6. SAT futures and development pathways

As you can see from the foregoing, we are very much involved in improving crops and managing natural resources. The Global Theme-2 (GT-2) on Crop improvement, management and utilization for food security and health is one of the major themes dealing with our mandate crops. These are sorghum, pearl millet, chickpea, pigeonpea and groundnut. These crops are grown by the poor farmers in the semi-arid tropics of the world.

GT-2 has regional projects in Asia and Africa. But for the purpose of this meeting which is focused on Asia, I would like to mention that this theme has two major projects in this region: one dealing with crop improvement and management and the other dealing with crop utilization including alternative uses and novel foods. This meeting will focus mainly on alternative utilization strategies, which can open up access to diversified high quality products, novel foods and feed formulations and should ultimately look at the market issues.

I am happy to inform you that since January 2003, ICRISAT, along with other partners has already initiated a DFID-funded project. This is titled "Exploring marketing opportunities through a research industry and users coalition: Sorghum poultry feed". We hope that this project will lead to the establishment of market links between sorghum farmer and poultry feed manufacturer. This is a pilot project to explore the alternative uses of the crop leading to commercialization.

I am very happy to see a wide range of participants from a number of countries from Asia, and also from USA; and a range of partners - research institutions, private sector seed companies, NGOs, feed manufacturers, alcohol and beverage industry, sugar industry, snack and food processors, market specialists, farmers' organizations and farmers. I am therefore confident that the results of this meeting will significantly boost our initiatives in alternative uses of sorghum and pearl millet in Asia. But most of all, our work should reach the most marginalized, disadvantaged and hungry. We must therefore tailor our research efforts to meet real human needs: reducing poverty, hunger, environmental degradation and social inequity. This is the heart of doing science with a human face.

You are going to discuss a subject of futuristic importance during the next 4 days. ICRISAT remains fully committed to this initiative of CFC and supported by many other partners on alternative uses of sorghum and pearl millet in Asia.

I wish you all success in this workshop and hope you will enjoy your brief stay at ICRISAT.

Thank you.

Opening Remarks by the CFC

A Kuleshov[1]

Distinguished Director General, Dr William Dar
Distinguished representative of the FAO
Dr Gowda, Global Theme Leader
Colleagues, Ladies and Gentlemen

It is a pleasure for me to greet you on behalf of the Managing Director of the Common Fund for Commodities (CFC), Dr Rolf W Boehnke in this Expert Meeting on utilization of sorghum and millet in Asia. First of all, I would like to thank ICRISAT, whose kind assistance to this project has made this meeting possible. I would also like to say how pleased I am to visit the state of Andhra Pradesh on this occasion. I want to express my gratitude to the people of Andhra Pradesh for welcoming the participants of this international meeting. Finally, I would like to thank all international participants for taking time to join the meeting.

The current meeting stems from two project proposals submitted to the CFC some 4 years ago concerning the realization of the development potential of sorghum and millet in the semi-arid tropics (SAT). While the CFC recognized the importance of sorghum and millet for producers' livelihoods and for general food security in the SAT, the Consultative Committee of the CFC also noted the complexity of the issues involved. In particular, the many programs currently being implemented in this field make prioritization essential in order to justify continued donor support for this undoubtedly worthy cause.

First and foremost, I see the meeting's purpose as to identify and prioritize the problems of sorghum and millet development in Asia and to work out actionable recommendations addressed to the broad development community. A systematic approach to the subject would avoid duplication and would help alleviate poverty and deal with the problems of nutrition in the sub-region.

In particular, I hope that this Expert Meeting will:

- Identify and prioritize the development issues in respect of sorghum and millet
- Work out a set of interventions on the basis of the development priorities

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- Explain the nature of problems and development priorities of the two commodities
- Provide such knowledge to donor agencies as a basis for joint action.

This meeting follows a similar meeting in West Africa and it is financed as a project under the CFC Fast Track Project facility. This in itself is an indication of the attention given to the development of sorghum and millet in the SAT The Common Fund Member countries would listen with attention to the practical recommendations emerging from expert discussions here in the next few days, and the decisions made afterwards will depend on the clarity and relevance of these recommendations to the overall development of the region.

Ladies and Gentlemen, I wish you a successful meeting.

Message from FAO

The Food and Agriculture Organization of the United Nations (FAO) is glad to know that the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and Common Fund for Commodities (CFC) are organizing an Expert Meeting on Alternative Uses of Sorghum and Pearl Millet in Asia. However, the FAO regrets not being able to attend this important event but wants to express its sincere thanks for the invitation. By a way of contributing to the discussions, FAO is providing this brief statement, reflecting on developments in Asian pearl millet and sorghum markets and providing its latest assessment of the global cereal market situation.

It may be important to draw attention to a collaborative study conducted by FAO and ICRISAT on world sorghum and millet markets (Source: FAO and ICRISAT 1996. The world sorghum and millet economies: Facts, trends and outlook). Reflecting on the main findings of that study, it could be said that little has changed in sorghum and millet economies, both in global as well as regional terms, since the publication of the results in 1996. Sorghum and millet remain important cereals in Asia, although well behind rice, wheat, maize and barley. Nonetheless, nearly 80% of the sorghum crop and over 85% of the millet crop are consumed as food in Asia. Food consumption of sorghum and millet has been declining gradually over the past decade across most Asian countries. In India, the largest sorghum consumer, the per caput food consumption of sorghum has declined from over 11 kg in the 1990s to around 7 kg in recent years; for millet, the per caput food consumption has fallen from around 10 kg to less than 9 kg. These declines are mostly driven by a continuing decrease in production during the past two decades, of sorghum in particular. Total sorghum production in Asia has dropped by almost 50% since the mid-1980s, to around 11 million t, due mostly to smaller outputs in India as well as in China, the second largest sorghum market in Asia. Although planted area has also declined in China, reduction in yields is the factor for smaller sorghum production in both countries. In fact, as it was also stated in the joint FAO and ICRISAT study, slow productivity growth and lower producer prices have reduced the competitiveness of millet and sorghum, resulting in crop substitution in many areas.

Trade patterns in these cereals have also changed little in the past decade. In the global context, trade in millet is very small and the Asian share is about 20% and generally stable. For sorghum, out of the estimated world trade volume of 7- 8 million t, Asian countries represent roughly 30% but nearly all of those imports are made by one country - Japan. With trade largely neutral to domestic market developments of sorghum and millet in most Asian countries, the declining trend in their production could reflect a continuing contraction in overall demand for these cereals. This could be an important issue for discussions in this Expert Meeting.

At this point, it may be opportune to draw the Group's attention to FAO's latest views on the current market situation for cereals. According to the information reported in Food Outlook, June 2003, global cereal output in 2003 is estimated at 1914 million t (including rice in milled equivalent), up some 4% above from the previous year's below-average level. World wheat production in 2003 is forecast at 584 million t, up 2% above the previous year's poor crop, although below the average of the past five years. At the regional level, output is forecast to rebound strongest in North America, Oceania and in North Africa. In Asia, output could decline by 2% and this largely due to China, India and Pakistan, where dry conditions have caused area reductions. World coarse grains output in 2003 is seen to increase by 6% to 934 million t. As in the case of wheat, the year-on-year increase would be largely due to an expected recovery in production in North America and Oceania following 2002 drought-reduced crops. However, output is also set to rise sharply in South America, where Brazil has gathered a bumper maize crop. Elsewhere, in Asia, Africa and Central America the coarse grains output is forecast to remain relatively unchanged in 2003. World production of sorghum in 2003 is forecast at 59 million t, up 5 million t from 2002 with most of the expansions in the United States. World production of millet is forecast to expand by nearly 3 million t in 2003 to nearly 27 million t, with a large increase expected in India.

As for rice production, based on the harvest results in the southern hemisphere so far, and the early indications of planting intentions in the northern hemisphere, overall global output in 2003 is forecast at 396 million t (592 million t in paddy terms), 2% higher than the previous year's reduced level. However, this figure is still highly tentative, since the final outcome will depend largely on the timing, extent and distribution of the Asian monsoon rainfall.

Preliminary indications for world cereal utilization in 2003/04 marketing season point to a possible increase of around 1.3% to 1981 million t. Cereal food consumption is likely to keep pace with population growth and cereal feed use is expected to show an increase of around 1.6%, mainly on expectation of a strong production rebound in several developed countries. Early indications for global cereal stocks by the end of seasons in 2004 point to a significant draw down for the fourth consecutive season. World cereal stocks at the end of countries' marketing seasons in 2004 are tentatively put at 399 million t, some 69 million t or 15% below their opening levels. Although a bigger global production is expected in 2003, the projected total cereal utilization in 2003/04 would still exceed the anticipated production, thus necessitating another significant release of stocks. As in the previous seasons, China would account for the bulk of the reduction in world stocks.

FAO's first forecast of the global trade in cereals in 2003/04 marketing seasons stands at 231 million t, which would represent a 3.5% contraction compared to 2002/03. It is expected that trade in nearly all major cereals will decrease in the new season with the most significant decline projected for wheat. International wheat trade in 2003/04 could fall to a five-year low of just 100 million t, with imports down 6 million t from the reduced 2002/03 estimated level. Most of the anticipated decline is expected in the European Union, where imports are forecast to be cut sharply following the recent imposition of an import quota system that would prevent large imports of cheap wheat, especially from Ukraine and the Russian Federation. Global trade in coarse grains in 2003/04 could be 105 million t, about 1.5 million t lower than in 2002/03. Again, most of the decrease would be concentrated in developed countries, where total imports are forecast to reach a five-year low of around 33 million t, down 3 million t from 2002/03, mainly on account of smaller maize purchases by Canada. Among the individual coarse grains, reduced maize and barley trade would account for most of the anticipated decline in world trade. World trade in sorghum is forecast to remain stable at around 7 million t in 2003/04 while trade in millet could contract slightly to about 160 thousand t. International trade in rice in 2003 is forecast to reach 27.1 million t, pointing to a contraction of 1 million t from the previous year. The year-to-year drop mainly reflects expectations of a sharp decline in exports by India and Australia, following production setbacks in these two countries, while on the import side, it results from smaller deliveries to some of the major rice markets, including the Philippines, Indonesia, the Islamic Republic of Iran and Iraq.

International prices of most cereals remained generally firm since April but the outlook for the coming months is mixed. For wheat, exportable availabilities among non-traditional exporters are forecast to drop. However, favorable crop prospects among major exporters, coupled with the forecast contraction in world import demand in 2003/04, could put prices under downward pressure in the coming months. For coarse grains, with an anticipated sharp decline in maize exports and stocks in China and much smaller feed wheat supplies in world markets, the 2003/04 global supply and demand seems fairly balanced, and international prices are expected to remain close to this year's levels. Prospects for international rice prices over the coming months point to some increases, since supplies available for export have come under pressure in the face of a resurgence in international demand, particularly by Brazil and some countries in Africa. However, beyond this period, the price outlook will be influenced by the status of paddy crops in northern hemisphere countries.

Under the scenarios mentioned above, the expert meeting on alternative uses of sorghum and pearl millet is extremely to explore ways to enhance production and utilization so that poor farmers in the semi-arid tropics can benefit. FAO wishes all participants a successful meeting during the next four days.

Objectives of the Expert Meeting on Alternative Uses of Sorghum and Pearl Millet in Asia

CLL Gowda[1]

On behalf of the Organizing Committee, 1 would like to welcome all the participants to this Expert Meeting on Alternative Uses of Sorghum and Pearl Millet in Asia. A special welcome and thanks to Mr Andrey Kuleshov from the Common Fund for Commodities (CFC), and delegates from China, India, Indonesia, Pakistan, Thailand and USA; and of course my colleagues from ICRISAT, including Dr AB Obilana who has traveled from Nairobi. Special thanks to Mr Myles Mielke, Secretary of FAO's Intergovernmental Group on Grains for his support to holding the meeting.

Sorghum (Sorghum bicolor) and pearl millet (Pennisetum glaucum) are the two most important cereal crops grown largely under rainfed conditions in the semi-arid tropics (SAT) of Asia, Africa and the Americas. Sorghum is grown over 90 countries in the world; Asia accounts 29% and Africa 52% of 42.8 million ha of total world area. In Asia, India accounts 84%, China 8% and Thailand 1.4% of the total 12.5 million ha area. The world estimated sorghum production is 59 million t, with a productivity of 1.4 t ha^{-1}. India's total production is estimated to be 9.5 million t, 74% of Asia, from a total of 10.5 million ha grown. Productivity in India is low, with 1.0 t ha^{-1} in rainy season and 0.8 t ha"[1] in postrainy season. On the other hand, China's productivity is estimated to be 2.8 t ha^{-1} with a total production of 2.7 million t accounting 21% of Asia's production. Thailand produces 0.17 million t (1.3% of Asia) from 0.11 ha with a productivity of 1.57 t ha^{-1}.

Pearl millet is a crop adapted to drought-prone, low fertility, saline and acid soils and is reported to be cultivated in 30 countries of Asia and Africa over 26 million ha, of which 46% is in Asia (11.5 m ha), with India accounting for 43% (10.7 m ha) of the total world area. Its productivity ranges from 0.6 to 0.7 t ha^{-1} both in Asia and Africa. India produces 9 million t with a productivity of 0.75 t ha^{-1}, China 1.94 million t with a productivity of 1.43 t ha^{-1}. Thailand has potential to cultivate pearl millet in marginal soils.

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In most of the developing countries of these continents both sorghum and pearl millet contribute significantly to food and nutritional security of the rural and urban poor people. Currently, India, China and Thailand in Asia are playing a major role in the development of sorghum and pearl millet cultivars in public and private sectors in partnership with ICRISAT. The adoption of improved and high-yielding cultivars is variable between crops and countries especially in India having >65% of the area in sorghum, and 80% in pearl millet. However, farmers do not get remunerative prices. One of the reasons for the low farm-gate prices is the several layers of traders between farmers and consumers. In the rainy season, sorghum is affected by grain molds, a disease caused by a complex of fungi, mostly including *Fusarium* spp and *Curvularia* spp, which produce fumonisin, a mycotoxin that is reported to be carcinogenic and immunosuppressive agent.

Both sorghum and pearl millet were staple cereals for the poor people in the SAT when ICRISAT was established 31 years ago. However, both crops are becoming less important in the economies of the SAT countries, and the demand for these grains as human food has been declining in the past 30 years (Source: Ryan and Spencer 2001. Future challenges and opportunities for agricultural R&D in the semi-arid tropics). This is more evident in Asia (especially in South Asia), where their share of food budgets of poor in SAT index fell from 17% in early 1970s to around 6% in early 1990s. The implication is that productivity improvement of these cereals has also led to price reduction. This is made worse by the government policies favoring rice *(Oryza sativa)* and wheat (*Triticum aestivum),* at the cost of sorghum and pearl millet. For example, in India the subsidized rice and wheat available under the Public Distribution System, at prices lower than the price of sorghum and pearl millet have adversely affected the market price of the latter. Naturally, the poor farmers of rainfed SAT who cannot grow crops other than sorghum and pearl millet are economically impacted negatively, as they cannot get reasonable price for the produce and thereby are forced into the vicious cycle of poverty and indebtedness.

However, there is hope. Recent growth and future projections of aggregate demand patterns suggest that there will be substantial increase in the demand for animal products (meat, milk and eggs) in developing countries by 2020 (Source: Ryan and Spencer 2001. Future challenges and opportunities for agricultural R & D in the semi-arid tropics). In addition to this, there are possibilities of other alternative uses of sorghum and pearl millet such as novel foods, processed foods and industrial uses - starch, beverages and ethanol.

Sorghum and pearl millet improvement research at ICRISAT makes great success stories, especially in the context of India, which is the largest producer of both crops in Asia. More than 50 hybrids of sorghum and more than 70 hybrids of pearl millet are grown on 60-65% of the total area under these two crops in India. About 70-80% of these hybrids are based on ICRISAT-bred male-sterile lines, or on proprietary parental lines developed from ICRISAT-bred germplasm.

Very little of the above would have occurred had it not been for productive public-private sector partnerships with diverse sectors in both crops. ICRISAT firmly believes in the power of partnerships, which brings together their complementary skills and resources to generate the synergy required to enhance the pace of technology development and dissemination.

Commercialization of alternative food, feed and industrial products is one of the ways to increase market demand for sorghum and pearl millet. This, however, would require innovative institutional alliances. I am convinced that this meeting will be able to identify commercializable food, feed and indirect products, identify research and development priorities, and also identify potential partners to develop innovative institutional alliances.

There is urgent need to develop and strengthen new linkages and relationships between commodity producers (the small-holder farmers), commodity-based science, and commodity markets, including industrial users. Innovations, both technical and institutional, need to be promoted through a broader and more iterative set of relationships than those embodied in conventional research-extension-farmer model of agricultural innovation. Giving context and urgency to this is the increasing evidence that lack of access to markets is a greater constraint to the diversified livelihood strategy of contemporary poor rural households, than the lack of access to food per se. In the case of coarse cereals, private sector industrial utilization has created market opportunities and there is potential for expansion both in terms of scope and volume. However, the institutional arrangements (rules and norms) and relationships (partnerships and alliances) linking science, producers and markets need to operate in a much more effective fashion than they do now.

A majority of the papers at this meeting discuss the various aspects of these existing and potential alternative uses of the crops. Therefore, the three major objectives of the meeting are to:

- Synthesize the available information and assess the future outlook for increasing the demand and expanding market opportunities for alternative uses of sorghum and pearl millet with special reference to alternative novel food products, livestock feed, starch and brewing/ distilling industries.
- Assess existing and improved sorghum and pearl millet cultivars for suitability of alternative uses mentioned above.
- Identify potential players and opportunities for stimulating the institutional alliances among public, private, industry and NGO sectors to enhance alternative uses (including industrial utilization) and market demand.

I sincerely hope that together we can map out the strategy for diversified alternative uses and nurture the necessary institutional alliances. I wish you all the best for a successful meeting.

Importance and Economics of Sorghum and Pearl Millet Production in Asia

B Dayakar Rao, BS Rana, S Hyma Jyothi, K Karthikeyan, KA Bharath Kumar and N Seetharama[1]

Abstract

The relative importance of sorghum and pearl millet as food grains in Asia is decreasing in terms of cultivated area and production. The same trend is in India except that the productivity of pearl millet is increasing. Generally the above changes can be explained in terms of increasing incomes, change in consumers' preferences and tastes, subsidized supply of wheat and rice through Public Distribution System (PDS), etc. Despite the decline in their consumption, food use still accounts for major share, especially of pearl millet. Sorghum is passing a transition stage from mere food and fodder crop to a valued industrial raw material such as feed (in India), sweet sorghum alcohol (in China and Thailand) and forage (in Pakistan).

Cotton, groundnut, pulses and castor are the major crops replacing sorghum in many areas. Soybean is the competing crop, especially in central and western India replacing sorghum. Cotton, sunflower, maize, groundnut, pulses and soybean are replacing pearl millet. Some factors responsible for replacement of sorghum and pearl millet by these competing crops are low productivity and profitability of sorghum and pearl millet vis-a-vis competing crops, increased irrigation availability and price support to other cash crops. The net returns from irrigated sorghum are up to five times that of dryland sorghum in India, making a pathway for its future commercialization.

The investment in R&D and outcome of research from private sector is growing at a faster rate than the public sector. Industrial uses such as animal feed, alcohol production (grain and sweet sorghum), jaggery and syrup (sweet sorghum), processed foods, malt/brewing and red sorghum exports will be the driving forces for commercialization of sorghum and pearl millet.

Productivity enhancement (maximization of yields) is the alternative in the absence of prospects of any increase in real prices of output. This will result in lowering per unit cost of production. Thus, yield improvements and value-addition through industrial utilization may enhance the profitability and alleviate rural poverty. Marketing, contract farming and farmer-industry linkages are the niches for commercialization of these crops.

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Sorghum (*Sorghum bicolor)* is cultivated over 42 million ha in the semi-arid regions of Asia, Americas, Australia and Africa. World production of sorghum trails behind rice *(Oryza sativa),* maize *(Zea mays),* wheat *(Triticum aestivum)* and barley *(Hordeum vulgare).* The developing countries in Asia and Africa contribute 90% of total sorghum area and 70% of total sorghum production. Asia alone contributes 30% of world sorghum production. The sorghum area to total cereals area is a meager 3.69%; however, it is the fifth important cereal in Asia. Sorghum production in Asia is concentrated mainly in India and China, which together contribute 86% of Asia's total sorghum production. Other Asian countries like Myanmar, Thailand, Pakistan and Yemen have relatively a smaller share. Of the two major producers of Asia, India alone contributes 67% of Asia's total sorghum production. Area and production of sorghum in India, China and Asia exhibit a downward trend during the last decade (Figs. 1 and 2). Sorghum is generally grown for food and fodder by the resource-poor farmers in the dryland regions of the semi-arid tropics offering food and fodder security to them. The relative importance of sorghum area to the total cereal area is shown in Table 1. The area under sorghum as a percentage of total area under cereals is relatively low, ie, about 10% in India and 1% in China. But in countries like Yemen and Saudi Arabia, sorghum area contributes significantly to the extent of 58% and 26%, respectively to the total cereal area.

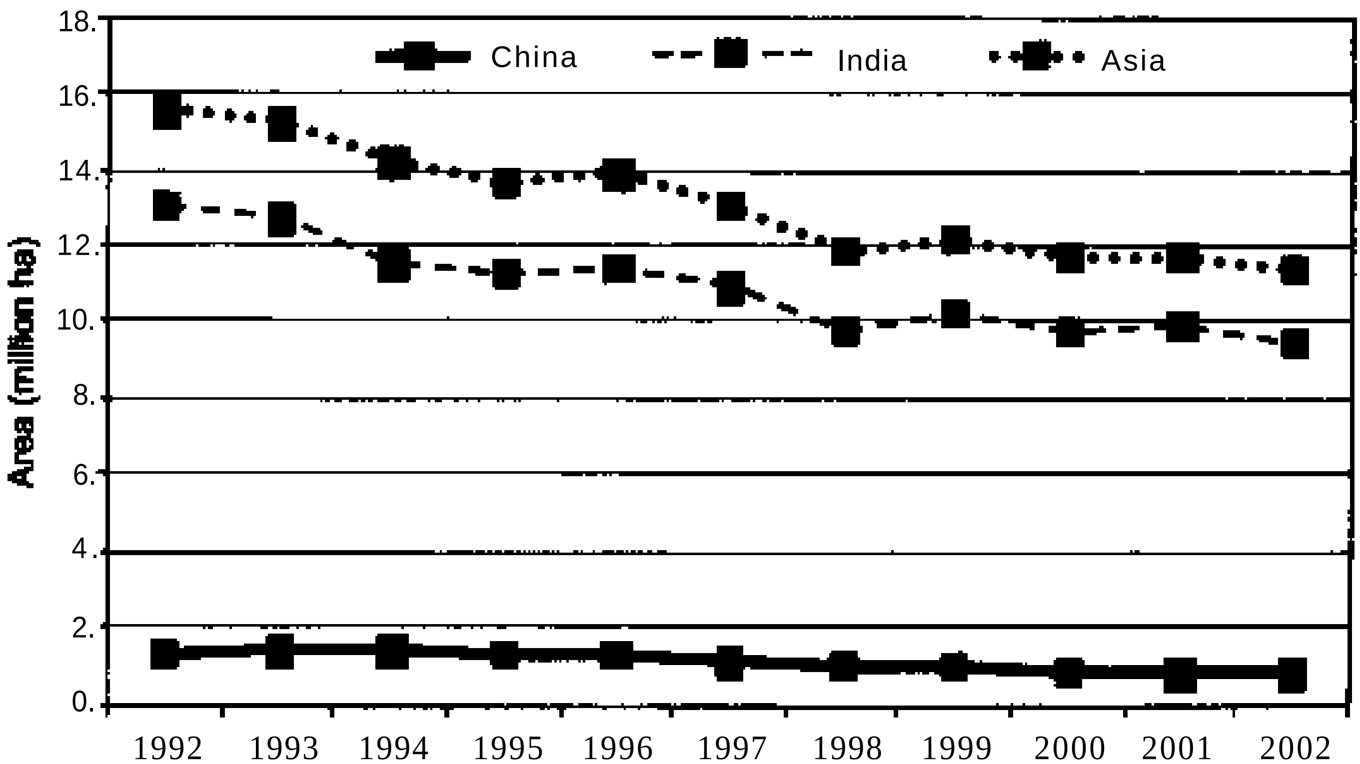

Figure 1. Recent trends in sorghum area in India, China and Asia.

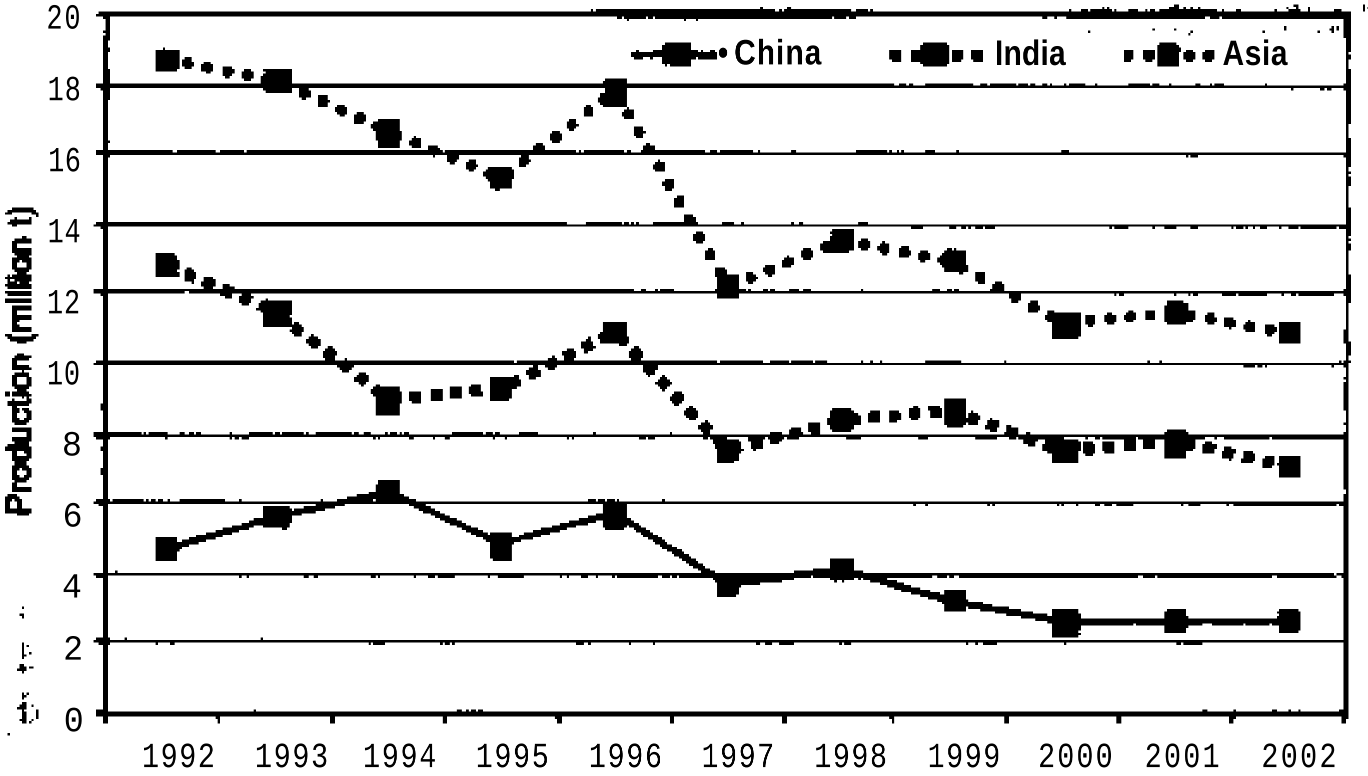

Figure 2. Recent trends in sorghum production in India, China and Asia.

Pearl millet *(Pennisetum glaucum)* accounts for almost half of the global millet production and is the most important millet species both in terms of cropped area and its role in providing food security in arid regions of Africa and Asia. It is highly resistant to drought and high temperatures, adaptable to poor soils, low vulnerability to diseases and insect pests and has good nutritive values, including a superior protein quality and highest fat content (6%) among cereals. Pearl millet grows well where other crops generally fail

Table 1. Relative proportion of sorghum area to total cereals area in Asia in triennium ending 2002.

Country	Total cereals area (million ha)	Sorghum area (million ha)	Sorghum area to total cereals area (%)
China	83.01	0.81	0.97
India	97.95	[illegible]	[illegible]
Korea (DPR)	1.24	0.01	0.80
Pakistan	12.29	0.37	3.00
Saudi Arabia	0.61	0.16	26.47
Thailand	11.25	0.11	0.98
Yemen	0.65	0.37	58.03
Asia	314.16	11.62	3.69

Source: FAO (2003).

completely. In Asia, it is mainly grown in India, Pakistan and Yemen. In the Near East Asian countries the area and production of pearl millet has increased during the past decade (Figs. 3 and 4). India could be probably the single country which is witnessing the largest decrease in area under pearl millet.

In this paper we discuss the Indian context only, due to the non-availability of separate statistics on pearl millet in other Asian countries, which is actually pooled under broader group of millets. Pearl millet in India forms 67% of Asia's total millet area contributing 57% of total millets production. Thus, any change in India's production perspective will have a major impact on Asian millet scenario.

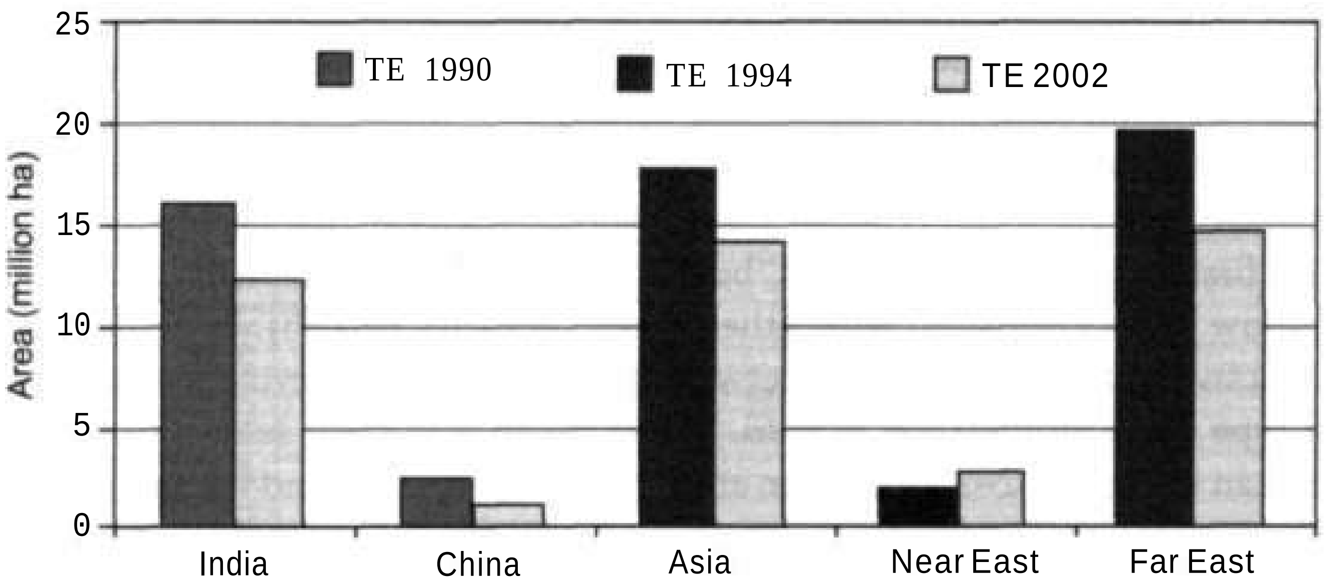

Figure 3. Changes in millet area in Asia.

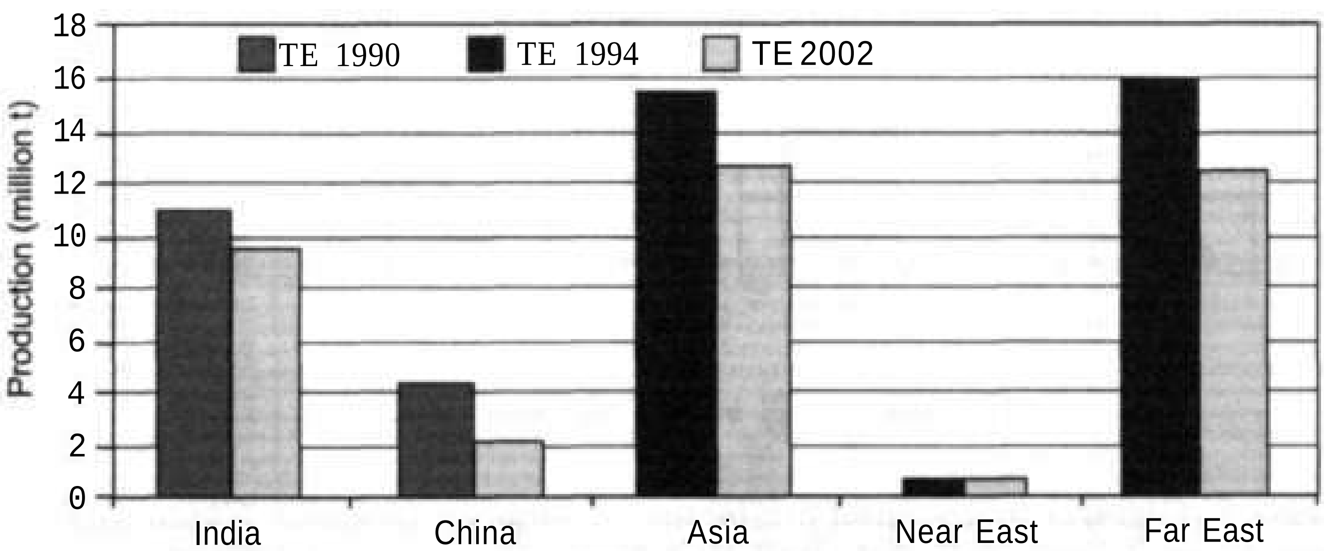

Figure 4. Changes in millet production in Asia.

Trends in production

Changes in area, production and productivity of sorghum

Sorghum is currently grown on 11.2 million ha in Asia. The area has declined in all the Asian countries, except Saudi Arabia. In India alone, about 4.83 million ha sorghum area was replaced by other crops. Although India is the major sorghum-growing country in Asia, the change in sorghum area between triennium ending (TE) 1990 and TE 2002 is about -33% (Table 2 and Fig. 5). Some of the plausible reasons for this are: cultivation on marginal lands, low input use, adverse agroclimatic conditions and unfavorable government policies. In all other Asian countries, although the percentage change in area under sorghum is significant, the absolute area under sorghum is low. As a consequence of reduction in land area, the total production also dropped in almost all Asian countries except Saudi Arabia.

Sorghum production in Asia declined steeply by 5.22% per annum between 1994 and 2002 (Fig. 5). Though sorghum production declined, India ranks first in area and production, but ranks seventh in productivity which is very low when compared with other Asian countries (Fig. 6). In India, the productivity of sorghum differs between the regions with varying rainfall and soil type and also between seasons. For example, the rainy season sorghum yields an average of 2-2.25 t ha^{-1} in areas with favorable soil and rainfall, while the postrainy season sorghum grown under unfavorable conditions yields

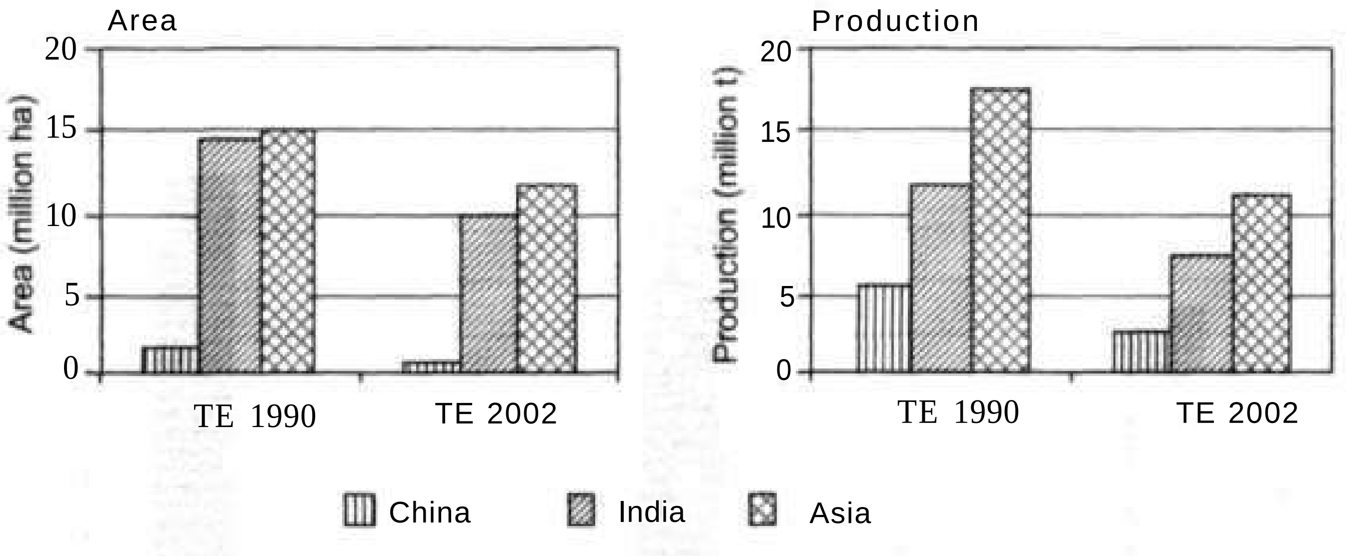

Figure 5. Changes in area and production of sorghum in India, China and Asia. (Note: Data are for TE 1990 for China and India and TE 1994 for Asia.)

Table 2. Changes in sorghum area, production and productivity in Asia.

	Area			Production			Productivity		
Country	Actual (TE 2002) ('000 ha)	Change (%) over TE 1990	Growth rate (%) (1988–2002)	Actual (TE 2002) ('000 t)	Change (%) over TE 1990	Growth rate (%) (1988–2002)	Actual (TE 2002) (kg ha^{-1})	Change (%) over TE 1990	Growth rate (%) (1988–2002)
China	812.2	–51.54	–5.62	2685.7	–49.8	–5.3	3328	3.9	–7.5
India	9760.4	–33.14	–3.24	7461.0	–35.6	–3.2	764	–3.6	0
Rainy	4398.0	–49.83	–5.69	4108.0	–49.9	–5.4	931	–0.6	0.2
Postrainy	5276.0	–9.52	–0.59	3317.0	–1.7	0.2	628	8.5	0.8
Korea (DPR)	10.0	0	–1.47	10.0	–33.3	–4.5	1000	–33.3	–3.0
Pakistan	370.4	–13.70	–1.08	223.3	–10.5	–0.7	604	3.8	0.3
Saudi Arabia	162.8	30.68	2.77	204.0	43.5	3.8	1186	4.4	0.6
Thailand	110.4	–38.61	–5.10	197.5	–13.5	–2.5	1762	39.3	2.6
Yemen	379.6	–29.90	–2.33	372.5	–26.0	–1.5	983	5.7	0.7
Asia[1]	11622.8	–22.37	–3.15	11204.7	–37.0	–5.2	964	–18.9	–2.4
World	42590.3	–3.64	–0.31	59737.7	–4.9	–0.3	1333	–1.3	–0.01

1. Data for triennium ending (TE) 1994 to TE 2002.

Source: FAO (2003).

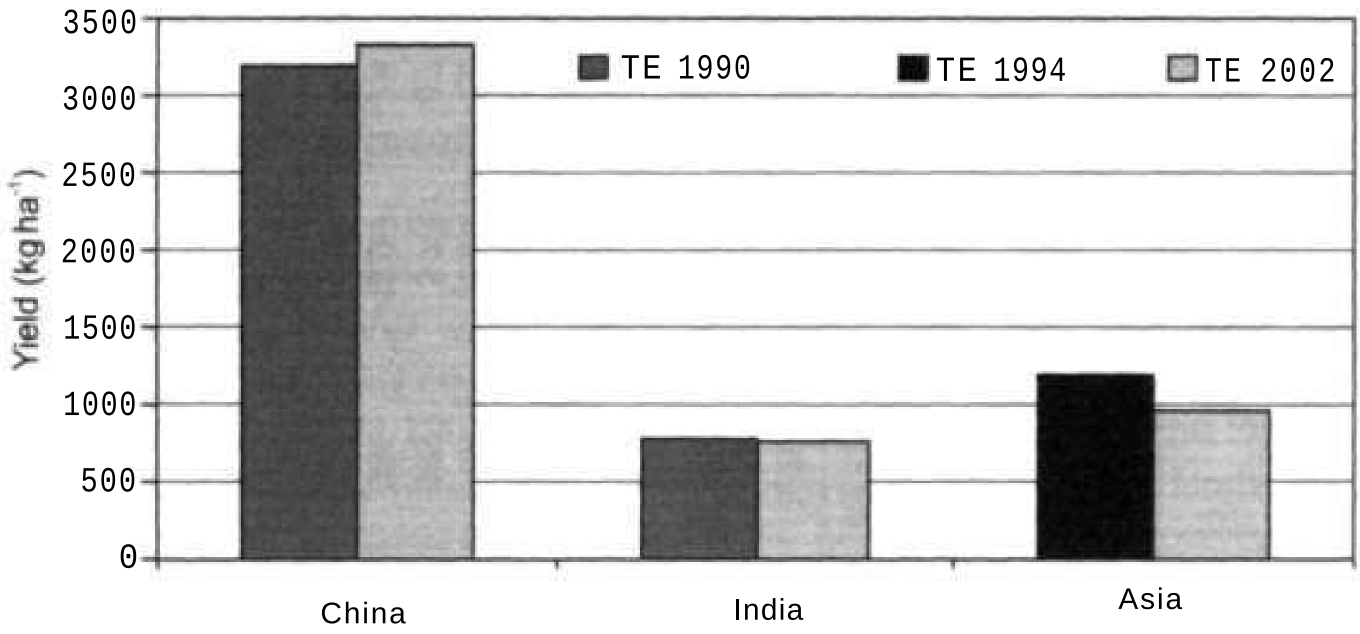

Figure 6. Changes in sorghum productivity in India, China and Asia.

around 500 kg ha^{-1}; thus the total production and productivity are considerably low. It appears that the higher productivity achieved till the 1990s might have plateaued; hence this staggered productivity was unable to tide over the steep decline in sorghum area to other competing crops and resulted in negative growth rate in production. This was also true in other major sorghum-growing countries in Asia. Thus, in India, the low average productivity levels are mainly due to low yield levels of postrainy season sorghum whose proportion in the total area is on the increase. Latest data revealed that postrainy season sorghum contributes 58% of total sorghum area in the country.

In China, the decline in production can be explained in terms of sharp decline both in area [cumulatiye growth rate (CGR) -5.6%] and yield (CGR -7.5%), while in India it is mainly due to decline in area (CGR -3.2%) rather than the yield (CGR -0.06%). The highest yield levels in Asia are recorded in China. With current yield levels over 3 t ha^{-1} it appears that there are no further productivity improvements possible in sorghum in China, thus eroding its competitiveness. Thailand and Saudi Arabia recorded second and third higher yield levels in Asia. In Thailand, the growth rate in yield is the highest (2.6%); however, this factor could not keep sorghum competitive due to shift in area to other crops. Saudi Arabia is the only major sorghum-growing country in Asia, where sorghum remained competitive with positive area growth of 2.7% per annum in spite of low productivity growth rate of 0.6% per annum. Consequently, production growth rate remained positive and relatively high (3.8%).

Crop distribution and utilization of sorghum in Asia

Present vs future

Overall in Asia sorghum is primarily used for food comprising *66%* of total utilization, while the rest is utilized for feed and industrial uses. In India, it is mostly used for food, while in China it is used for food, feed and brewing. The declining trend in utilization can be attributed to two major factors: (1) the overall reduction in sorghum production during the reference period; and (2) the population growth rate surpassed the growth in sorghum production (Asia comprising China and India, the most populous countries).

The per capita utilization of sorghum decreased mainly due to the reduction in food use, and factors such as changing consumer tastes and preferences, rapid urbanization, social status attached to wheat and rice consumption and unfavorable government policies towards sorghum cultivation. Previous studies have shown that the increased feed usage of coarse grains offsets the decrease in food use of these crops (Swaminathan and Sinha 1986).

The breakup of utilization of sorghum for various end uses in some Asian countries shows notable trends (Table 3). All the countries in Asia registered a negative growth in food, feed and other uses during the reference period. Sorghum grain is primarily used as food and feed while the stalk is used as forage; the stalk of sweet sorghum is used for alcohol production (Table 4).

China

In China, declining food use of sorghum at a higher rate (-6.5%) than the feed use (-0.2%) revealed its importance for livestock feed. It is mainly cultivated in Liaoning, Shanxi, Julin, Heilongiang, Hebei and Sichuan provinces. The rapid economic development witnessed in China also changed the role of sorghum from food and feed crop to a high value industrial raw material for brewing industry. The change of role may be due to improvement in the agricultural production conditions, shift in consumer preferences from sorghum to rice and wheat, increase in household income over the period, reduction in production and increased importance of other uses of sorghum (other than food). However, during mid 1990s there was a considerable decrease in sorghum area for food purpose due to decline in its consumption.

Table 3. Sorghum utilization in Asia.

	Food use			Feed use[1]			Total utilization			Per capita utilization		
Country	Actual (TE 2000) ('000 t)	Change (%) over TE 1990	Growth rate (%) (1988–2000)	Actual (TE 2000) ('000 t)	Change (%) over TE 1990	Growth rate (%) (1988–2000)	Actual (TE 2002) ('000 t)	Change (%) over TE 1990	Growth rate (%) (1988–2000)	Actual (TE 2002) (kg yr⁻¹)	Change (%) over TE 1990	Growth rate (%) (1988–2000)
China	1291	–50.30	–6.49	1877 (18)	–1.10 (–35.71)	–0.22 (–4.29)	3186	–29.57	–3.35	1.0	–56.52	–7.30
India	7231	–2.97	–3.23	98	–28.46	–3.02	7329	–28.96	–3.23	7.3	–41.12	–4.95
Israel	–	–	–	125	–66.03	–5.67	125	–66.03	–5.67	–	–	–
Korea (DPR)	7	–50.00	–4.07	1	–50.00	–1.52	8	–50.00	–3.51	0.3	–57.14	–4.67
Pakistan	193	–11.05	–0.93	11	–8.30	–0.79	204	–10.91	–0.92	1.4	–30.00	–3.45
Saudi Arabia	191	43.60	4.31	–	–	–	191	43.60	4.31	9.7	7.70	–1.66
Thailand	–	–	–	138	–5.47	–0.64	138	–5.47	–0.64	–	–	–
Yemen	21	–19.23	–	374	–18.16	–	395	–18.21	–	21.2	–48.41	–
Asia	9288	–32.30	–3.50	4713 (18)	–32.24 (–35.71)	–3.48 (–4.29)	14019	–32.28	–3.35	2.6	–42.22	–7.30

1. Values for other uses are given in parentheses.

Source: FAO (2003).

Table 4. Utilization of sorghum grain and stalk in Asia.		
Country	Grain	Stalk
Rainy season sorghum		
India	Food, feed, alcohol	Dry fodder (livestock), forage (livestock), alcohol (industrial)
Myanmar	Food	Fodder
Pakistan	Feed (less emphasis)	Dry fodder (livestock), forage (livestock - dairy)
Thailand	Feed (livestock)	Dry fodder (livestock)
Postrainy season (winter) sorghum		
India	Food	Dry fodder (livestock)
Summer sorghum		
India (limited)	Food	Dry fodder (livestock)
Iran	Feed (livestock), syrup, particle board (industrial)	Forage (livestock - dairy)
Cool temperature sorghum		
China	Feed (livestock), alcohol, minor alternative uses	Sweet sorghum (alcohol)
CIS	Feed (livestock)	
Rice fallow sorghum		
Philippines	Feed (livestock)	
Indonesia	Feed (livestock)	

Source: Gowda and Stenhouse (1993).

India

In India, which is the largest producer of sorghum, both food and feed use is declining at 3% (FAO 2003). However, some farm-level studies clearly indicate the transforming roles of food and fodder in India, the latter emerging as being of primary importance. The recently conducted exhaustive industrial surveys in India pointed that sorghum was utilized not only in animal feed industry (0.57 to 0.86 million t) but also in alcohol industry (0.09 to 0.10 million t) and projected that the utilization of sorghum for animal feed would go up to 2.11 to 3.7 million t in 2010 AD. With the projection of positive growth in livestock industry, there would be a huge demand for sorghum grain in future. Kumar (1998) projected that by 2020 the demand of feed grain will grow to 14.5-23.0 million t comprising 9-14 million t of coarse grain and the remaining from other crop sources. In future, sorghum in livestock feed utilization, especially poultry feed industry depends upon such factors as availability of maize (sorghum's potential competitor), relative price with maize and providing knowledge and removing apprehensions about feed usage of sorghum among its users. According to the above mentioned surveys, currently rainy season sorghum grain was found to have established alternative uses in India, as a raw material in potable alcohol production and to a lesser extent in starch industry, which may increase sorghum utilization especially when the crop is facing challenges due to decrease in household consumption for food.

Myanmar

In Myanmar, sorghum is grown only under rainfed conditions and occupies the second largest area only after rice among cereals. It is mainly grown as a food and fodder crop in Magway, Mandalay and Sagaing divisions (states) in semi-arid tropics followed by Chin and Kayah states in sub-tropics.

Pakistan

In Pakistan sorghum is cultivated for both food grain and as forage crop, and 90% of production is consumed on-farm as food and seed. Sorghum area is equally divided between rainfed and irrigated cultivation and at least one quarter of rainfed and half of irrigated crop is grown mainly for forage use. Sorghum is cultivated for green fodder during winter and the feed usage of sorghum grain is increasing.

Thailand

Sorghum in Thailand occupies third position after rice and maize. But the increasing demand for animal feed (thus the derived demand for sorghum grain) compensates the decrease in export demand, thus maintaining the area of its cultivation. Thailand also foresees a considerable demand for sorghum as there is no sufficient production of maize to be used in animal feed. In Thailand alternative uses of sorghum such as ornamental usage of sorghum spikes/spikelets and supplementing the fodder for milch cows with fresh stalks are practiced extensively. Also, research is going on for exploring ethanol production from sweet sorghum.

Changes in area, production and productivity of pearl millet in India

In India, pearl millet alone accounts for 9.4 million ha of total cereals area and 6.9 million t of total cereals production (Table 5). Though India recorded the highest decrease in area during the past decade, it showed increase in production and productivity (Fig. 7). Although pearl millet is grown under highly unfavorable rainfed conditions, the ever increasing competition from crops such as maize, cotton (*Gossypium* sp), groundnut *(Arachis hypogaea)* and sunflower (*Helianthus annuus)* is also affecting its production. In India, the western states (Rajasthan, Gujarat and Maharashtra) have more share in pearl millet area and production than the rest of the country. India, the largest millet producer in the world, accounts for about 40% of the world's output whereas pearl millet alone contributes to two-third of this total world millet production. In some parts of India, especially in Gujarat, pearl millet production involves a high degree of commercialization as the crop residue is a valued fodder for milch animals. Also, in areas where double cropping is practiced, it involves high value crop cultivation. Despite the harsh environments in which it is cultivated the growth in pearl millet productivity is the reward for the adoption of improved cultivars especially in some favorable environments. Most of the crop improvement in India was by development of high-yielding varieties (HYVs) and matching production-protection technologies which are specially adopted to favorable environments.

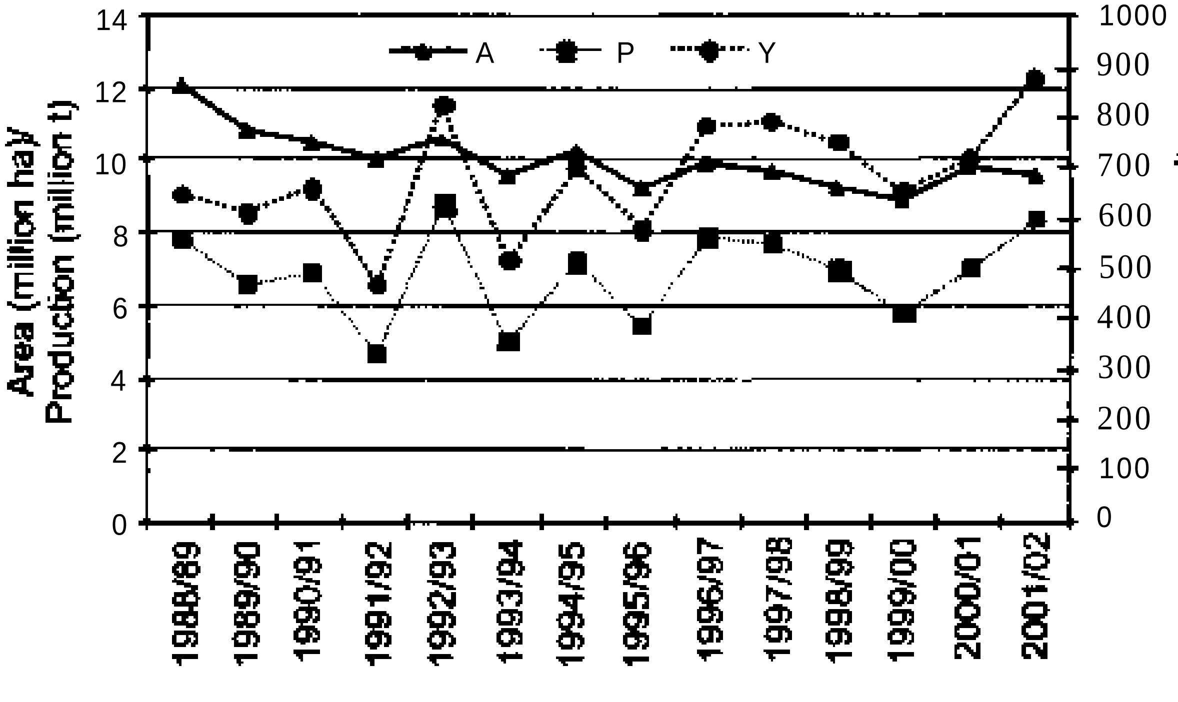

Figure 7. Area (A), production (?) and yield (Y) of pearl millet in India.

Table 5. Changes in area, production and productivity of pearl millet in India.

	Area			Production			Productivity		
State	Actual (TE 2001) ('000 ha)	Change (%) over TE 1990	Growth rate (%) (1988–2001)	Actual (TE 2001) ('000 t)	Change (%) over TE 1990	Growth rate (%) (1988–2001)	Actual (TE 2001) (kg ha^{-1})	Change (%) over TE 1990	Growth rate (%) (1988–2001)
Andhra Pradesh	117.33	–54.38	–7.34	105.66	–41.97	–3.39	880.33	24.16	2.11
Gujarat	963.76	–31.95	–2.87	978.80	–29.02	–0.42	1031.30	19.59	2.52
Haryana	593.66	–11.66	–	690.66	8.14	–	1164.33	25.69	–
Karnataka	357.66	–23.55	–2.53	228.00	–1.25	–0.80	619.00	26.06	1.78
Maharashtra	1645.13	–14.95	–1.54	1017.36	–5.19	0.07	617.00	11.05	1.63
Rajasthan	4559.03	–11.73	–1.07	2383.10	1.90	0.99	505.00	11.72	2.08
Uttar Pradesh	851.66	3.70	–	1131.66	29.80	–	1326.66	24.84	–
All India	9424.60	–13.29	–1.43	6998.60	1.50	0.73	737.66	15.62	2.19

Source: CMIE (2002), Government of India (2002).

Utilization of pearl millet in Asia: present vs future

Over 95% of pearl millet grain production in Asia is utilized for food use and the rest is used in feed industry. It is primarily grown for grain, stover, and sometimes as a green fodder in India, Pakistan and Yemen. It is also used as green forage in Thailand and the Republic of Korea (Gowda and Ramakrishna 1996). Previous studies show that the food usage of pearl millet is declining over the study period in India at a lower rate (-0.76%). Though it is nutritionally equal or even superior to other cereals, its consumption has decreased due to rising incomes, changing food preferences and supply of wheat and rice at subsidized prices (in India). However, its cultivation will continue under subsistence farming, where other crops cannot be grown. In more favorable areas of Asia, grain is produced, and it is often used in rations for draft and milch animals, and for poultry. Stover is used during the dry season to maintain rations for cattle in areas where sorghum stover is not readily available (Hash 1996). The usage of pearl millet for forage purpose and as a cover crop or mulch crop for intensive legume production on tropical arid soils is becoming increasingly important.

Causes of changes in area and replacement crops

Sorghum

Sorghum cropped area was replaced by a host of competing crops grown under the same ecology across Asia. In India, various studies based on on-farm surveys reported that cotton, groundnut and pulse crops replaced rainy season sorghum till 1980s, while in 1990s it was replaced by crops such as soybean (*Glycine max)* (Madhya Pradesh and Maharashtra), castor *(Ricinus communis)* (Andhra Pradesh), moth bean *(Vigna aconitifolia)* (Rajasthan and Gujarat) and other pulse crops. Postrainy season sorghum was relatively stable due to absence of any alternative crops that can be grown under similar situations, ie, receding soil moisture and drought. However, whenever irrigation was possible, crops such as wheat, maize and sunflower were grown instead of sorghum. Interestingly, in the rainy season, crops like cotton were also increasingly replaced by a commercial crop like soybean. In central India (Madhya Pradesh), it appears that sorghum is again becoming popular due to the climatic conditions and need for fodder in the region (Dayakar Rao et al. 2003). In China, it was reported that sorghum area was mainly replaced by maize and its cultivation has moved from fertile semi-humid regions to semi-arid regions with poor soil fertility. The cropping pattern here also changed from monocropping to intercropping with potato *[Solarium tuberosum)* or wheat and sequential planting after wheat.

In India, area changes under rainy season sorghum are more conspicuous than postrainy season sorghum. One of the earliest studies by Kelley and Parthasarathy Rao (1993) pointed that sorghum productivity growth at national level has lagged behind other competing cereal crops such as wheat, rice and maize. Sorghum prices have also failed to keep pace with competing crops such as wheat, rice, pulses and oilseeds. Together, these two factors have weakened the competitiveness of the crop over time, translating into reduced area under sorghum cultivation. The low competitiveness at farm level and the factors such as lack of consumption demand at household level and low profitability of sorghum vis-a-vis competing crops were responsible for the loss of competitiveness of sorghum. The Government of India's policy to supply subsidized rice and wheat in sorghum-growing regions led to a shift in consumption in favor of the former. Another study by Hall and Yoganand (2000) listed that better irrigation facilities, improved transport and marketing facilities and government policies favoring oilseed crops through price support also led to substitution of sorghum by other crops. A recent study by Dayakar Rao et al. (2003) confirmed earlier findings that adoption of HYVs facilitated high productivity levels of sorghum under constant or decreasing consumption regime (due to changes in tastes and preferences), which in turn led to a situation where sorghum area was spared for other commercial crops.

Kaur and Kaur (2002) analyzed the changes in area, production and productivity of coarse cereals (which include sorghum and pearl millet) in India during 1949-50 to 2000-01. It was found that during 1966-67 to 1997-98, the gross cropped area under coarse cereals dropped from 28 to 16% owing to absence of effective price support, procurement programs and inadequate technological improvements.

The sorghum area in Thailand is declining due to lack of export demand and competition from other crops such as sunflower and maize.

Pearl millet

The area under pearl millet is relatively constant due to its adaptability to harsh habitat. However, in better ecological regimes and with protective irrigation cotton, sunflower, maize, groundnut, rapeseed (Brassica napus) and mustard (Brassica sp), pulses and sorghum have replaced pearl millet in India. The extent of replacement by these crops varies across states in India.

The changes in the cropped area of pearl millet are in both directions. It is usually replaced by other crops where permanent land improvements are made, either in terms of soil health or irrigation facilities. Thus the cultivation of pearl millet is relegated to marginal lands. When pearl millet cultivation is continued in a region, its area has actually increased mainly due to three factors: (1) availability of only few other crop (particularly cereal) alternatives; (2) strong preference for millet as the major staple in the region; and (3) preference for millet straw as a highly valued livestock feed.

The results of recent farm surveys (Dayakar Rao et al. 2003) revealed that the lack of crop alternatives and continued preference as staple diet and fodder for livestock have attracted farmers to continue pearl millet cultivation, especially in states like Rajasthan. However, in Maharashtra and few other states pearl millet lost its competitiveness, because of increasing availability of crop alternatives with remunerative output prices. As in sorghum, the adoption of HYVs has also resulted in reduction of pearl millet area without any significant reduction in total production, thus sparing land for other commercial crop alternatives. Besides, there is a significant decline in household demand for food.

Pearl millet is often grown under highly unfavorable conditions and hence has low productivity. Government policies on input subsidies and output prices are lopsided towards wheat and rice. The market interventions also do not adequately support this crop. The bulk procurement of pearl millet for supply through Public Distribution System (PDS) may be necessary to increase its demand in India.

Food and nutritional security

As discussed earlier, sorghum and pearl millet are mainly produced and consumed as main staple food by the rural poor in developing countries of Asia and Africa, providing 80% of their energy requirement and nutrients except vitamin A and vitamin C. A study by the National Institute of Nutrition (NIN), Hyderabad, India in 1996 has shown that a balanced diet containing at least 460 g of cereals besides pulses, vegetables, milk, etc should be consumed to attain a minimum daily per capita energy requirement of 2738 k cal. Accordingly the per capita requirement of cereals should be around 165.6 kg yr^{1}.

The average per capita energy requirement of around 2738 k cal day^{-1} is mainly supplied by cereal consumption. In India the required energy supply mainly comes from rice and wheat, except for the major sorghum-growing states like Maharashtra and Karnataka where nearly 19% of daily energy requirement is supplied through sorghum and the rest from other cereals. Sorghum and millets also supply the needed nutrients to the poor people who cannot afford other expensive sources of these essential nutrients, and thus can be an effective shield against food and nutritional insecurity.

Sorghum and millets are nutritionally superior to other cereals, but their downward demand in cereal basket may be caused by factors like rising incomes, social status attached to fine grains, subsidized supply of fine grains, low productivity of coarse cereals, short shelf life of flour and more effort needed in making chapati (unleavened bread). Efforts are to be made by the government (especially in India) to include sorghum in PDS.

Sorghum and pearl millet for improved livelihood

Sorghum is also cultivated for feed in many countries in Asia. In India, it is perceived as a crop meant for human consumption largely by the rural poor and to a lesser extent by the urban poor and the rural rich. In India, sorghum is considered an important staple food after rice and wheat, despite a continuous decline in its consumption. The relevance of sorghum to the livelihood of the poor is established in the context of food, fodder, income generation and source of employment. Dayakar Rao (2000) concluded that majority of the sample households pursued mixed livelihood strategies (across wealth groups). In postrainy season sorghum-growing districts, sorghum constituted 55% of total cereal consumption while it was 58% in rainy season sorghum-growing districts. Food habits of the rich families is largely determined by taste and preferences and crops they grow, while in case of the poor it is determined by price, kind of payment (for labor) and crops they grow. In rainy season sorghum areas, quality of rainy season sorghum and subsidized supply of wheat and rice motivate people to consume the preferred cereals. When both rich and poor household consumption patterns are examined together, sorghum contributes over half of the total cereal consumption. A study by Azam-Ali and Start (1999) revealed that sorghum continues to be an important staple for the urban poor where there is a sufficient supply to meet the demand and also price is the major determinant.

The National Sample Survey Organisation (NSSO) data on per capita consumption of sorghum for major rainy season sorghum-growing districts in selected Indian states showed that out of 24 districts the consumption remained stable in 13 districts while a major decline (greater than 20%) was witnessed in districts where introduction of irrigation rendered changes in cropping patterns.

Sorghum and pearl millet are also the preferred cereal crop residues for milch and draft animals in India and their importance has increased manifold due to increase in demand for milk products and realized fodder scarcities during drought periods. Sorghum as fodder is quantified around 20-50% of total value of sorghum crop. Dayakar Rao (2000) revealed that 96% of total stover fed to livestock in postrainy season sorghum areas and 88% in rainy season sorghum areas is sorghum. Nearly 38% households in postrainy season sorghum area allocated their land based on fodder demand, while only 28% households allocated land in rainy season sorghum area. Thus, one of the key determinants for sorghum area is the household demand for fodder.

Source of employment

Sorghum is gaining importance as a source of employment in postrainy season sorghum areas where crop alternatives are absent or limited, but is less important in rainy season sorghum areas (Dayakar Rao 2000). In sorghum-based cropping pattern, mostly family labor is engaged in various operations.

Source of income

The contribution of sorghum to the gross income was very low, ie, about 2% (Dayakar Rao 2000). It is mainly due to relatively low price for sorghum and lesser share of sorghum in total cropping pattern. For the poor farmers, sorghum offers buffer cash at times of distress or urgent cash needs. The grain set apart for food is generally sold to meet such situations. However, when grain is in short supply, it is usually bought from open market.

In India, traditionally sorghum grain is offered as payment for wages to agricultural laborers. However, in good rainfall years resulting in bumper crop, laborers opted for a mix of cash and grain, but preference is more towards cash. In bad years of crop production, laborers opted more grains than cash because of high prices of grain as they can sell it to buy cheaper foods. As new technologies and market access offered diverse livelihood opportunities to farmers, sorghum became less attractive because of its low price and low profitability compared to other cash crops.

Dual-purpose roles of sorghum and pearl millet

In the semi-arid tropics of Asia, sorghum and pearl millet are widely seen as dual-purpose crops (grain and fodder) where the crop-livestock (mixed) farming system is widely practiced. Nearly 70% of rainy season sorghum grown was for dual purpose with less importance attached to grain yield (NRCS 1998).

In rainy season sorghum areas, grain is considered as a bonus and sorghum stalk as main product by rich farmers (Dayakar Rao 2000). The importance of sorghum is more pronounced in areas where livestock enterprise is one of the important livelihood strategies of people. In the states of Rajasthan, Punjab, Haryana, Gujarat, Uttar Pradesh, Andhra Pradesh and Madhya Pradesh where cattle population is more, sorghum cultivation is key for supplying fodder, while in states like Maharashtra and Karnataka sorghum is grown over a large area with equal importance for both grain and fodder. In Maharashtra and Karnataka, the large area under sorghum compensates for fodder demand and thus dual-purpose plant type maximizes grain yield. In other states with less area under sorghum, tall fodder types are cultivated to meet the fodder demand. Dayakar Rao et al. (2000) also pointed that 40% of sample farmers in selected postrainy season sorghum districts of Karnataka and Maharashtra and 33% in rainy season sorghum districts of Maharashtra cultivated sorghum mainly for green fodder. Also, 31% of respondents in postrainy season districts and 48% in rainy season districts grow sorghum with equal importance to grain and fodder usage.

Dual-purpose sorghum in Myanmar is usually taken up as a second crop after early sorghum or legumes in the mid-monsoon season. For green fodder, sorghum is sown at the onset of monsoon, as a sole crop. Dual-purpose sorghum is either sole cropped or intercropped with pigeonpea *(Cajanus cajan),* mung bean *(Vigna radiata),* groundnut or sunflower.

Private sector investment in sorghum and pearl millet research

Since 1985, public sector investment in agricultural research in India is growing at a slower rate compared to private sector investments in plant breeding research which has recently doubled between the period 1995 and 2002. During 1987-95 the private sector investments in R&D increased from Rs 55 million (US$1.2 million) to Rs 200 million (US$5.8 million) through increased number of private firms from 17 to 38. A medium-sized private seed company operating in five states with an annual sales turnover of Rs 150-200 million, spends 7-10% of it on R&D, while large seed companies limit their R&D expenditure to 3-5% of their annual sales turnover. Private research is growing more rapidly than public research, but the total R&D expenditures in the private sector still amounted to only 16% of the total funding of Indian agricultural research in 1998.

There are very few corporate players in the animal feed industry. The bulk of animal feed is produced by the small scale or cooperative sector units. Besides, many farmers prepare their own animal feed mixes. The share of the corporate sector in the animal feed industry is nearly 33% and is rising. The research arms of animal feed firms essentially test new ingredients, reducing anti-nutritional factors and test new additives provided by other firms.

The widespread use of hybrids in Asia is attracting private investments in breeding and seed production. According to the seed industry sources, at present private sector investments in India in product development and marketing of sorghum and pearl millet are Rs 280 million and Rs 219 million, respectively. This may be due to strong R&D of public sector spread across the country. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India is engaged in developing hybrid parental lines and private firms make use of them for development of hybrids. Thus, it appears that private sector in the past was not constrained to invest much on R & D in these two crops.

The market share of private sector sorghum hybrids is also steadily increasing due to lack of support of seed production to public sector notified hybrids. In Andhra Pradesh (sorghum) and Karnataka (pearl millet and sorghum) private sector hybrids have significantly contributed to the yield of these crops. In case of sorghum, in Karnataka both private and public sector HYVs have shown positive significant effect on yield while in case of pearl millet, private sector HYVs of Karnataka and public sector HYVs of Maharashtra have exerted a positive and significant influence on yield (Table 6).

In sorghum, seed quantities produced by private companies did not increase substantially and only increased from 6000 t in 1990-91 to 6050 t in 1998-99, but in terms of private hybrids as percentage of total hybrids, the increase was from 20% to 50%. In pearl millet due to reduction in seed supply of public sector hybrids, the market share of private companies increased

Table 6. Effect of private and public sector sorghum and pearl millet high-yielding varieties (HYVs) on yield in India during 1998[1].

Crop/state	Private HYVs	Public HYVs	Estimation technique
Sorghum			
Andhra Pradesh	0.0027* (1.92)	-0.09(1.54)	Random effect
Karnataka	0.0083** (2.34)	0.44** (2.99)	Random effect
Maharashtra	0.008(1.54)	0.23* (1.88)	Fixed effect
Pearl millet			
Andhra Pradesh	0.007 (0.27)	-0.84(1.1)	Fixed effect
Karnataka	0.01* (1.91)	0.02 (0.32)	Fixed effect
Maharashtra	-0.002(0.11)	0.39** (3.2)	Random effect

1. * = Estimates significant at 10% level; ** = Estimates significant at 5% level; figures in parentheses are respective t-values.

Source: Ramaswami et al. (1999).

from 50% to 63% during the same period. Such a situation could not be encountered in pearl millet where total seed supply remained same for the periods 1990-91 and 1998-99 with noticeable increase in private sector seed supply up to 63%. Private seed companies appeared more efficient in maintaining seed quality of their proprietary hybrids and supplying in time to the farmer in a cost-effective manner.

Relative economics of irrigated and dry sorghum and pearl millet

Besides China, India is the major sorghum and pearl millet growing country in Asia. Hence, economics of these crops have been dealt with only in the Indian context. Almost entire rainy season sorghum in India is rainfed, while scattered areas are irrigated in postrainy season. It is certain that most of the irrigated area accounted belongs to summer sorghum especially in certain belts of Maharashtra, Karnataka and Tamil Nadu. With area under rainy season sorghum being eroded, irrigated summer sorghum was envisaged to mitigate peak fodder shortages during summer in these regions. Summer sorghum is mainly an early hybrid producing clean grain for consumption as food and fodder primarily for farmers' own livestock; about 10-20% surplus fodder is sold in the market.

The economics of sorghum production in India was studied under three situations: (1) rainy season sorghum; (2) postrainy season sorghum; and

(3) irrigated summer sorghum. The economics of pearl millet production was examined only under dryland conditions due to lack of available related literature. In Maharashtra sorghum yields under irrigated situations were about five times as that of dryland yields (rainy and postrainy situations). The irrigated summer sorghum yielded substantially high net returns mainly due to high grain and fodder yields which usually fetch higher prices. In postrainy season sorghum, though the grain fetches high prices the yields are generally very low. Postrainy season sorghum is typified by the absence of high-yielding cultivars under moisture stress. The yield of rainfed postrainy season sorghum is half that of irrigated summer sorghum. Though the rainy season sorghum yields relatively higher output than postrainy season sorghum, its per unit grain price is quite low to make it competitive over its replacement crops.

In case of economics of pearl millet in Ahmednagar, Maharashtra, the net returns are positive (Rs 1720 ha^{-1}), with output-input ratio of 1.2:1 (Table 7), because of its cultivation in lands with better soil and water environments. In the states like Rajasthan usually net returns are negative when fixed costs are accounted. In the latter, output is quite low and prices are also not so remunerative. However, its cultivation is not discontinued because of lack of other crop alternatives. In Maharashtra, due to adoption of HYVs the yields are better. However, its area is declining with decline in consumption levels.

Table 7. Economics of sorghum and pearl millet production in Maharashtra, India.

	Sorghum			Pearl millet
Particulars	Rainy (2000/01)	Postrainy (2000/01)	Summer (2002/03)	(Rainy) (2000/01)
Crop yield (t ha^{-1})				
Main crop	1.93	1.06	2.61	1.18
Byproduct	3.76	3.30	5.50	2.47
Total cost (Rs ha^{1})	9720	8259	12198	7168
Cost of production (Rs t^{-1})	3669	6951	4659	6036
Price received (Rs t^{-1})				
Grain	4347	6700	5000	6003
Fodder	695	704	1000	711
Net returns (Rs ha^{1})	1313	1200	6392	1720
Output-input ratio	1.1	1.1	1.5	1.2

Future thrust: commercialization and potential new niches

As a consequence of commercialization of agriculture, not only in developed world but also in the developing world, the traditional subsistence crops like sorghum and pearl millet have also entered into commercial cultivation. In Asia, these crops are transforming from subsistence level to semi-subsistence and heading for commercial level of cultivation.

In India, various farm-level studies confirmed that the marketed surplus of sorghum could be up to 30% of total production of farms, which is mainly marketed through village-level non-regulated markets (Marsland and Parthasarathy Rao 1999). Commercialization can be promoted through maximization of grain/stalk yields, where the emphasis should be on productivity enhancement. The current low productivity levels render sorghum non-competitive with other crops both at farm level and at utilization level with presently used raw material in its alternative uses. Contract farming and promotion of industrial uses will enhance the demand. According to Kumar (1998), the average yield of coarse cereals in India should be improved by 16% by 2010 and 36% by 2020 in order to meet the domestic demand. For commercialization of these crops, potential niches need to be identified where these can be commercially exploited for income generation.

Forage sorghum

In areas with need for dual-purpose varieties the major researchable concern should focus to introduce such dual-purpose sorghum which can also be grown for quality green forage production elsewhere in other states of India to sustain their dairy industry and other livestock. Sweet stalk sorghum with high photosynthetic rate and biomass production potential may add to higher animal productivity.

Development of dwarf short-duration hybrids for rainy season

Demand for labor is very high during harvest of rainy season crops. Therefore, limited labor (family/hired labor) is deployed for harvest of high-value crops. Sorghum remains in the field for longer time even after maturity and is prone to grain mold as conditions become more favorable. Therefore, development of early-maturing dwarf genotypes which are amenable for combined harvesting are necessary to get clean grain when there is a peak demand for labor. The economy in harvest operation and mold-free, clean-grain harvest will ensure better food and market prices. Such early-maturing dwarf cultivars will also fit in intercropping systems based on low canopy crops such as soybean and groundnut which replaced sorghum in the past.

Sorghum production in rice fallows for market surplus

Introduction of sorghum in rice fallows, especially in non-conventional areas appears to be potentially promising. Planting of sorghum in late December to January ensures high fodder yield to meet the stover demand of these areas.

Red sorghum for feed and exports

To meet the feed demand in high rainfall regions, red grain sorghum (imparts rich yellowness to yolk of egg) may be targeted as potential raw material for poultry. The red grain types have good demand in many countries for feed. In Japan, sorghum is considered as a valued constituent in livestock feed rather than maize (imparts more yellow color to the meat) as consumers prefer white colored meat. Hence, Indian sorghums may be exploited for this purpose.

Industrial alternative uses

Animal feed

Sorghum grain is perceived to be utilized as a raw material in animal feed, especially poultry feed. At present in India about 1.5-1.7 million t of sorghum grain is being used for animal feed. Genetic enhancement in digestibility of grain will ensure better nutrition. The poultry feed industries will continue to be the major user of sorghum in the future (Fig. 8).

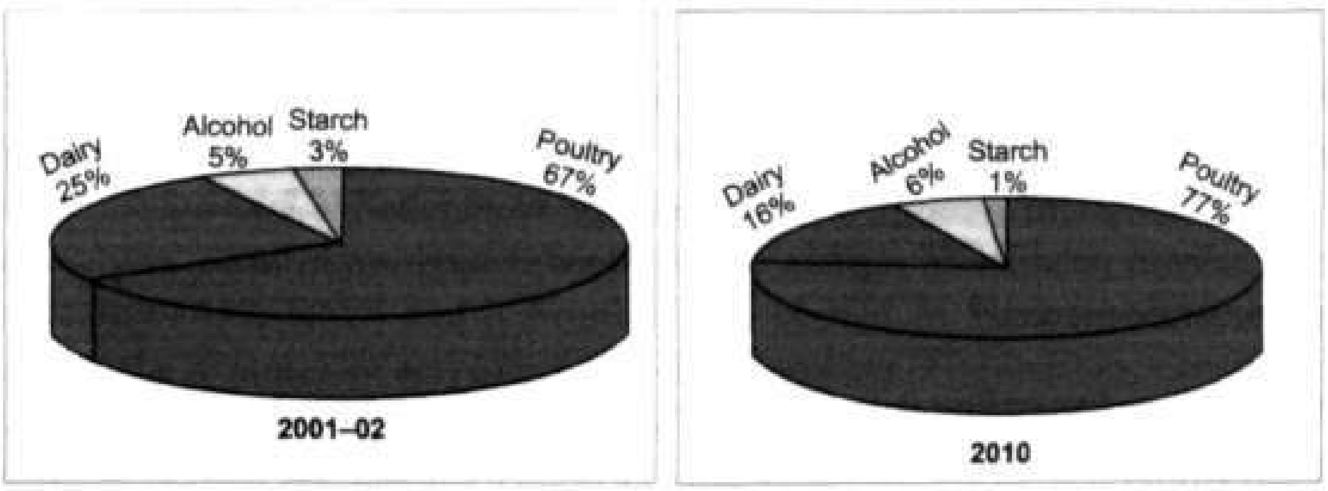

Figure 8. Relative contribution of alternate uses of sorghum in India.

Potable alcohol from grain

Another important potential niche could be utilization of sorghum grain for alcohol production. At least ten manufacturing units in India are already utilizing grain for the production of potable alcohol. With the implementation of Government of India's new policy to blend ethanol with petrol, initially up to 5% and increase up to 10%, huge demand is created for ethanol production. It is likely that sugarcane *(Saccharum officinarum)* molasses can be used as raw material for bio-fuel production, while sorghum grain may be used in potable alcohol sector owing to its better quality and gap created by diversion of molasses.

Sweet sorghum as bio-energy source

Sweet sorghum is an excellent source for bio-fuel production. The stalks which are rich in sugar can be used for ethanol production or jaggery production. Sweet sorghum is similar to grain sorghum in terms of wide adaptability. It can produce up to 5,000-7,000 L ethanol ha^{-1} which makes it highly attractive to supplement petroleum reserves. Sweet sorghum, with one-third water requirement of sugarcane, supplements later in the lean period and increases the capacity of utilization of the sugar plant. A techno-economic feasibility study undertaken by the National Research Centre for Sorghum (NRCS), Hyderabad with M/s Renuka Sugars Ltd, Belgaum, Karnataka, India indicated that the cost of production of ethanol from sweet sorghum stalks worked out to be Rs 13.11 L^{-1} in comparison with sugarcane molasses from Rs 9.25 L^{-1} (own molasses generated in sugar factory) to Rs 12.55 L^{-1} (from purchased molasses).

Malt

Another potential area could be the use of sorghum malt and as an adjunct in brewing industry. Malted sorghum is used for brewing beer in Ghana and Nigeria. Sorghum's comparative advantage would be its low output price, especially in production regions of rainy season sorghum in India over that of existing raw material.

Processing for other food uses

Apart from these industrial uses many traditional value-added products can be prepared from sorghum and millets owing to their nutritive value. These include diabetic foods with high fiber content (antioxidants) and in various bakery products like bun, bread, cakes, cookies and biscuits which should target the urban consumers.

Pearl millet feed and food products

More recently pearl millet is being used as a low-cost substitute for maize in poultry and dairy feed, which is gaining momentum. In addition, there are other niches for pearl millet:

- Due to its rich protein content, the grain can be used for preparation of protein-rich foods.
- The bran is rich in oil; hence it can complement rice bran in oil extraction.
- Pearl millet can also be used for brewing in those favorable areas with marketed surplus where the factories are located.
- The high fiber content in the grain can be exploited to prepare health foods. Diabetic food products can also be prepared.

Increasing the productivity through improved technologies and quality of product would result in reduced cost of production per unit or increased profitability per unit area. Due to this reduced cost, sorghum and pearl millet may be extensively used in value-added and industrial applications which may fetch high remuneration for poor farmers thus alleviating poverty. To hasten this process, aspects like marketing, contract farming and farmer-industry linkages should be strengthened that may result in a fair degree of commercialization. To minimize competition with preferred cereals, improvements in shelf life of flour and storability are essential features.

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Sorghum and Pearl Millet: Health Foods and Industrial Products in Developed Countries

JA Dahlberg[1], JP Wilson[2] and T Snyder[1]

Abstract

Sorghum and pearl millet are important staples to millions of people worldwide. The use of these cereals in the developed world has been primarily restricted to animal feed and little work has been done to evaluate them in industrial food systems. Recent work has suggested that these cereals possess unique characteristics that have both nutritional and functional properties that lend themselves to the development of healthy, nutritious foods. Both cereals are gluten-free, have unique phenolic compounds, which are being identified as having medicinal properties and contain proteins and starch characteristics that lend themselves to functional food uses that may impact health. In Africa and Asia, these cereals have been used in traditional food products, but now their use in industrial settings is being explored. Both developed and developing countries have similar problems in using these two crops for high-end food systems. These problems form the foundation that keeps the 'technology bridge' from collapsing as research is moved to market development. These foundations are stable, reliable sources of relatively inexpensive high quality grain and new market development in Africa and Asia. Without these basic requirements, development of new food markets for sorghum or pearl millet will be extremely difficult.

Sorghum *(Sorghum bicolor)* and pearl millet *(Pennisetum glaucum)* are the major cereal crops throughout the world. In 2002, 42.1 million ha of sorghum were harvested worldwide, with a total production of 55.3 million t. Africa, India and the United States are the largest producers of sorghum representing approximately 54.0%, 23.5% and 7.2%) of the total harvested area and 37.8%, 14.5% and 17.5% of the total world production, respectively. The average productivity of sorghum is approximately 3,181 kg ha^{-1} in the United States, while it is 920 and 808 kg ha^{-1} in Africa and India, respectively. Pearl millet is planted on 36.9 million ha worldwide with a total production of 25.8 million t. Africa represents 57.0% of the total world production while India accounts for 32.5%. Very little millet is grown for grain in the United States. Africa and India produce 83.0% of the millets consumed worldwide, while the United States produces only 0.3 million t (FAO 2003).

1. National Grain Sorghum Producers, PO Box 5309, Lubbock, Texas 79408, USA.
2. USDA-ARS, Coastal Plain Experiment Station, PO Box 748, Tifton, Georgia 31793, USA.

In most developed countries, both sorghum and millet, primarily pearl millet, have been used as animal feed. Pearl millet is grown primarily for forage in the United States, though it is beginning to be used as a component in poultry rations. Sorghum grain has traditionally been used in feed rations for beef and dairy cattle, poultry, pork and sheep, while sorghum forages are widely used in the beef and dairy industry. Sorghum grain can be pelleted, extruded, steam-flaked, rolled, cracked and fed whole (Doggett 1988, Smith and Frederiksen 2000).

Sorghum and millets provide an important component to the diets of many people in the world in the form of unleavened breads, boiled porridge or gruel, malted beverages, and specialty foods such as popped grain and beer. Syrup is made from sweet sorghum. Rooney and Waniska (2000] provide an excellent review of sorghum use in food and industrial utilization; however, these foods are primarily consumed in developing countries. Traditionally, sorghum has been used in unfermented and fermented breads, porridges, couscous, rice *(Oryza sativa)*-like products, snacks, and malted alcoholic and nonalcoholic beverages. In many cases, the same is true for millet. Andrews and Kumar (1992), FAO (1995) and Murty and Kumar (1995) provide excellent reviews of pearl millet uses in food systems, but again these are primarily uses found within developing countries.

Recently, interest in both sorghum and millet in high-end food products, especially in health food markets, has begun in regions of the world that have traditionally not used these grains in human food systems. Japan has taken the lead in developing snack-food products using sorghum, and interest in sorghum's 'gluten-free' properties has developed a demand for high quality food sorghums within the United States. The pros and cons of creating food markets for sorghum and millet primarily in the United States and also in other developed countries are discussed.

Grain characteristics of sorghum and pearl millet for use in food products

Sorghum and millets in the developed countries have been used for animal feed and therefore there has been little breeding work to develop these grains for high-value food uses. Genes have been incorporated in hybrids and lines that make use of light colored grain and glumes that reduce the amount of staining and increase quality of the grain enabling the development of acceptable food products. In 2003, approximately 8100 ha of food-grade sorghums were planted in the United States. Food-grade sorghums are defined as types having white grain with both tan plant and glume characteristics. The National Grain Sorghum Producers (NGSP), Texas, USA have developed a program to assist in the identity preservation of these grains.

Caryopses of pearl millet and sorghum consist of three anatomically distinct components, the pericarp, endosperm and germ. Though pearl millet tends to be approximately one-third the size of sorghum, the proportion of germ and bran tend to be greater (Table 1). Chemical and amino acid composition of both sorghum and pearl millet are outlined in Table 2.

Table 1. Caryopsis makeup of sorghum and pearl millet.

Description	Sorghum	Pearl millet
Endosperm (%)	84.2	75.0
Germ (%)	9.4	17.0
Pericarp (%)	6.5	8.0

Source: Andrews and Kumar (1992), Waniska and Rooney (2000).

Table 2. Chemical composition and essential amino acid composition of sorghum and pearl millet.

Composition	Sorghum	Pearl millet
Chemical composition (%)		
Protein	11.0	14.5
	(7.3-15.6)[1]	(8.6-19.4)
Fiber	2.7	2.0
	(1.2-6.6)	(1.4-7.3)
Lipid	3.2	5.1
	(0.5-5.2)	(1.5-6.8)
Ash	1.8	2.0
	(1.1-4.5)	(1.6-3.6)
Starch	70.8	71.6
	(55.6-75.2)	(63.1-78.5)
Essential amino acids (%)		
Lysine	2.2	3.0
Threonine	3.3	3.6
Valine	5.4	3.9
Methionine	1.4	2.3
Isoleucine	4.1	4.6
Leucine	14.7	9.6
Phenylalanine	5.0	5.5

1. Range values are given in parentheses.
Source: Andrews and Kumar (1992), Sema-Saldivar and Rooney (1995), Waniska and Rooney (2000).

Both grains develop in 'open' panicles and this environment is more favorable for fungi that produce low levels of regulated and non-regulated mycotoxins (for a greater review of mycotoxins, see CAST 2003). Both aflatoxin and fumonisin can be major issues in maize *(Zea mays),* but are typically not serious issues in either sorghum or in pearl millet (Table 3). Storage fungi can develop in grain that is improperly handled and storage practices are important in preventing the deterioration of grain quality.

Sorghum and pearl millet grains are small and this has been perceived as a problem for their use in food products within the United States. However, extensive research has shown that both cereals can be used in a wide range of processing technologies that lends itself to food products. Andrews and Kumar (1992) and Rooney and Waniska (2000) provide excellent reviews of the grain characteristics of sorghum and pearl millet and how they fit into processing technologies.

Because both cereals tend to be grown under marginal conditions and with little input, variability within the crops due to the environment leads to a wide range of quality of the grain. The definition of 'high grain quality' depends upon the characteristics considered to be desirable. In the African context, the subsistence crop, which provides food for the household can

Table 3. Results of assays for mycotoxins in pearl millet grain produced in the southeastern United States.

Mycotoxin	Maximum preharvest levels[1] (PPb)	Preharvest levels in crops grown side-by-side[2] (PPb)		Mycotoxin levels after high moisture storage[3] (PPb)	
		Maize	Millet	Initial	Final
Aflatoxin	290	0-564	0-21	290	1750
Fumonisin	240	0-80,000	0-250	0	0
Zearalenone	170			0	400
Deoxynivalenol	10			400	400
Nivalenol	420			400	400
Moniliformin	184	0	0-200	11	11
Beauvaricin	1044	0-118	0-1000	2190	2190

1. Data from 1990-93, 1996-98, 2000-01.
2. Evaluation conducted over 13 planting dates in 2000 and 2001.
3. Grain stored at approximately 22% moisture for 1 month. Common fungi in high moisture grain were *Aspergillus glaucus, A. candidus, A, niger* and *A. flaws.* Grain was stable for several months when treated with either propionic acid or ammonium propionate at 1 to 1.5%.

Source: Wilson et al. (1993,1995, 2000, 2002), DM Wilson, University of Georgia, College of Agricultural and Environmental Sciences, Tifton, Georgia, USA (personal communication).

differ from the cash crop sold to industrial processors. The small holder subsistence farmer often uses low-yielding 'traditional' varieties with preferred food and taste qualities. The grain is extremely hard and resists insects in storage, and can store well for years while maintaining seed viability. Storage problems are more common when farmers adopt higher yielding varieties that tend to have softer endosperms, which are more susceptible to insect and mold infestation (FAO 2002). Food-grade quality varieties that have hard, white, round grain would be suitable for industrial processing. The lack of a reliable, consistent supply of grain for commercial and industrial food uses has been the biggest obstacle to greater use of sorghum and millet in food systems.

Health factors in sorghum and pearl millet food products

Sorghum and pearl millet could find a significant niche in the nutritional foods market in developed countries. Unique health foods that have high levels of insoluble dietary fiber, phytates and phytochemicals could be made from sorghums with high levels of catechins, flavonoids, phytates and harder to digest proteins. Tannin sorghums contain high levels of antioxidants and may have anticancer properties (Chung et al. 1998). Phenols in some sorghums range from 4.1 to 20.9 mg g^{-1} (dry weight basis) while the condensed tannins (catechin equivalents) range from 0 to 36.8 mg g^{-1}. Converted to a dry weight basis, blueberries (*Vaccinium* spp) have 3.4 to 24.2 mg g^{-1} of phenols (Heinonen et al. 1998). Thus, the concentration of phenols in some sorghums is comparable to or higher than that of blueberries. Phenolic compounds, especially flavonoids, have been found to inhibit tumor development (Huang and Ferraro 1992). Some grain sorghums have been found to contain these useful compounds (Shahidi and Naczk 1992). Polyphenols and tannins are found in pearl millet; however, little work has been done in USA to evaluate them. Sripriya et al. (1996) reported phenolic contents of 51.4 and 43.1 mg $100g^{-1}$ dry weight of pearl millet and sorghum, respectively. Further research is needed, but given the values reported by these authors pearl millet would seem to have excellent levels of antioxidant compounds.

The phenolic compounds, flavonoids and tannins are concentrated in the pericarp and testa, which can be abrasively milled to produce ingredients providing health benefits. Dry milling using decortication separates the pericarp from the endosperm, which concentrates the phenols 4- to 7-fold in the bran fractions. Brans of several tannin-containing sorghums decorticated 10-15% had 140-180 mg catechin equivalents g^{-1} (tannin) and 53-72 gallic acid equivalents g^{-1} (phenolic compounds). White sorghum bran and wheat bran were less than 10% of these values (Awika 2000). LW Rooney and coworkers, Texas A & M University, Texas, USA have identified and analyzed gallic, protocatechuic, p-hydroxybenzoic, vanillic, caffeic, p-coumaric, ferulic and cinnamic acids in sorghum (Hahn et al. 1984). Eight other phenolic acids were unidentified.

Oxygen radical absorbance capacity (ORAC) of bran from the brown, tannin-containing sorghum was the highest [410 umol Trolox equivalents (TE) g^{-1}]. ORAC values of the brown and black sorghum brans were higher than those of blueberries (Tables 4 and 5). White sorghum and wheat *(Triticum aestivum)* bran had the lowest ORAC values due to their low levels of phenols.

Table 4. Levels of phenols and fiber in bran and other products (dry matter basis).

Bran/Component	Phenols (mg g^{-1})	Tannins (mg g^{-1})	Anthocyanins (abs g^{-1} ml^{-1})	ORAC[1] (umol TE g^{-1})	Dietary fiber (%)
Red wheat	3	-	-	31	48
White sorghum	4	-	-	27	41
Brown sorghum	107	175	31	401	45
Black sorghum	22	10	520	114	43
Blueberries	26	20	50	-	-
Berries[2]	1-22	-	-	63-282	-

1. ORAC = Oxygen radical absorbance capacity; TE = Trolox equivalents.
2. Source: Prior et al. (1998).

Table 5. Phenolic compounds and dietary fiber added to bread.

Bran[1]	Bran (g 56 g^{-1})	Phenols (mg $56g^{-1}$)	Tannins (mg $56g^{-1}$)	ORAC[2] (umol TE $56g^{-1}$)
Red wheat	5.4	14		149
White sorghum	5.4	18		123
Brown sorghum	5.4	504	828	1900
Black sorghum	5.4	106	47	539

1. Calculated from bran data; 15% bran $loaf^{-1}$ of bread.
2. ORAC = Oxygen radical absorbance capacity; TE = Trolox equivalents.

Positive correlations were observed between the ORAC values and tannins (r = 0.89) and phenols (r = 0.94) in the sorghum brans. The high levels of dietary fiber in these fractions could offer additional benefits. Dietary fiber levels in the bran fractions ranged between 36.1 and 42.9% on dry weight basis. Wheat bran had a dietary fiber value of 47.6%. Sorghum bran fractions have produced bread with excellent quality containing high levels of phenols with good antioxidant values.

Sorghum brans could be exploited as a source of phytonutrients in foods. Substituting 15% of each of the four brans for wheat flour resulted in breads with similar physical properties: specific volume of 4.2-4.6 $cm^3 g^{-1}$, similar loaf appearance (shape), compression force of 3.8-5.1 Newtons at 2 h, moisture of 39.6-40.0% and an additional 1.9-2.3 g dietary fiber per 56 g serving. These treatments were selected as the optimum levels for addition of the bran because of their higher dietary fiber and phenolic content while still maintaining desirable attributes. Adding 15% brown or black sorghum bran to bread yields brownish, dark-colored loaves, without the addition of caramel color, and adds significant levels of phenolic compounds and dietary fiber. Such breads have a rich flavor and dense texture like many commercially available specialty breads, including dark rye (*Secale cereale)* and pumpernickel breads, and could be marketed as nutraceutical products.

Nutraceuticals is the fastest growing segment of the food industry (Sloan 1999). The market is expected to remain strong and stable. Clearly, with the increasing demand for antioxidant rich foods and products, new sources are bound to play an important role in this market. Specialty sorghum brans are a promising source of these compounds, given their excellent coloring ability and antioxidant activity. The brown, tannin sorghums are undesirable for animal feeds and human foods where they reduce the nutritional value by 15 to 30% depending upon animal species and feeding and processing methods (Rooney and Pflugfelder 1986). Phytate and dietary fiber levels in sorghum pericarp are high as well; thus in addition to antioxidants, the sorghums could reduce caloric value of foods and add dietary fiber. Research conducted on pearl millet would also suggest that this grain would have similar properties as sorghum and could be further exploited in these new markets with additional research.

The starches in sorghum are released more slowly than those in other cereals (Klopfenstein and Hoseney 1995), and so it is considered beneficial to diabetics (more than 30% of Americans have diabetic related problems). Pearl millet has a very high α-amylase activity, about 10 times that of wheat. Maltose and D-ribose are the predominant sugars in the flour, while fructose and glucose levels are low (Oshodi et al. 1999). Foods with a low glycaemic index are useful to manage maturity-onset diabetes, by improving metabolic control of blood pressure and plasma low-density lipoprotein cholesterol levels due to the less pronounced insulin response (Asp 1996).

Hamaker et al. (1987) reported that sorghum proteins are significantly less digestible than other cereal proteins; however, this has the potential of being a health benefit for certain dietary groups. Protein quality is primarily a function of its amino acid composition. Grain proteins are classified according to their solubility characteristics: albumin (water soluble), globulin (soluble in dilute salt solution), prolamin (soluble in alcohol) and glutelin (extractable in dilute alkali or acid solutions). Albumin + globulin levels are higher in pearl millet than sorghum. Millet contains fewer cross-linked prolamins, which may be an additional factor contributing to higher digestibility of pearl millet proteins.

Gluten intolerant persons (celiacs) allergic to gliadin, a prolamin specific to wheat and some other common grains, comprise approximately 500,000 people in the United States or 1 in every 541 people (based on US Census Bureau resident population estimate, 1998). Sorghum and pearl millet are gluten-free; however, more information is required to demonstrate that they can be used in the diets of celiacs.

Celiac disease (CD) is a malabsorptive disorder, present in genetically predisposed individuals, that is the result of ingestion of gluten proteins in wheat, or related proteins from barley (Hordeum vulgare), rye, and possibly oats (Avena sativa) (Trier 1983, Marsh 1992, Feighery 1999). Exposure to these proteins in CD patients causes damage to the small intestine, thereby limiting the ability to absorb nutrients, ie, malabsorption. Symptoms of CD are variable in intensity and all symptoms are not present in all patients (Trier 1983, Marsh 1992, Maki and Collin 1997, Feighery 1999). Symptoms include, diarrhea, pale (often gray colored) stools, enlarged abdomen, physical wasting, anorexia, vomiting, anemia, loss of appetite, fatigue, infertility, anxiety, depression, osteoporosis and weakness. The prevalence has been estimated at ~ 1:5000 in USA; however, a number of researchers feel that this is too low and that many cases of CD go undiagnosed (Falchuk 1999). Some estimate rates as high as 1:200 (Feighery 1999).

CD is a reaction to gluten proteins (Kasarda 1981, Marsh 1992). Gluten is a complex mixture composed primarily of two classes of the wheat storage proteins, gliadins and glutenins (Kasarda 1981). Gliadins are generally recognized as the primary agent responsible for the developement of CD in genetically predisposed people (Cornell 1996). Most of the research into the toxic effects of gliadins has been done with a fraction of α-gliadins, called A-gliadin, either intact or digested into small peptides (Cornell 1996, Silano and De Vincenzi 1999). However, all classes of gliadins are reported as toxic (Cornell 1996, Silano and De Vincenzi 1999).

Proteins from rye, barley and oats produce toxic effects although oats are not as much of a problem (Kasarda 1981, Marsh 1992). Rice and maize proteins do not cause toxic effects in CD patients (Feighery 1999). Little work has been done on CD with either sorghum or pearl millet. Sorghum is more closely related to maize, which has not been reported to cause CD when consumed by celiacs. Because maize has been found to be non-toxic to CD patients, it is reasonable to expect that sorghum would also be safe. Prolamins from rice, maize, sorghum and millet did not cross react to monoclonal antibodies to A-gliadin from wheat, indicating structural dissimilarity (Ellis et al. 1998). Unfortunately, the specific type of millet was not indicated. Pearl millet is likely to be non-toxic; however, pennisetins, the class of prolamins in pearl millet, differ from the somewhat homologous prolamin zeins in maize and kafirins in sorghum (Marcellino et al. 2002). If sorghum and pearl millet were found to be safe for CD, they would represent new and somewhat novel food items that could be used for CD patients. More complete characterization of sorghum and pearl millet proteins and their functionality would provide useful information for marketing celiac foods.

Processing and food product technologies and shelf life

Extensive research information is available on the processing and product development of sorghum. Rooney and Waniska (2000) provide an excellent review of the current state of research on sorghum for use in food products. Their basic conclusion is that sorghum can be used in similar fashion, with slight modifications, as other grains in production of food products through processing technologies that are currently available. Research and technologies are not limiting factors in the production of these products. Andrews and Kumar (1992) also present a similar survey of the current technologies available for use in pearl millet. Research is somewhat limited on this cereal but it could be used in various food products with additional research. Because both grains would be typically used as a whole grain, there is potential for some shelf life problems, especially in pearl millet (because of its high proportion of germ which is rich in oils), though with proper processing, handling and storage these should be somewhat irrelevant issues.

Applications of current technologies to the production of high-value snacks made from sorghum are currently under way in Japan and several snack-food products are available in the market. Technology is not limiting use of either sorghum or pearl millet; it is the availability of a high quality, reliable supply of these grains that is the major limiting factor to use in food production systems.

Price structure and commercialization: The current sorghum market as a case study

Grain sorghum marketing fits no ordinary marketing model within the United States. Traditionally only 8 to 9% of the crop carries over to the next marketing year. There are two primary reasons for this low carryover. First, grain sorghum as a commodity moves in and out of feeding channels as a replacement for maize in most markets due to lower price. Second, the traditional market for grain sorghum is a replacement starch source market. Markets for starch include binders for making wallboard and for ethanol production. In the United States, one of the fastest growing areas of new utilization is in the production of ethanol, which now uses approximately 12% of the total sorghum grain production in the country.

Prices of sorghum in central USA and the Gulf Coast often equal or exceed maize pricing. In the major sorghum belt, large volume ethanol consumers and pet food manufacturers boost the grain sorghum price. In regions without access to either ethanol or other high volume starch consuming manufacturers, such as in the Texas Panhandle, grain sorghum prices fall many times to 30 or 40 cents below maize.

There are new value-added markets developing for grain sorghum exports. Japan and Mexico have raised the awareness that grain sorghum benefits from specific marketable traits. Mexico imports varieties preferably having high protein and starch, primarily for use in poultry production. Japan has begun to import high quality food-grade (white seeded, tan plant, tan glume) sorghum for its high protein content, color and flexibility of use in snack-food systems. These traits usually confer higher value to sorghum that typically bring in significantly greater market prices.

The challenge to new markets

Traditionally, sorghum has been viewed within the United States as simply a replacement for maize in both industrial utilization and feed. Those that have worked to move sorghum into new markets have been stymied by what can be termed as 'death valley' (Fig. 1). Fundamental research on unique uses of sorghum has taken place within the United States for several years (Rooney and Waniska 2000). But, the difficulty has been moving products from experimental consideration to actual market development. We have lacked the 'technology transfer bridge' to cross over our research findings into market opportunities (Fig. 1). The need is for the foundation of this ' bridge ' to be built so that products can move from development to production.

In many ways, these are the same hurdles that countries in the developing world face in introducing new food products to consumers: Is there a demand? Who will market it? Who will produce it? Is there a

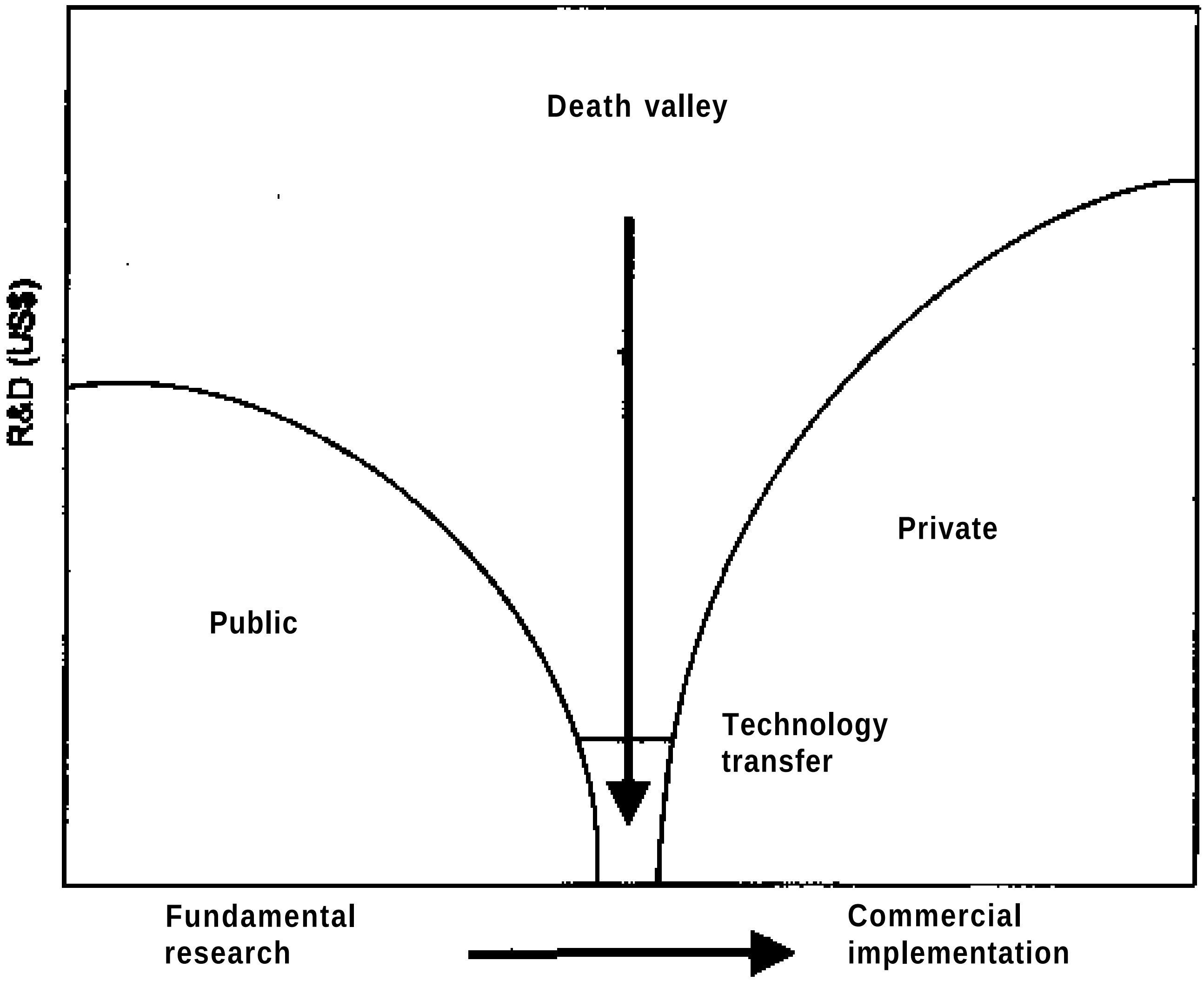

Figure 1. Technology bridge that fills the gap between basic research and commercialization (Source: Peter Johnsen, USDA-ARS-NCAUR, USA).

consistent supply of high-quality product? Another term that has been coined for such a dilemma is ' the chicken or the egg' syndrome. This has been one of the major stumbling blocks to get sorghum into the food market in the United States. In the sorghum example, the egg could be qualified as supply, while the chicken would be a new consumer product.

Dr Rooney may have been one of the first food researchers in sorghum in the United States to run into these issues when he tried getting private industry involved in food development using sorghum. He had developed the 'chicken', a food product, but only had a limited supply of the 'egg' in this case, a high quality food-grade sorghum needed by industry to develop the product. Without the two, the interest in a marketable product was effectively shelved. This has been the difficulty in trying to generate interest in food products made from sorghum.

New market development in pearl millet

In traditional regions, the area dedicated to pearl millet cultivation is decreasing, as is per capita consumption of the grain. Factors influencing these trends include the stigma of poverty associated with its consumption, time and energy required to prepare millet-based foods, inadequate infrastructure for storage, marketing, and transportation, poor processing techniques, competition with alternative crops and uses for land resources, and availability of low-cost, subsidized alternative products (FAO 1995, Pionetti 1997).

The reduction in acreage planted to millet is to be expected as diets are diversified. Given the economic and socio-cultural constraints, it would be naive to suggest that caloric and nutrient needs are being satisfied by current diets in many African countries, but the overall decreasing demand for pearl millet suggests that greater diversity is being introduced into diets. This phenomenon may reflect a developing trend for the role of pearl millet changing from a staple to a dietary component, which is desirable from the nutritional standpoint of a population.

Although traditional markets for the grain are slowly eroding, they will continue to play a key role in defining research and marketing plans for the foreseeable future. Convenience-formulations of traditional products should find significant markets in traditional areas. The size of this portion of the ethnic-food market in the United States will remain limited. Many of the traditional products such as porridges, fermented breads and opaque beers will have only limited penetration into US markets. Research into convenience formulations of traditional products should be balanced with new product development for non-traditional regions.

Expanding the total market share in traditional regions can be accomplished by substituting pearl millet for wheat in traditional wheat-based products. Pearl millet flour can substitute for up to 10 to 20% of wheat flour in ' whole-grain ' breads. The substitution rate is limited by the effects on product color and loaf density. Composite flours can be used but are usually not desired. If composite flours are produced, fats in the non-wheat component may reduce shelf life. Substitution strategies are a valid approach to temporarily support local economies by increasing market outlets for a locally-produced grain, but its value as a long-term strategy is questionable for well-established food products. As a marketing strategy for the United States, substitution of pearl millet for one of the more common commodity grains is unlikely to be successful, since product quality is often inferior to current standards and the practice does not contribute to supporting local economies.

To integrate pearl millet into the US market, new products will be required and research should focus on their development. Based upon popularity of specific foods in the United States, products that are likely to be successful might include pearl millet as a component of mixed whole-grain breads, crackers and pretzel-like snacks, or use as a rice alternative. Use in tortillas, dry and creamed cereals, and as a component in specialty beers would be a secondary consideration. Use of pearl millet in products should be highlighted, and an effort should be made to redefine its role from that of a staple crop in subsistence agriculture to that of a health item with superior nutritional qualities.

Adoption of pearl millet into US markets will require products that are formulated for convenience and taste. Because of the widespread practice of fortification, nutritional qualities and health benefits of the grain are an advantage from a marketing standpoint, but are less critical from a dietary standpoint. The novelty of the use of pearl millet will permit some entry into the health food market of the United States, but expanded use in the processed food industry will depend upon its flavor and/or functionality in formulations. Unless pearl millet represents a substantial component of the diet, its nutritional qualities are relevant not in contrast to, but in context with other dietary items.

Specific combinations with other products should be identified that make pearl millet a desirable ingredient in formulations or recipes. Its contribution to product flavor will most likely be a result of factors associated with its inherently high levels of lipids and/or proteins in combination with other ingredients. It will be important to determine the quality and stability of flavor when blended with other grains, meats, fruits and vegetables in convenience formulations. As has been demonstrated in the sorghum industry, product development is unlikely until food-grade pearl millet becomes readily and consistently available.

Future efforts

New food-grade sorghums and specialty sorghums are currently available in the US market and can be used for food and for the nutrition and health food specialty markets. Markets in north central USA currently sell grain sorghum-based products while making very significant health claims attributable to the benefits of whole grain sorghum. Keeping in line with these research efforts and the demand for attribute specific marketing, NGSP has undertaken the task of identifying and building new markets into the 'human consumption' food chain, specialty medical markets, pet food applications and expanded animal feed markets.

To further differentiate quality grain, the 'NGSP Certified Sorghum' program was developed to provide the infrastructure necessary to build confidence in grain sorghum as a 'non-GMO' (genetically modified organism), gluten-free, identity preserved food source for human consumption. It provides trait specific marketing for medicine and functional foods under our 'Specialty' label and will help facilitate new markets for internal use and export trade by providing a traceable source for grain sorghum under the 'Certified Sorghum Food' label. By building this program, NGSP believes it will reestablish the different varieties of grain sorghum into new and existing growth oriented marketing channels. The program does not certify seed. It does, however, provide approved varieties for delivery into approved marketing channels. This will allow the producer to sell his or her grain and have a reasonable expectation of gaining a profit in a new or expanded market.

The advent of the 'NGSP Certified Sorghum' program and the development of other value-added programs should ensure the confidence of the seed industry, marketers, manufacturers and consumers of grain sorghum.

We continue to work on solving the 'quantity' issue and work on reintroducing sorghum to those in the food market who will develop food products. With the quantity and quality issues being resolved, grain sorghum can be traded into markets where specific food quality sorghums are required. Now, an East African country can request 'food sorghums' and be assured of a specific set of quality characteristics and an adequate supply for delivery. This is how research and marketing grain sorghum has worked together to construct the 'technology bridge' that spans the gap between research and market development.

In Africa and Asia, similar issues hinder the development of profitable sorghum and pearl millet products. Food processors in Africa and Asia face problems of limited production of reliable, high quality sorghum or pearl millet that are critical to the development of new food markets. Then how will Africa and Asia build the necessary foundation to ensure the 'technology bridge' does not collapse and prevent the development of other markets?

A serious issue in Africa is that many countries lack a diversified market that would help stabilize the market and provide a consistent and stable grain price. Without the development of alternative markets, such as a feed market, the price of sorghum and pearl millet will continually be affected by wild price fluctuations that will hinder the ability of a food company to produce a product that is viable in the market. Creation of new markets other than for human consumption will provide avenues for selling the commodities in times when quality is an issue, and will help to stabilize pricing. Development of these markets will require storage and transportation infrastructure that ensures ready supplies of grain. Without these basic requirements, development of these new food markets for sorghum or pearl millet will be extremely difficult.

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Recent Technologies in Pearl Millet and Sorghum Processing and Food Product Development

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Abstract

Pearl millet and sorghum are highly valuable in semi-arid regions because of their short growing season and higher productivity under heat and drought conditions. Both pearl millet and sorghum grains are nutritionally comparable and even superior to major cereals with respect to protein, energy, vitamins and minerals. They are also a rich source of dietary fiber, phytochemicals and micronutrients.

In spite of huge production, consumption of sorghum and pearl millet is restricted to the poorer section of population. Utilization of pearl millet and sorghum can be increased by various processing treatments including blanching, malting, dry heating, acid treatment, popping, etc. All these treatments decrease the level of antinutrients, improve digestibility and increase shelf life. Pearl millet and sorghum can be utilized for development of various food products. These include traditional products (porridges, flat breads, chips, bhakri, suhali, khichri, dalia, shakkerpara, *etc), baked products, extruded products, health products, weaning and supplementary foods. Products developed from processed flour have longer shelf life and higher starch and protein digestibility than products prepared from unprocessed flour. Utilization of pearl millet and sorghum for novel product development will help in diversifying their use which will be beneficial for human health and increase profits to farmers. However, there is a need to popularize the new products developed from sorghum and pearl millet.*

Millets are highly valuable small-seeded crop species indigenous to many areas of the world. They can grow under low soil fertility, low moisture and hot environmental conditions. They are valuable in the semi-arid regions because of their short growing season and high productivity under heat and drought conditions.

Millet grains are nutritionally comparable and even superior to major cereals with respect to protein, energy, vitamins and minerals. Besides they are a rich source of dietary fiber, phytochemicals and micronutrients and hence, they are rightly termed as 'nutri-cereals'. However, the utilization of

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millets for food is still mostly confined to the traditional consumers and population of lower socioeconomic strata, partly due to the non-availability of these grains in ready-to-use or ready-to-eat forms (Malleshi and Desikachar 1985).

Sorghum (*Sorghum bicolor)* and pearl millet *(Pennisetum glaucutn)* have a place of prominence because of their widespread cultivation in different parts of the globe and large-scale food uses and feed value. Other millets grown in India are finger millet *(Eleusine coracana),* foxtail millet *(Setaria italica),* kodo millet *(Paspalum scrobiculatum),* proso millet (*Panicum miliaceum),* little millet *(Panicum miliare)* and barnyard millet *(Echinochloa frumentacea).*

Both sorghum and pearl millet are important cereals in the diet of many people in Africa and India. Sorghum ranked fifth with 69.1 million t total production in 1996. Pearl millet is one of the most popular crops in India and during 1999 its production was 8.1 million t (FAO 2000).

Structure and physical properties

Pearl millet grain is a caryopsis and the pericarp is completely fused to the seed. The kernel is composed of pericarp, endosperm and germ, which comprises 8.4, 75.1 and 16.5% of total kernel weight, respectively (Abdelrahman et al. 1984). Pearl millet has one to two layers thick epicarp, a mesocarp that varies in thickness due to genetic factors and an endocarp layer that contains cross and tube cells.

Pearl millet varieties from the world collection have more variation in physical characteristics than any other millet (McDonough and Rooney 1985). Kernel color ranges from white, gray, yellow, green to black. Kernel shape has five major classes: obovate, hexagonal, lanceolate, globular and elliptical.

The sorghum kernel is a naked caryopsis and consists of three main anatomical parts: pericarp (outer layer), endosperm (storage tissue) and germ (embryo), which generally account for 6, 84 and 10% of the seed mass, respectively. Sorghum is the only cereal grain known to have starch in the mesocarp layer of pericarp. The endosperm, composed of aleurone layer, peripheral, corneous and floury areas is the main storage tissue. The 1000-seed mass of pearl millet varieties ranged from 6.75 to 8.76 g whereas that of sorghum varieties ranged from 19.0 to 28.5 g (Sehgal et al. 2002).

Nutrient composition of pearl millet and sorghum

The nutrient composition of grains is affected by both environment and genetics and varies widely among species.

Pearl millet

In pearl millet the percentage of crude protein ranges from 7.02 to 13.67, fat from 4.0 to 7.8, crude fiber from 0.5 to 4.0 and ash content from 0.25 to 2.54 as reported in various analytical studies (Table 1). Pearl millet grain bran, which represents about 8% of grain is rich in non-protein nitrogen; non-protein nitrogen ranges from 39.02 to 73.0 mg $100g^{-1}$ and true protein content from 9.9 to 12.2% (Aggarwal 1992).

The total quantity of proteins and their amino acid composition is important for better nutritional quality. The amino acid profile of pearl millet is better than that of sorghum and maize *(Zea mays)* and is comparable to

Table 1. Proximate composition (g 100 g^{-1}) of pearl millet grains.

Moisture	Protein	Fat	Ash	Fiber	Reference
-	10.6	-	-	-	Andrews (1990)
-	10.5-11.1	4.0-6.3	1.5-1.8	0.8-1.2	Saxena et al. (1992)
-	10.4	6.0	1.6	-	Aggarwal(1992)
-	-	-	-	1.5	Navita and Sumathi (1992)
-	9.4	6.5	2.0	-	Kumar and Chauhan (1993)
10.7	15.4	5.2	1.7	-	Almeida-Dominguez et al. (1993b)
-	12.7	4.3	1.5	-	Hadimani and Malleshi (1993)
10.3	17.9	6.7	1.8	-	Serna-Saldivar et al. (1994)
-	-	6.1-7.5	-	-	Dalvi (1995)
-	8.1-13.9	3.4-7.4	1.1-2.4	-	Hadimani et al. (1995)
-	12.3	5.3	2.4	-	Bashay(1996)
7.4 - 8.4	8.7-10.8	6.0-6.4	-	-	Elkhalifa and Singh (1996)
11.30-11.49	11.3-13.2	7.2-7.8	1.9-2.1	1.64-1.99	Archana(1997)
11.26-11.37	12.8-13.1	6.2-7.4	1.9-2.1	1.74-1.95	Rekha(1997)
-	8.5-15.1	2.7-7.1	1.6-2.4	2.6-4.0	Abdalla et al. (1998)
-	16.9	5.1	1.5	1.6	Malleshi and Klopfenstein (1998)
-	-	6.2	-	-	Banger etal. (1999)
-	11.4	-	-	-	Oshodi et al. (1999)
7.13	12.2	4.5	0.25	0.54	Akubor and Obiegbuna (1999)
8.1-9.26	10.9-13.3	5.8-7.1	1.4-2.0	0.8-1.1	Malik (1999)
8.78	10.36	7.63	2.03	1.26	Poonam (2002)
10.12-13.30	8.83-13.67	4.42-6.90	1.74-2.54	1.30-2.50	Sehgal et al. (2002)

wheat (*Triticum aestivum),* barley *(Hordeum vulgare)* and rice (*Oryza sativa)* (Ejeta et al. 1987, Hadimani et al. 1995, Abdalla et al. 1998). The endosperm protein fraction of pearl millet contains low level of lysine (1.4 g $100g^{-1}$ protein) whereas the germ contains 5.16 g $100g^{-1}$ protein. The amino acid composition of protein is also influenced by relative amount of specific protein class present in total protein. It was found that prolamines and glutelins account for about 60% of total protein. Albumin and globulin on an average account for 15 and 9% protein, respectively. The albumin and globulin have been found to be rich in basic amino acids, ie, lysine, arginine, histidine, cystine and methionine. The prolamines of pearl millet are high in glutamic acid, proline and leucine.

Carbohydrate in pearl millet is comparable with other cereals. Total carbohydrate ranges from 59.8 to 77.3% (Sawhney and Naik 1969, Rekha 1997). Soluble carbohydrate in pearl millet ranges from 1.40 to 2.78%. About 63% of soluble carbohydrate is sucrose and 29% is raffinose. Other carbohydrates include stachyose, glucose and fructose. Total sugar in pearl millet ranges from 2.55 to 2.93%, non-reducing sugar from 2.15 to 2.57% and reducing sugar from 0.34 to 0.39% (Rekha 1997, Poonam 2002).

Starch is the major component in pearl millet and constitutes about 56-65% of total carbohydrate. Wide variation in the starch content (53.0 to 70.3%) among different varieties was also recorded by Hadimani et al. (1995). Raghuwanshi et al. (1999) reported amylose content in the range of 28.8 to 31.9%.

The mineral content in pearl millet is higher than other cereals. Sodium, magnesium and copper in pearl millet are reported to be at par with wheat whereas potassium, phosphorus and iron are higher than in wheat. Calcium content in pearl millet varieties ranges from 10.0 to 80.0 mg $100g^{-1}$ and phosphorus from 185 to 990 mg $100g^{-1}$ grain. Iron content in pearl millet as reported in various studies varies from 3.0 to 18.0 mg $100g^{-1}$ (Table 2).

Antinutritional factors

Pearl millet has high nutrient content but the bioavailability is low due to the presence of certain antinutritional factors. Phytate is a naturally occurring organic compound found in seeds (seed coat and germ), roots and tuber (Mahgoub and Elhag 1998). It forms insoluble or nearly soluble compounds with mineral elements including calcium, iron, magnesium and zinc. Most of the phosphorus in cereals is reported to be present in the form of phytic acid which is not available to human system. Phytates interact with protein

Table 2. **Mineral composition (mg $100g^{-1}$) of pearl millet grains.**

Phosphorus	Calcium	Iron	Zinc	Copper	Manganese	Reference
185.0-363.0	13.0-52.0	4.0-5.83	1.0-6.6	0.6-21.2	0.2-1.8	Jambunathan and Subramanian (1988)
302	51.4	16.3	2.67	1.21	1.53	Alpana(1989)
-	50.0	18.0	2.7			Khetarpaul and Chauhan (1991)
290	54.8	11.8	4.09			Aggarwal(1992)
272-326	27-46	-	-	-	-	Saxenaetal.(1992)
-	51.4	16.3	2.67			Kumar and Chauhan (1993)
300.5	-	3.00	-	-	-	Hadimani and Malleshi (1993)
355	79.0	-	—			Serna-Saldivar et al. (1994)
349.0-376.7	45.7-50.0	8.9-9.7	2.7-2.9	1.11-1.23	1.16-1.20	Archana (1997)
364.0-385.6	44.5-49.7	8.9-9.4	2.7-2.8	1.16-1.23	1.16-1.23	Rekha(1997)
450.0-990.0	10.0-60.0	7.0-18.0	5.3-7.0	1.0-1.8	1.8-2.3	Abdallaetal. (1998)
-	19.9-22.5	8.3-9.9	2.8-3.2	0.9-1.0		Malik (1999)
348.40	39.60	8.16	2.85	0.99	1.20	Poonam (2002)

reducing their availability. Phytic acid inhibits the activity of protease, α-amylase and trypsin and thus reduces starch utilization. Phytate content in different pearl millet varieties as reported by various workers ranges from 354 to 857 mg $100g^{-1}$ (Aggarwal 1992, Kumar and Chauhan 1993, Rekha 1997, Abdalla et al. 1998, Malik 1999, Poonam 2002). The phytate level in plant material is found to decrease during certain food processing operations such as milling, germination, fermentation and heat treatment (Kadlag et al. 1995, Chaturvedi and Sarojini 1996, Mahgoub and Elhag 1998).

Polyphenols occur mostly in pericarp of seed. Polyphenols are major antinutritional factors because they inhibit activities of several hydrolytic enzymes such as trypsin, chymotrypsin, amylases, cellulases and β-galactosidase (Singh 1984) and also form tannin protein complexes, thus limiting protein and starch utilization (Thompson and Yoon 1984, Pawar and Parlikar 1990). Phenols also reduce availability of minerals and vitamins (Singh and Nainawatee 1999). Various workers reported wide variation in concentration of polyphenol in pearl millet which ranged from 285 to 790 mg $100g^{-1}$ (Khetarpaul and Chauhan 1991, Aggarwal 1992, Chaudhary 1993, Rekha 1997, Malik 1999, Poonam 2002).

In vitro digestibility

Pearl millet has been found to have low protein and starch digestibility which is attributed to the presence of antinutritional factors in grain. Protein and starch digestibility is inhibited by polyphenol and phytic acid insoluble complexes with amylase and α-glucosidase are formed by polyphenols, and protein mineral complexes are formed by phytic acid.

Protein digestibility in pearl millet varieties ranges from 54.2 to 59.2% (Alpana 1989, Kumar and Chauhan 1993). Different studies on pearl millet have shown that protein digestibility ranges from 49.9 to 61.9% (Rekha 1997), 57.9 to 60.4% (Malik 1999) and 55.73% (Poonam 2002).

Starch digestibility of pearl millet has been reported to range from 12 to 18.7 mg maltose released per g and was found to be negatively correlated with phytic acid content (Aggarwal 1992, Archana 1997, Poonam 2002).

Sorghum

Starch is a major grain component in sorghum followed by protein. Most of the sorghum starch contains 70-80% branched amylopectin and 20-30% amylose. Waxy or glutinous sorghum varieties contain starch that is 100% amylopectin.

Chemical composition of sorghum grain was studied by Bach Knudsen and Munck (1985), Rooney et al. 1986 and Torres-Cepeda et al. (1996) (Table 3). In sorghum grain, approximately 80% of the protein is in the endosperm, 16% in the germ and 13% in the pericarp (Taylor and Schussler 1986). Kafirin, an alcohol soluble protein, comprises 50% or more of the protein. Kafirin is rich in proline, aspartic acid and glutamic acid and contains little lysine.

Sorghum contains high levels of insoluble fiber with low levels of (3-glucans. Most of the crude fiber is present in the pericarp and endosperm cell walls. The fiber is composed mainly of cellulose, hemicellulose and small quantities of lignin. Some of the high tannin sorghums have higher levels of dietary fiber because of complexes between sorghum tannins and proteins (Bach Knudsen and Munck 1985).

Constraints to utilization of pearl millet and sorghum

In spite of greater availability, low cost and comparatively good nutritional value, use of pearl millet and sorghum in food industry is very little. Pearl millet has remained a food for economically weaker sections (Desikachar 1975) because of some constraints that limit its acceptability. The major constraints are gray color and poor shelf life of the flour. Sorghum has fibrous seed coat, colored pigment and characteristic astringent flavor.

Table 3. Typical composition of sorghum grain[1].

Constituent	Mean	Range	Number of samples
Proximate analyses			
Protein (%)	11.6	8.1-16.8	1463
Ether extract (%)	3.4	1.4-6.2	1462
Crude fiber (%)	2.7	0.4-7.3	1383
Ash (%)	2.2	1.2-7.1	1436
Nitrogen-free extract (%)	79.5	65.3-81.0	1372
Fiber (%)			
Dietary insoluble	7.2	6.5-7.9	2
Dietary soluble	1.1	1.0-1.2	2
Acid detergent	3.3	2.9-3.6	2
Protein fractionation			
Prolamine (%)	52.7	39.3-72.9	5
Glutelins (%)	34.4	23.5-45.0	5
Albumins (%)	5.7	1.6-9.2	5
Globulins (%)	7.1	1.9-10.3	5
Essential amino acids (g $100g^{-1}$ protein)			
Lysine	2.1	1.6-2.6	640
Leucine	14.2	10.2-15.4	582
Phenylalanine	5.1	3.8-5.5	582
Valine	5.4	0-5.8	582
Tryptophan	1.0	0.7-1.3	92
Methionine	1.0	0.8-2.0	582
Threonine	3.3	2.4-3.7	582
Histidine	2.1	1.7-2.3	582
Isoleucine	4.1	2.9-4.8	582

1. All values are expressed on dry matter basis.

Source: Bach Knudsen and Munck (1985), Rooney et al. (1986).

Rapid development of rancidity and bitterness in the flour has been a major problem in the acceptability and utilization of pearl millet flour (Kaced et al. 1984). Pearl millet grain can be stored for longer periods without substantial quality alteration if the kernels remain intact (Kaced et al. 1984, Kachare and Chavan 1992). However, once the grain is decorticated and ground the quality of flour deteriorates rapidly (Varriano-Marston and Hoseney 1983, Reddy et al. 1986). Both hydrolytic and oxidative changes are reported in the lipids of the meal (Lai and Varriano-Marston 1980, Varriano-Marston and Hoseney 1983) resulting in release of free fatty acid and formation of peroxides.

Chauhan et al. (1986) suggested that the degree of unsaturation in pearl millet lipids is one of the main factors responsible for development of rancidity in pearl millet flour. Odor developed during the storage of pearl millet flour is probably due to high fat content, high unsaturated fatty acids, non-occurrence of natural antioxidants and high enzymatic hydrolytic activities (Hoseney et al. 1981, Kaced et al. 1984, Reddy et al. 1986). Water soluble phenolic and peroxidase activity, concentrated mostly in germ fraction of grain appeared to be responsible for odor generation in stored pearl millet (Banger et al. 1999).

Another major constraint for utilization of pearl millet is gray to yellow green color of pearl millet flour which is not preferred by many consumers (Panwal and Pawar 1989). Presence of gray, brown or greenish pigments in pearl millet limits its use in bakery products (Naikare et al. 1986). Removal of pigments enhances its acceptability (Panwal and Pawar 1989). The removal of bran containing pigments to obtain white flour is the major objective in pearl millet processing (Naikare et al. 1986). Phenolic pigments are easily removed by acidic solution and high temperature during extraction process (Miean and Mohamed 2001).

Processing of grain

Various processing treatments like milling, decortication, germination, malting, blanching, fermentation and popping improve the nutritional quality as well as the consumer acceptability of pearl millet and sorghum. Enhancement of nutritive value and shelf life of pearl millet flour depends upon the grain processing techniques.

Pearl millet

Milling

Millets are normally decorticated and ground with mortar and pestle prior to use. Most millets can be decorticated in rice mills or other modified mills. Millets are also decorticated using abrasive disks in mechanical dehullers and ground into flour in hammer mills. Pearl millet with thick pericarp is more easily decorticated than those with thin pericarp. Pearl millet has a tendency to become rancid after being ground into flour. An effective milling operation should be able to remove most of the germ to increase shelf life of the flour.

Starch yield from pearl millet after wet milling is reported to be significantly lower than that obtained from maize or sorghum. Decortication has been found to reduce the fat, fiber, ash, calcium, iron, lysine and methionine content, but it improves the digestibility of nutrients.

Bookwalter et al. (1987) also reported that both processed (heated at 97°C for 2 min) and unprocessed millet were milled to 50% and 80% extraction flours. The 80% extraction flour contained germ fractions, which resulted in much higher protein, lipid, thiamine, riboflavin, niacin, iron, zinc, available lysine and protein efficiency ratio than 50% extraction flour. The decorticated grains contain fewer phenolic acids than whole kernels. In vitro protein digestibility could be increased by 69.1% after dehulling the grain (Ramchandra et al. 1978).

Ground millet storage stability is improved by dry milling processes that remove the major lipid containing portions of grain (ie, the germ and covering layer) from the endosperm (Bookwalter et al. 1987). Decortication of raw grains significantly increases apparent protein and dry matter digestibility. However, decortication resulted in loss of protein, insoluble dietary fiber, fat, ash, lysine and other amino acids (Serna-Saldivar et al. 1994). Debranning reduces the phytic acid, amylase inhibitors and polyphenols and thus increases the digestibility (Sharma and Kapoor 1996, Malleshi and Klopfenstein 1998).

Malting

Malting helps to improve the availability of nutrients, sensory attributes and extends the shelf life. Sorghum and millet malts find use as a cereal base for low dietary bulk and calorie-dense weaning food, supplementary foods, health foods and also amylase-rich foods.

Malting of pearl millet grain is described by Chaturvedi and Sarojini (1996), Rekha (1997) and Archana (1997). For malting, pearl millet grains are soaked in 0.1% formaldehyde solution for six hours. After that aeration is done for three hours and grains are again steeped in fresh formaldehyde solution for 16 hours. The grains are germinated for 12, 24, 36, 48 and 72 hours, dried in oven and vegetative growth is removed by abrasive action. Malting improves the germination of grains in such a way as to degrade or modify the endosperm with minimal loss in grain weight. It also helps in mobilization of seed reserves and elaboration of the activity of a- and β-amylase, lipids and protease. The process results in higher protein efficiency ratio and bioavailability of minerals (Rao 1987).

Malting of grains results in improvement of total protein, fat, ash, certain amino acids, total sugars and B group vitamins. Malting causes significant dry matter loss in grain and it is attributed to the metabolic activity and separation of vegetative growth (Chaturvedi and Sarojini 1996). Opoku et al. (1981) analyzed the pearl millet malt and reported a reduction of 57, 66, 21, 10, 82 and 17% in moisture, lipid, ash, carbohydrate, phytic acid and total calcium, respectively and also significant increase in protein, lignin, fiber, soluble calcium and all vitamins (Table 4).

After malting, pearl millet starch is more susceptible to amylolysis than foxtail millet starch. The grain is malted, mixed with legume flour and offered as porridge to infants. The malt enzyme decreases the viscosity of foods and improves the palatability of products for children. Pearl millet combined with cowpea *(Vigna unguiculata)* produces acceptable weaning foods (Almeida-Dominguez et al. 1993b).

About 97% increase in the in vitro starch digestibility, 17% in protein digestibility and 71 % in total sugar is obtained by steeping pearl millet in water for 16 h followed by germination for 72 h (Chaturvedi and Sarojini 1996).

Malting helps to decrease the starch, protein, crude fiber, fat and polyphenol content and increases soluble protein, free amino acids and reducing sugars (Pawar and Pawar 1997). Malting produces high amount of

Table 4. Proximate analysis of pearl millet grain and malt.

Constituent	Grain	Malt
Moisture (%)	10.2	4.3
Protein (%)	8.6	11.8
Lipid (%)	7.5	2.5
Ash(%)	4.1	3.2
Lignin (%)	1.3	4.4
Fiber (%)	10.4	18.6
Carbohydrate (%)	53.9	48.5
Tannin (%)	1.6	0.83
Total phenol (%)	0.32	0.485
Total oxalate (%)	0.619	0.433
Soluble oxalate (%)	0.502	0.068
Phytic acid (%)	0.264	0.045
Total calcium (mg $100g^{-1}$)	20.4	16.8
Soluble calcium (mg $100g^{-1}$)	2.4	14.12

Source: Opoku et al. (1981).

reducing sugars and high amylase activity (Nirmala et al. 2000). Malting for 72 h has been observed to decrease the polyphenol content by 40.9% and phytic acid from 52.8% and increase the protein digestibility by 26.9% and starch digestibility by 112.7% (Archana et al. 2000).

Blanching

Blanching aids in increasing the shelf life of pearl millet. Blanching has been observed to be effective in retarding enzymatic activity and thus improves the shelf life of pearl millet flour without much alteration in the nutrient content (Chavan and Kachare 1994). Blanching is usually done by steeping the grains in boiling water (at 98°C) (1:5 ratio of seeds to boiling water) for 30 sec and drying at 50°C for one hour.

Blanching of seeds at 98°C for 10 sec in boiling water before milling effectively retarded the development of fat acidity in flour and enhanced shelf life by 25 days (Kadlag et al. 1995) (Table 5). Fat acidity increased by about 6-fold in untreated pearl millet flour whereas it remained almost unchanged in

Table 5. Effect of hot water blanching of seeds on changes in lipids of pearl millet during storage.

Treatment	0[1]	5	10	15	20	30
Fat acidity (mg KOH $100g^{-1}$ meal)						
Unblanched (control)	13.7	60.6	108.0	147.4	201.3	267.6
Blanched at 98± 2°C						
10 sec	8.7	9.5	31.3	32.5	4.4	71.8
20 sec	10.6	11.7	30.3	33.2	45.6	80.2
Free fatty acid (%)						
Unblanched (control)	0.8	4.8	6.5	8.7	11.7	16.8
Blanched at 98±2°C						
10 sec	0.6	2.1	2.1	2.7	3.1	4.1
20 sec	0.7	3.1	2.2	2.4	3.6	4.6
Peroxide value (meq kg^{-1} oil)						
Unblanched (control)	1.7	0.4	6.0	3.7	2.7	2.1
Blanched at 98±2°C						
10 sec	7.1	3.0	4.9	4.8	3.1	2.3
20 sec	5.9	4.9	3.8	3.6	2.8	2.6

1. Storage period in days.
Source: Kadlag et al. (1995).

flour obtained from grains blanched in boiling water (98°C for 30 sec) (Chavan and Kachare 1994). Blanching of pearl millet seeds also reduced polyphenol by 28% and phytic acid content by 38% (Table 6). Fat acidity has been found to reduce significantly in blanched pearl millet flour as compared to raw flour after 28 days of storage (Rekha 1997).

Acid treatment

Gray color of pearl millet and its products is the main reason for non-preference by consumers. Pigments in pearl millet make the products bitter. The pigments glyceosylvitexin, glycoxyl orientation and alkali-labile ferulic acid are responsible for natural gray color of peripheral endosperm and are highly sensitive to change in pH.

Acid treatment helps to reduce the gray color and thus improves acceptability of the product. Various studies have reported that soaking of pearl millet in acidic solutions like sour milk and tamarind *(Tamarindus indica),* markedly reduces the color of the grain. The acidic solution penetrates the whole grain through areas around the embryo. Dehulled grains decolorize faster than whole grains because the acidic solution penetrates the grain faster (Reichert and Youngs 1979).

Dilute hydrochloric acid (HC1) was a more effective chemical treatment in removing pigments from whole grain before milling as compared to citric acid and acetic acid (Naikare et al. 1986). Soaking grains in dilute HCl for 15 to 24 h reduces a major portion of these pigments and thus helps in the production of creamy white grains.

Acid soaking of pearl millet grain (0.2 N HC1) for 6, 12, 18 and 24 h is effective in reducing the polyphenol and phytic acid (Table 7). Acid treatment for 6 and 24 h increases the in vitro protein digestibility by 29.0 and 59.3%,

Table 6. Effect of malting and blanching on polyphenols and phytic acid content of pearl millet (mg $100g^{-1}$ dry matter).

Treatment	Polyphenols	Phytic acid
Control	755.04+1.44	858.72±2.22
Malting (48 h)	449.35±0.41 (-40.49)[1]	481.42±1.41 (-43.94)
Malting (72 h)	420.53±0.40 (-44.30)	429.5011.75 (-49.98)
Blanching	529.85±0.047 (-29.82)	565.58+1.16 (-34.14)
CD at 5%	2.40	4.96

1. Figures in parentheses indicate percentage over control.

Source: Rekha (1997).

Table 7. Effect of acid on the antinutrient content of pearl millet (mg 100g^{-1} dry matter)[1].

Treatment	Phytic acid	Polyphenol
Control	710.15	687.26
Acid treatment		
6 h	411.16 (42.10)	450.33 (34.47)
12 h	286.20 (59.70)	294.93 (57.09)
18 h	234.30(67.01)	203.70 (70.36)
24 h	182.50(74.30)	153.06(77.73)
P<0.05	2.01	1.38

1. Data is mean ± SE of three independent determinations. Figures in parentheses indicate percentage over control.

respectively and the in vitro starch digestibility by 39.7 and 84.6%, respectively (Table 8) (Pawar and Parlikar 1990, Poonam 2002). Soaking of grain in 0.1 N has been shown to improve the grain color of various varieties of pearl millet (Reichert and Youngs 1979).

Fat acidity was found to increase by 1.5-fold in acid soaked grain flour during storage as against 6-fold increase in untreated and dry heated grain flour (Chavan and Kachare 1994).

Dry heat treatment

Lipase activity is the major cause of spoilage of pearl millet meal, so its inactivation before milling is essential. The application of dry heat to meal effectively retards the lipase activity and minimizes lipid decomposition

Table 8. Effect of acid on the in vitro digestibility of pearl millet[1].

Treatment	In vitro protein digestibility (g 100g^{-1})	In vitro starch digestibility (mg maltose released g^{-1})
Control	55.73	14.03
Acid treatment		
6 h	71.93(29.07)	19.60(39.70)
12 h	80.40 (44.27)	22.00 (56.80)
18 h	86.73 (55.62)	24.66 (75.77)
24 h	88.80 (59.34)	25.90 (84.60)
P<0.05	2.04	0.62

1. Data is mean ± SE of three independent determinations on dry matter basis. Figures in parentheses indicate percentage over control.

Source: Poonam (2002).

during storage. Pearl millet seeds were given dry heat treatment in hot air oven at 100±2°C for different time periods, ie, 30, 60, 90 and 120 min and then cooled to room temperature. Increase in fat acidity and free fatty acids in the meal obtained from heated pearl millet grains was 3- to 4-fold lower than the meal from unheated grain. Heating of grains for 120 min was most effective for maximum retardation of the lipolytic decomposition of lipids during storage (Kadlag et al. 1995). Fat acidity, free fatty acid and lipase activity was reported to decrease significantly during 28 days of storage in pearl millet flour given acid (18 h) and heat (120 min) treatment (Table 9). Also heat treatment increased the shelf life of pearl millet flour as compared to raw flour (Poonam 2002).

Popping

Popped grain is a crunchy, porous and precooked product. Popping improves taste and flavor and leads to the development of pleasing texture. Popped

Table 9. Changes in fat acidity, free fatty acids and lipase activity of acid and heat treated pearl millet flour during storage[1].

Treatment	0[2]	7	14	21	28	CD at 5%
Fat acidity (mg KOH $100g^{-1}$)						
Control	30.30	42.40	58.10	87.30	123.70	3.36
Acid treatment	35.10	35.00	36.20	38.60	38.00	1.82
Heat treatment	28.00	30.90	34.40	41.20	50.50	1.27
CD at 5%	2.56	2.17	1.26	3.65	2.56	
Free fatty acids (mg $100g^{-1}$ fat)						
Control	282.00	427.30	789.00	942.00	1115.00	4.32
Acid treatment	208.00	210.30	216.00	221.00	230.30	4.27
Heat treatment	67.00	70.00	75.00	80.00	84.00	5.68
CD at 5%	3.82	3.94	5.99	6.82	5.20	
Lipase activity[3]						
Control	3.69	5.60	10.34	12.35	14.61	0.06
Acid treatment	2.90	2.93	3.01	3.08	3.21	0.06
Heat treatment	0.89	0.93	1.00	1.06	1.12	0.08
CD at 5%	0.05	0.05	0.08	0.09	0.07	

1. Data is mean ± SE of three independent determinations.
2. Storage period in days.
3. Enzyme activity (%) on fat (%) basis.

Source: Poonam (2002).

grain/product formulation has very low moisture, which helps in minimizing deterioration during storage and thus increases the shelf life of products.

Popping can be done using common salt as heating medium in an open iron pan (grain to salt in the ratio of 1:10) at 240 to 260°C for 1 5-25 seconds. Salt can be removed by sieving. Popped starch exhibited higher in vitro enzyme digestibility. More than 50% of popped pearl millet starch was reported to be hydrolyzed by pancreatic amylase within 120 minutes (Murlikrishna et al. 1986).

Popping in different varieties of pearl millet varies from 52.3 to 79.2%. Maximum popping percentage was found in HHB-60 and minimum in HHB-68 (Sehgal et al. 2003).

Sorghum

Milling

Most traditional foods in Asian and African countries are produced from decorticated sorghum which is milled into flour. Highly refined sorghum products are produced by abrasive removal of pericarp followed by 'degermination' and physical separation and/or classification of dry milled fraction. Industrial sorghum decortication involves the use of mills with abrasive disks or carborundum stones. Mechanical dehulling improves both the quantity and quality of sorghum grits or flour (Munck 1995).

Decortication of sorghum reduces the amount of fiber, minerals, proteins and lysine. It resulted in 40% loss of lysine in manual sorghum decortication (yield = 75-80%) and 14% loss in mechanical sorghum decortication (yield = 90%). Nutrient digestibility of decorticated sorghum is slightly higher than that of whole grain, but nitrogen retention and protein efficiency ratios are considerably lower in decorticated grain because the germ fraction with the highest amount of lysine is partially lost.

Decortication of brown sorghum significantly reduces the amount of condensed tannins and can overcome the deleterious effect of tannins on the nutritional value of sorghum grain (Mwasaru et al. 1988). The decortication process reduced the tannin content from 4.5 to 0.2 catechin equivalent in the kernel in which 37% of its original weight was removed (Chibber et al. 1980).

Dehulling improves the sensory qualities of *roti* (flat, unleavened bread) made with sorghum flour and also minimizes varietal differences with respect to grain hardness, without affecting the rolling and kneading qualities of *roti* (Vimala et al. 1996). For making a good quality sorghum flour, a 60-mesh sieve could be used for sieving the sorghum flour milled by either traditional *chakki* mill or hammer mill (Table 10) (Naikare 2002).

A small-scale unit for dehulling and milling sorghum was developed by rural industries innovation center in Botswana. The machine allows progressive abrasion of outer layer of grains throughout the length of the barrel (Mmapatsi et al. 1994).

Malting

Sorghum malt is produced by traditional process and on an industrial basis in Africa (Daiber and Taylor 1995) and India. Diastatic activity developed during malting depends on temperature, moisture content, duration of malting, germination level and types of grain used. Sorghum malt is high in α-amylase and low in β-amylase for use in brewing lager beer. Losses during malting are about 20%. Traditional and industrial sorghum malting involves the following steps: (1) steeping (1-3 days); (2) germination (2-6 days); (3) sun drying; and (4) grinding with mortar and pestle.

Naikare (2002) has described standard malting procedure for the popular sorghum variety M 35-1. Malting of sorghum increases protein content, fat, fiber, minerals, in vitro protein digestibility (IVPD) and in vitro

Table 10. Overall nutritional composition of sorghum flour obtained by traditional *chakki* and hammer mill[1].

Constituent[2]	Traditional *chakki*	Hammer mill
Moisture (%)	7.2	8.0
Protein (%)	9.8	10.2
Fat (%)	1.9	2.3
Total carbohydrates (%)	79.8	77.9
Starch (%)	76.7	74.3
Soluble sugars (%)	1.5	1.8
Ash (minerals) (%)	1.3	1.6
Crude fiber (%)	1.6	1.8
IVSD (mg maltose g^{-1} meal per 5 min)	73.0	75.0
IVPD (mg maltose g^{-1} meal per 5 min)	82.0	84.0

1. Data is mean of three determinations.
2. IVSD = In vitro starch digestibility; IVPD = In vitro protein digestibility.

starch digestibility (IVSD). The malting process of grain sorghum has improved the overall physico-chemical and nutritional values of resultant flour (Table 11).

Germination reduces effect on viscosity of cereals. Flour behavior indices of sorghum approached unity with increased germination time. Appreciable α-amlase activity was obtained 48 h after germination.

Parboiling

A good quality parboiled sorghum could be processed by soaking the grains for 24 h in hot water, draining, steaming for 10 min in pressure cooker (15 lbs psi), drying and finally grinding into flour or grits. Such produce was opaque, had low calorie content and remained in good condition in vacuumized pack (Naikare 2002). The yield of parboiled grits *(suji)* was 80-82%, while that of fine flour was 18-20% when resultant meal was sieved through 40-mesh sieve, and no bran was obtained. No microbial spoilage or a physical damage was observed up to 6 months when packed in polypropylene flexible bags after vacuumization and stored under ambient conditions. The parboiled grains can be used for various snack food items especially for diabetic patients. The fine flour of parboiled sorghum can be used in gruel preparation.

Table 11. Chemical composition of malted flour from three sorghum cultivars[1].

	M 35-1		Swati		CSH 5	
Constituent[2]	Unmalted	Malted	Unmalted	Malted	Unmalted	Malted
Moisture (%)	5.1	5.2	5.4	5.1	5.0	5.4
Protein (%)	9.6	9.9	9.4	9.7	9.0	9.5
Fat (%)	1.7	1.2	1.6	1.0	1.3	1.0
Carbohydrate (%)	82.4	82.2	82.3	82.2	83.3	82.4
Fiber (%)	1.4	1.6	1.6	1.8	1.8	1.9
Minerals (%)	1.2	1.5	1.3	1.6	1.4	1.7
IVPD (mg maltose g^{-1} meal per 5 min)	73	77	72	75	70	74
IVSD (mg maltose g^{-1} meal per 5 min)	84	87	80	84	80	82

1. Data is mean of three determinations.
2. IVPD = In vitro protein digestibility; IVSD = In vitro starch digestibility.

Source: Naikare (2002).

Popping

The grain puffing/popping process is based on the principle of heat shock treatment, which causes expansion of the grains with porous and crunchy texture and roasted flavor. At this time the grain has about 17% moisture content. The grains are soaked in brine water for about 1-2 h prior to roasting. The grains are roasted along with fine sand in an iron skillet at about 200-230°C for about 5-7 min. The grains are puffed quickly with crackling sound. Sorghum pops can be made available in the market by vacuum packaging/ nitrogen flushing (Naikare 2002). Characteristics of popped grain of four sorghum cultivars are presented in Table 12.

Utilization of pearl millet and sorghum in food products

In India pearl millet and sorghum are used in preparation of conventional foods such as porridge, *roti* or *bhakhri* (stiff *roti),* made from either coarsely or finely ground flour. But the major constraint is that the flour becomes rancid within a few days after milling. To overcome this problem, the grains of pearl millet and sorghum are subjected to processing treatments like blanching, malting, popping and dry heat treatment before product development, which produces a flour with longer shelf life and better nutritional profile. The products prepared from processed flour were found to have longer shelf life than those prepared from unprocessed flour.

Table 12. Characteristics of popped grain of four sorghum cultivars.

Characteristics	M 35-1	Local	CSH 15	Swati	SE	CD at 5%
Popping (%)	80.0	88.5	73.5	78.0	1.0	3.0
Expansion volume (pop:grain)	3.5:1	4:1	3:1	3.4:1		
Flake size	Big, full	Big, full	Small, full	Big, full		
Color of popped grains	White	White	White	White		
Organoleptic quality characteristics						
Color	White	White	White	White		
Flavor	Good	Good	Good	Good		
Taste/crispiness	Good	Good	Good	Good		
Overall acceptability	Good	Good	Good	Good		

Source: Naikare (2002).

Pearl millet products

In Africa pearl millet is consumed, primarily in the form of thick and thin porridges (fermented or unfermented), flat breads (fermented or unfermented), steamed or boiled cooked products, snacks, alcoholic beverages, and in composite flours for bread, cookies, noodles, etc.

Traditional products

Porridges. Porridges are made in both Asia and Africa using various methods. In some preparations, the flour may be soaked overnight with sour milk or fermented briefly, before cooking. In Africa porridge is prepared by steeping the whole grain for 2 or 3 days in water before it is crushed and the bran removed. As a result, seeds germinate with the resultant changes in endosperm and germ. Germination and fermentation have been shown to improve the nutritive value through improved protein quality and digestibility and increased vitamin content (Serna-Saldivar et al. 1990).

Flat breads. In many countries in Asia and Africa, pearl millet flour is used for making flat, rounded, unleavened bread. This is baked on flat iron over hot fire. For making fermented breads, the flour is first mixed with water and a starter and allowed to ferment for 12 to 24 h, and then cooked at high temperature or in clay oven.

In Nigeria, pearl millet is dry milled into flour and mixed with wheat flour for production of bread. *Chapati* prepared from pearl millet flour enriched with soybean (*Glycine max)* flour produced high protein efficiency ratio with minimal thickness and increased puffing and uniformity of color and texture. *Chapati* prepared with bleached pearl millet has better acceptability. Overall acceptability score of *chapati* prepared with acid-treated pearl millet flour and heat-treated pearl millet flour increased significantly as compared to that prepared from raw flour (Poonam 2002).

Other products. Attempts have been made by many workers to incorporate processed pearl millet flour in other traditional products to improve the nutritive value and shelf life of products and also to reduce the cost of products.

Rekha (1997) incorporated blanched and malted pearl millet flour in various traditional products and the products were found to be organoleptically acceptable. An earlier study by Chaudhary (1993) also indicated that traditional products prepared from pearl millet were not only acceptable, but their protein and starch digestibilities were also better.

The products developed using blanched and malted pearl millet flour were highly acceptable and had longer shelf life up to 3 months. Use of processed flour in comparison to raw flour has been found to reduce the antinutrients and increase the digestibility (Singh 2003).

Baked products

Attempts have been made by various researchers to increase the consumption of pearl millet flour by incorporating it in various baked products. Millet flour itself is not a good raw material for baking industry, since it does not contain gluten and forms dough of poor consistency (Haber et al. 1980). Cookies made from pearl millet flour do not spread during baking; these have a poor top grain character and are also dense and compact (Badi and Hoseney 1976). However, if the millet flour is hydrated with water and dried and supplemented with 0.6% unrefined soylecithin, the spreading characteristics of cookies are similar to those of soft wheat flour.

Pearl millet biscuit had better amino acid composition. Therefore, biscuit prepared from combined pearl millet and chickpea *(Cicer arietinum)* had better true digestibility and net protein utilization as compared to that prepared from finger millet and chickpea (Geervani et al. 1996).

Various types of biscuits and cakes were developed using blanched pearl millet flour and all were organoleptically acceptable (Sehgal et al. 2002). Different types of biscuits and *nankhatai* were developed by incorporating different levels of blanched as well as malted pearl millet flour. All the products were in the range of slight to moderate acceptability and the products stored well up to three months.

Extruded products

Noodles, macaronies and pasta can be prepared from millet flour (Desikachar 1975). Extruded snacks prepared with millet flour mixed with either rice flour and/or maize flour and/or cassava *(Manihot esculenta)* starch in various proportions have acceptable appearance, color, texture and flavor (Siwawij and Trangwacharakul 1995). Porridge prepared from extruded pearl millet after blending with press-dried cowpea produces high nutritional quality with intermediate consistency, smooth texture, pleasant color and flavor (Almeida-Dominguez et al. 1993a).

Inclusion of extruded pearl millet and sorghum (60% each) with roasted mung bean *(Vigna radiata)* (30%) and non-fat dried milk (10%) increased the dietary fiber content up to 7.6 to 10.1%. Extrusion cooking also enhanced the in vitro protein digestibility of foods. Extruded products have been prepared from blanched pearl millet flour in combination with soybean flour or mung bean flour or chickpea flour. The developed pasta was not only acceptable but also had high protein and fiber content (Sehgal et al. 2003).

Supplementary and weaning foods

Germination and malting increase the food value of cereal grains and addition of legume flour and vitamins can produce a balanced weaning food (Malleshi and Desikachar 1986). Weaning mixtures prepared with 45% precooked pearl millet flour, skimmed milk powder, groundnut *(Arachis hypogaea)* oil and sucrose have high nutritive value and an efficient diet for the treatment of protein energy malnutrition (Guiro et al. 1987).

Pearl millet-based baby food prepared from 70% flour, 13% malt and 17% milk powder increased digestibility and lowered the viscosity of the foods and provided adequate protein and energy level for one-year-old children (Badi et al. 1990). Extrusion of baby food prepared from 70% pearl millet and 30% cowpea supplied 1 7% of the daily needs of protein, 72% lysine and 110% of threonine in two-year-old children (Almeida-Dominguez et al. 1990).

Four types of supplement mixtures using whole wheat or pearl millet, chickpea or mung bean, groundnut, amaranth (*Amaranthus* sp) leaves and jaggery (40:10:10:10:40) were developed using roasting and malting techniques and all the products were organoleptically acceptable (Dahiya and Kapoor 1994).

Homemade weaning food produced from pearl millet combined with mung bean, amaranthus and jaggery was comparable to nutritive value of Cerelac, a commercial weaning food in India. The protein efficiency ratio ranged from 2.04 to 2.13, biological value from 79.6 to 80.7, net protein utilization from 66.8 to 67.9, net protein retention from 2.13 to 2.76 and protein retention efficiency from 34.1 to 44.2 (Gupta and Sehgal 1992).

Six weaning mixtures having pearl millet (raw/malted/blanched), cowpea or mung bean, skim milk powder, sugar and ghee (clarified butter) in the ratio 45:25:25:15:5 had high organoleptic acceptability and stored well up to one month. Weaning mixture prepared from processed flour was more acceptable in terms of all sensory attributes and had increased shelf life (Archana 1997).

Health foods

Various types of health foods can be prepared from pearl millet as it contains relatively higher proportion of unavailable carbohydrates and the release of sugar is slow, making it suitable for diabetic persons. Six recipes of commonly consumed foods (pearl millet, sorghum, finger millet, mung bean) were tested in western India for their glycemic index (GI). Recipe based on pearl millet was found to have lowest GI (55) as compared to other recipes. This suggests that presence of high phytin phosphorus content of pearl millet influences the glycemic response (Mani et al. 1993).

Pearl millet, fenugreek *(Trigonella foenum-graecum)* seeds and legumes were used after processing to formulate three nutritious diabetic Indian food products - *dhokla, upma* and *laddu;* of these *upma* had lowest GI (17.60), followed by *laddu* (23.52) and *dhokla* (34.96) (Pathak et al. 2000). Other products were developed for diabetic persons after incorporating bleached pearl millet, fenugreek and chickpea in different proportions. Results showed that minimum GI was observed in pearl millet-based *dhokla* (38) followed by *chapati* (48), instant *idli* (52), pasta (54) and biscuit (58). The products had high fiber content as compared to control and could be used for diabetics (Archana 2002).

Sorghum

In India, sorghum is traditionally used for food products like *roti, bhakri,* porridge, *khicheri,* popped grain and roasted grain.

Traditional foods

Porridge. Sorghum is used extensively for making porridge. Couscous is made from sorghum and millet in West Africa (Galiba et al. 1987, 1988). It is made by agglomerating flour with water, steaming the covered flour, mixing and sizing the partially cooked flour and adding mucilaginous material during final steaming. Sometimes couscous is dried and used as convenience food.

Flat bread. Parboiling has been used to produce good products from sorghum and millet (Young et al. 1990, Serna-Saldivar et al. 1994). The cooked product has excellent texture and color. *Roti* made from sorghum has been shown to be organoleptically acceptable.

Bhakri. Sorghum flour has been successfully used for *bhakri* preparation and lot of research is being conducted for increasing the shelf life. *Bhakri* prepared from M 35-1 sorghum flour with addition of phosphatide starch (5%) or guar (*Cyamopsis tetragonoloba)* gum (3%) using standard method, then packed in low density polyethylene pouch (150 guage) or polypropylene pouch or laminated pouch, hermetically sealed after vacuumization and stored under ambient condition remained in the acceptable condition for about two days without any sign of spoilage or staleness (Naikare 2002).

Flakes. Good quality sorghum flakes can be prepared by boiling or autoclaving grains for 30 min, then flaking and drying up to 5.0-6.0% moisture content. The flakes exhibited excellent taste and crispiness. The finished products stored well up to 75 days in vacuumized package without spoilage and breakage (Naikare 2002).

Chips. Acceptable tortilla chips can be produced from blends containing 50% sorghum and 50% maize (Serna-Saldivar et al. 1988). Flour from white sorghum can replace up to 20% of wheat flour for the production of tortillas (Torres et al. 1993).

Papad. Sorghum can be effectively utilized for *papad* making. A good quality *papad* from malted sorghum can be prepared by addition of 40%) malted finger millet, which improves the nutritional value and quality of sorghum *papad* (Naikare 2002). Vacuum packaging significantly extended the shelf life.

Baked products

Sorghum flour does not contain proteins that produce viscoelastic gluten as in wheat. Sorghum and wheat flour blends have been used to produce baked products including yeast leavened breads, cakes, muffins, cookies and biscuits (Morad et al. 1983, Torres et al. 1993, Suhendro 1998). Usually 5-50% sorghum flour is substituted for wheat flour.

Sorghum flour at 15% produces acceptable breads without affecting the loaf volume, crust color and crumb texture (Iwuoha et al. 1997, Rao and Rao 1997). Sorghum and wheat composite flour in the proportion 50:50 produced organoleptically acceptable biscuit (Orewa and Iloh 1989, Priyolkar 1989).

Blends of wheat, sorghum and soy flour at 65:30:5 have been used to make bread, and at 40:55:5 to make biscuits. Replacement of wheat up to 20% with sorghum flour is acceptable for bread while further substitution up to 55% by sorghum flour gave acceptable biscuit. Blend of 70%) sorghum flour and 30% detoxified cassava starch produced acceptable bread and cakes (Olatunji et al. 1989). Sorghum flour was added to wheat flour for preparation of bread and biscuit; bread prepared with 5% sorghum and 30 ppm cystine gave acceptable bread by straight dough method. Also, high quality biscuit was prepared by addition of 20% sorghum flour and cystine (60 ppm $100g^{-1}$ flour).

Pasta

Sorghum with soft texture, yellow endosperm with white pericarp and without pigmented testa produce the best pasta products. Noodles from 100% sorghum flour were not equal in quality to rice noodles but they were edible and could be cooked without losing their texture (Lekalake 1993, Kunetz 1997).

Health foods

High fiber contents are very important for reducing gastro-intestinal problem of diabetics. Sorghum is rich in fiber as well as mineral content and incorporation of sorghum in various products increases the fiber content and decreases sugar level. Consumption of whole sorghum recipes resulted in lower glucose level, lesser peak rise in glucose and lesser area under curve in diabetics, compared to dehulled sorghum and wheat recipes (Lukshmi and Vimala 1996). Various types of cookies and biscuits were prepared for diabetic diets using malted and unmalted sorghum flour. Cookies prepared from 40% wheat flour blended with 60% malted sorghum flour increased fiber content and calories whereas biscuits prepared from 40% refined flour blended with 60% malted sorghum flour and 8% bran were superior in terms of cooking quality. The products remained acceptable without any sign of spoilage or development of off-flavor or rancidity for about 3 months after packaging in vacuumized low density polyethylene (LDPE) pack (Naikare 2002).

Conclusion and recommendations

All millet-based food products generally have strong flavor and aroma. These products have more nutritional value and health benefits as compared to similar products developed from major cereals. Moreover these value-added products are not available in the market. The cost of millet-based value-added products is about 50% less than that of traditional products. But the health benefits are more and cannot be quantified.

The technology of acceptable millet-based products can be taken up by housewives at household level as the raw ingredients are already available in their homes. The consumption of these products will improve the nutritional status and provide many health benefits.

Efforts can be made to popularize millet-based low-cost high protein and energy rich products among population through ongoing nutritional intervention programs. Development and consumption of such value-added food claiming health benefits could go a long way in improving the nutritional status of the population especially those suffering from protein malnutrition and other deficiency diseases.

The preparation and production of such products at home and commercial level would initiate the production units on small scale in rural and urban areas to raise the income level of housewives. The manufacture of millet-based value-added products will help to upgrade not only the health status but also the economic status of growers.

Industrial linkages for development and commercialization of these food products will secure market for millet especially pearl millet and sorghum. The developed value-added, baked, supplementary and health foods in spite of being inexpensive, acceptable and nutritionally superior are not taken up by industries for commercialization as people are not aware about the production technology and health benefits. There is a need to create awareness about the technical know-how of the processing and product development. There is scope for commercialization of various products from health and cost point of view.

Future strategies

- There is a need to popularize the developed and standardized millet-based products to common masses for adoption of technology at household level.
- Some simple processing techniques for sorghum and pearl millet can be taken up at household level/commercial level.
- Blanching of pearl millet grain before milling at commercial level needs to be taken up by milling industries as it will help in increasing the shelf life of the flour. Also, milling industries can take up the sale of pearl millet flour.
- To resolve the problem of gray color of pearl millet flour, bleaching process using HC1 or other organic acid could be initiated at small scale.
- Industrial linkage needs to be strengthened for uptake of developed products for commercialization. Efforts are required to popularize and commercialize health food including diabetic food and weaning food based on millet.

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Dynamics of Utilization, Markets, Trade and Coalitions: Sorghum and Millets in Asia

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Abstract

Production and consumption patterns of sorghum and millet in Asia have changed significantly in the last decade. While food use is declining, non-food or industrial uses are on the increase. This has implications on crop production and marketing with the entry of private industry in coarse cereal economies. This paper highlights the recent trends in the production, consumption and trade of sorghum and millet and spells out the need for a stronger coalition of sector stakeholders as a way of developing the non-food market by effectively linking farmers with new sources of demand for these crops.

Production and consumption patterns of sorghum (*Sorghum bicolor)* and millet have changed significantly in Asia in the last decade and this has important implications for cereal improvement programs, particularly those seeking to support the livelihoods of rural households. Notably, an increasing shift from food to non-food uses has made private industry a much more important player in coarse cereal economies. In this paper, recent trends in the production, consumption and trade of sorghum and millets are reviewed. The implications for institutional changes associated with the way public research programs might constructively interact with private companies, farmers and intermediary organization such as non-governmental organization (NGO) and farmer-operated enterprises such as associations and cooperatives are discussed.

The dilemma embodied by these developments is that not only there are clear social benefits to be derived for a crop that is primarily grown by small farmers in marginal production environments but also there is a need to ensure a smooth transition from food to markets for other uses. A coalition approach might be a useful way to strengthen links between scientists, industry and farmers so as to negotiate and generate technical and institutional innovations that will fulfill the agendas of all stakeholders. This is discussed in the final section of this paper.

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Evolving sorghum and millet economies: an overview

In 2002, Asia produced 22% of the world's sorghum and 39% of the world's millet[2]. Of approximately 987 million t of cereals produced in Asia in 2002, sorghum and millet account for 11.7 and 12.6 million t, respectively. Sorghum and millets are primarily grown in low rainfall and drought-prone areas that are unsuitable for growing other crops unless irrigation is available. Production is characterized by semi-extensive system under low input conditions. In contrast, in developed countries intensive commercialized production systems exist with yields averaging 3-5 t ha[1]; the grain is used and traded mainly for livestock feed.

Both sorghum and millet contribute to household food security in some of the most insecure regions of Asia. However, during the last two decades, several factors are contributing to a change in the traditional role of these crops as food security crops. Firstly, on the supply side the area planted to these crops is declining, due to slow productivity growth compared to competing crops and low/declining producer price. On the demand side, food use particularly for sorghum has declined due to income growth, urbanization and change in tastes and preferences, further lowering the prices. But utilization patterns in Asia are in a dynamic phase. Sorghum and to lesser extent millet grain are moving from their traditional use as a food crop to alternative uses such as livestock and poultry feed, bakery products [blended with wheat (*Triticum aestivum*)], potable alcohol and starch industry. In non-traditional uses, price competition from competing crops like maize *(Zea mays)* is an important determinant of demand for sorghum and millet. The straw/stover of these crops, however, continues to be valued as an important source of feed for livestock particularly in areas where other fodder sources are limited or year round fodder supplies are not available.

Sorghum and millet research needs to be placed in the context of current and future market forces that would have a bearing on the future prospects of these crops in various uses. In several niche areas where only sorghum and millet can be grown, they will continue to play an important role as a food security crop. But even here productivity increases can translate into higher incomes for the marginal and small farmers.

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2. The Food and Agriculture Organization of the United Nations (FAO) does not publish separate data for pearl millet. For this analysis, area and production for all millets are reported. For the major millet-growing countries in Asia, pearl millet accounts for 10% of total millet production. Pearl millet accounts for 90% of millet production in Bangladesh, 58% in India, 85% in Mynamar and 90% in Pakistan (ICRISAT and FAO 1996).

In the sections that follow, the changes in the production, consumption trade and marketing patterns for sorghum and millets in Asia with particular reference to India are discussed.

Area and production

Asia accounts for 11.8 million t of sorghum (triennium ending 2002), with an average yield of one t ha^{-1}, except China where yields averaged 3.5 t ha^{-1}, comparable to yields in developed countries. India is a major producer accounting for 68% of total production in Asia followed by China. Sorghum area and production declined in major producing countries in Asia, and thus all Asia level (Table 1). Sorghum yields, however, increased in all countries averaging 1.1% annual growth between 1980 and 2002. The crop is capable of higher yields but is constrained since in many countries like India, China and Pakistan it is increasingly being pushed to more and more marginal areas

Table 1. Sorghum area, production and yield in major producing countries in Asia, triennium ending, 2000-02.

Country/Region	Area (million ha)	Production (million t)	Yield (t ha^{-1})	Annual growth rate (1980-2002) (%) Area	Production	Yield
Asia						
India	10.0	8.0	0.8	-2.7	-1.6	1.1
China	0.8	2.7	3.3	-5.7	-4.1	1.7
Yemen	0.4	0.4	1.0	.-2.5	-0.5	2.1
Pakistan	0.4	0.2	0.6	-0.3	0.03	0.3
Saudi Arabia	0.2	0.2	1.2	3.9	7.3	3.2
Thailand	0.1	0.2	1.5	-4.8	-3.0	1.9
Bangladesh	0.001	0.001	1.2	-4.7	-2.4	2.4
Syrian Arab Republic	0.004	0.003	0.8	6.0	4.4	-1.5
Region						
Asia	11.9	11.7	1.0	-2.9	-2.3	0.7
South Asia	10.4	8.3	0.8	-2.7	-1.6	1.1
Developing	38.2	42.8	1.1	-0.2	-0.2	-0.1
Developed	4.3	14.7	3.4	-2.4	-1.8	0.7
World	42.4	57.5	1.4	-0.4	-0.7	-0.3

Source: FAO (2003).

(Kelley and Parthasarathy Rao 1993). Developed countries account for only 10% of the total global area under sorghum but account for almost 26% of global production.

Asia produces 12.6 million t millets and as in the case for sorghum, India and China are the major producers. Unlike sorghum, developing countries account for bulk of millet production. Average yields are close to one t ha^{-1}, with the exception of China, where yields are higher. Between 1980 and 2002, as for sorghum, millet area too declined in all countries in Asia. Yield increases are generally positive thus dampening the decline in production (Table 2).

Thus, despite technological change for both sorghum and millet, area under these crops is declining. Relative profitability of competing crops, declining role as a food crop at the aggregate level, lower market prices, urbanization, income growth and change in tastes and preferences are some of the factors explaining decline in area and production.

Table 2. Millet area, production and yield in major producing countries in Asia, triennium ending, 2000-02.

				Annual growth rate (1980-2002) (%)		
Country/Region	Area (million ha)	Production (million t)	Yield (t ha^{1})	Area	Production	Yield
Asia						
India	12.3	9.6	0.8	-2.0	0.1	2.1
China	1.2	2.1	1.8	-6.2	-5.4	0.9
Pakistan	0.4	0.2	0.5	-1.3	-1.2	0.1
Nepal	0.3	0.3	1.1	4.3	5.1	0.8
Myanmar	0.2	0.2	0.7	1.9	1.3	-0.6
Bangladesh	0.1	0.1	0.7	-0.5	-0.6	-0.1
Yemen	0.1	0.1	0.6	-0.3	1.1	-0.8
Saudi Arabia	0.01	0.01	1.2	-1.2	-2.3	3.6
Region						
Asia	14.8	12.6	0.8	-2.3	-1.4	0.9
South Asia	13.1	10.1	0.8	-1.9	0.1	2.0
Developing	35.1	26.0	0.7	0.2	0.4	0.2
Developed	1.7	1.6	0.9	*-4.1*	-3.4	0.8
World	36.8	27.5	0.7	-0.1	0.1	0.2

Source: FAO (2003).

Utilization

Sorghum

The role of sorghum and millets as food staples at the aggregate level has declined since 1980. In Asia, sorghum for food use contributed 5.7 kg capita^{-1} yr^{-1} and millets 5.2 kg capita"^{1} yr^{1} in 1980. In 2000, it declined to 2.3 kg capita^{-1} yr^{-1} for sorghum and 3 kg capita"^{1} yr^{1} for millets. During the same period the per capita availability of all cereals in Asia increased marginally from 164 kg capita^{-1} yr^{-1} to 171 kg capita^{-1} yr^{-1} (Table 3). Per capita availability of sorghum and millets declined in all countries including China, India and Pakistan. In India, the per capita availability of sorghum reduced by more than half and for millets by less than one-third. Despite the low and declining per

Table 3. Food use (kg capita^{-1} yr^{-1}) of total cereals, sorghum and millet in Asia[1].

	Total cereals		Sorghum		Millet	
Country/Region	1980	2000	1980	2000	1980	2000
Asia						
Myanmar	192	215	-	-	1.9	2.9
China	186	183	4.5	0.9	4.4	0.9
Syrian Arab Republic	171	177			0.6	0.0
Bangladesh	168	179	0.1	0.0	0.4	0.4
Nepal	164	194	-	-	7.2	10.7
Thailand	153	126	-	-		
Yemen	148	164	616	18.3	7.8	3.3
Saudi Arabia	145	154	12.4	9.7	0.7	0.5
Pakistan	144	149	2.3	1.3	1.1	0.6
India	140	159	13.4	6.6	12.2	9.0
Region						
Asia	164	171	5.7	2.3	5.2	3.0
South Asia	143	160	10.7	5.1	9.8	7.1
Developing	157	162	7.2	5.0	5.8	4.5
Developed	130	129	0.2	0.4	1.2	0.4
World	150	155	5.3	4.0	4.6	3.6

1. Domestic availability for food use, ie, domestic production - exports + imports ± stock changes - feed and other industrial uses.

Source: FAO (2003).

capita availability of sorghum and millets at the aggregate level their importance as food crops cannot be underestimated. For example, in the Indian states of Gujarat, Rajasthan, Maharashtra and Karnataka, coarse cereals accounted for 20-30% of the total cereal consumption in 1999-2000. For households below the poverty line in these states, coarse cereals account for more than 50% of the total cereal intake (Chand and Kumar 2002). Additionally, for many poor livestock keepers in the marginal areas sorghum straw is the only source of feed for bovines throughout the year (Kelley and Parthasarathy Rao 1994, Hall 2000).

The Indian government's agriculture and food policy geared towards rice *(Oryza sativa)* and wheat played an important role in reducing consumption of coarse cereals. Due to subsidies on farm inputs (irrigation, electricity, fertilizers), production of rice and wheat increased faster than the population growth rate. Also, subsidies on sale of rice and wheat through Public Distribution System (PDS) further contributed to reduction in sorghum and millet consumption (Chand and Kumar 2002). Due to high tariffs on edible oil imports, oilseeds production became more competitive replacing sorghum and millets (Gulati and Kelley 1999, Hall 2000).

Besides its traditional use as food grain crop in Asia, sorghum is used as feed grain in China, Thailand, Japan and South Korea, for liquor production in China and as a green fodder crop in India, Pakistan and China. In recent years its use as feed grain and to a limited extent other non-food uses is increasing in countries where it is traditionally used as a food crop (Table 4). In Asia, 35% of sorghum grain is used as livestock feed and other industrial uses; 58% is used in China and 8-10% in India and Pakistan. In a study on industrial uses of sorghum in India, it is projected that 2.5 to 4.3 million t of sorghum will be used in industrial uses by 2010, ie, three- to four-fold increase from its current usage levels in 1998. Poultry feed will account for bulk of the use followed by dairy feed, alcohol production and starch production (Kleih et al. 2000).

With expanding dairy and meat industry due to rising demand for livestock products (Ryan and Spencer 2002), forage sorghum has become important in many Asian countries. It is increasingly being grown both under irrigated and dryland conditions. However, data on area under forage sorghum are not readily available.

Millet

Food use is still the most important use of millets. In 2000, only 14% of total grain production in Asia was used for feed and other non-food uses. Feed use is high in China and Pakistan. In India, although, only 6% of millet production is used for feed its importance is increasing in recent years. For example, in Tamil Nadu in southern India, farmers growing improved cultivars of pearl millet (*Pennisetum glaucum*) are able to market their surplus to the animal feed sector, mainly poultry and cattle feed manufacturing units (Ramaswamy et al. 2000).

In contrast to sorghum and millet, more than 70% of maize production is used as feed and other industrial uses (starch, bakery products) in Asia as also at the global level. However, there are countries in Asia like India, where its use as feed grain is only 15%). Globally, maize is one of the main competing crops to sorghum and millets in non-food uses.

Table 4. Feed and other industrial uses (% to domestic availability) of sorghum, millet and maize in Asia.

	Sorghum		Millet		Maize	
Country/Region	1980	2000	1980	2000	1980	2000
Asia						
Syrian Arab Republic	98.5	96.8	68.4	-	94.3	95.4
Thailand	91.9	99.4	100.0	100.0	64.3	90.3
China	37.3	57.7	20.5	42.5	59.4	78.2
Saudi Arabia	12.5	5.0	26.7	5.0	95.0	99.1
Pakistan	10.6	10.0	55.0	55.3	39.9	37.7
Bangladesh	10.0	10.0	0.0	0.0	10.0	15.5
Yemen	8.8	8.0	4.0	4.0	36.3	48.6
India	7.8	8.2	6.3	6.5	14.5	14.3
Myanmar	-	-	15.0	15.0	28.1	58.2
Nepal	-	-	10.7	10.5	16.4	27.6
Region						
Asia	36.1	35.4	12.7	13.9	59.6	71.1
South Asia	7.9	8.2	7.4	7.5	17.5	18.5
Developing	40.0	46.9	15.7	16.7	54.3	64.0
Developed	97.1	88.5	25.6	71.3	89.0	79.1
World	56.8	55.8	16.5	20.0	75.4	71.6

Source: FAO (2003).

Trade

International trade

Sorghum

In 2002 about 7 million t of sorghum (13% of global production) was traded globally indicating a decline from 11 million t (20% of production) in 1980 (Table 5). Global sorghum trade compares favorably with trade in all cereals, which is about 12-13% of production. Developed countries account for the bulk of trade in sorghum, which is mainly for feed use (Fig. 1). In Asia, major sorghum-growing countries account for a small fraction of global trade, and their share has been declining over time (Fig. 1). Thailand was a major exporter of sorghum in the 1980s and China in the early 1990s. Exports from Asia declined drastically in 2001, reflecting the growing demand for sorghum in non-food uses.

Sorghum imports to Asia declined from 5.4 million t in 1980 to 2 million t in 2001. Japan accounts for bulk of these imports. China, Malaysia, Republic of Korea and Yemen import small quantities, with no discernable trend (Table 6).

Table 5. Sorghum exports in Asia.

	Exports ('000 t)			Exports as % of production	
Country/Region	1980	1990	2001	1980	2001
Asia					
Thailand	180.6	19.8	0.3	76.2	0.2
Indonesia	12.6	-	-	-	-
Singapore	9.8	0.1	0.2	-	-
Pakistan	5.4	0.0	0.02	2.3	0.01
China	1.0	289.3	19.0	0.015	0.7
India	0.1	0.0	0.4	0.001	0.004
Region					
Asia	209.5	309.5	20.6	1.1	0.2
South Asia	5.5	0.0	0.4	0.05	0.005
Developing	2,053.7	1,501.9	518.8	5.1	1.2
Developed	9,125.7	7,362.6	6,494.5	53.2	40.2
World	11,179.4	8,864.5	7,013.3	19.5	11.6

Source: FAO (2003).

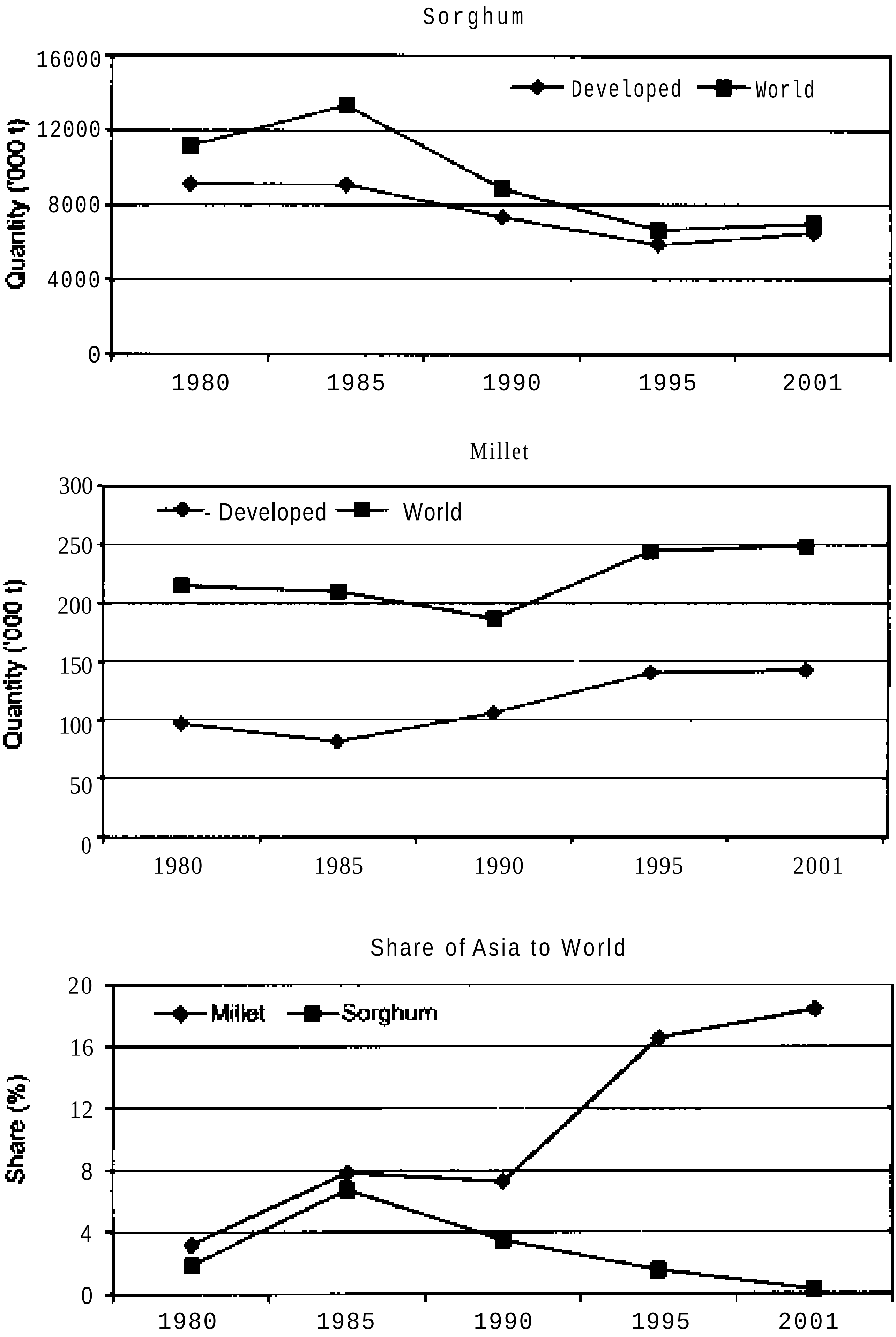

Figure 1. Sorghum and millet exports.

Table 6. Sorghum imports ('000 t) in Asia.			
Country/Region	1980	1990	2001
Asia			
Japan	4,219	3,763	1,908
China	417	33	37
Israel	314	367	55
Cyprus	99	0.002	0.007
Saudi Arabia	31.9	0.5	0.1
Singapore	19.8	0.4	0.1
Malaysia	12.7	2.3	0.3
Republic of Korea	12.2	92.3	4.2
Bangladesh	5.7	0.0	0.0
Yemen	2.5	18.7	0.5
India	1.5	0.0	0.0
Thailand	0.1	1.3	0.9
Iraq	0	155.0	0.0
Lebanon	0	0.0	4.5
Philippines	0	0.3	4.5
Turkey	0	25.8	0.0
Region			
Asia	5,144.4	4,468.0	2,015.7
South Asia	7.1	0.004	0.013
Developing	3,659.3	3,556.0	5,301.9
Developed	7,372.6	5,035.9	2,265.6
World	11,031.9	8,591.9	7,567.5

Source: FAO (2003).

Millet

Around less than 1% of global production of millet is traded. This figure could be an underestimate since substantial quantities of millet trade are unrecorded (ICRISAT and FAO 1996). Official records on prices, etc are also not regularly published. Unlike sorghum, both developed and developing countries are important exporters of millet, and exports have generally increased over time (Fig. 1). Asia accounts for one-fifth of global exports and China and India are the major exporting countries (Table 7). Unlike sorghum, share of Asia in total exports of millet has increased over time although from a small base (Fig. 1). Asia imported about 66000 t of millets in 2001. Japan and Republic of Korea account for bulk of the imports (Table 8). Several other countries in Asia import small quantities mainly for food use.

Table 7. Millet exports in Asia.

Country/Region	Exports ('000 t) 1980	1990	2001	Exports as % of production 1980	2001
Asia					
China	5	3.9	21.4	0.09	1.09
Sri Lanka	1.4	0.002	0.005	8.90	0.12
Singapore	0.4	0.3	0.02	-	-
Thailand	0.03	1.3	0.2	-	-
Iran, Islamic Rep of	0.03	0.0	2.0	0.29	22.2
Turkey	0.002	0.6	0.8	0.01	12.3
India	0	4.5	19.1	0	0.17
Yemen	0	0.0	0.1	0	0.21
Kazakhstan	0	0.0	1.7	0	1.98
Region					
Asia	6.9	13.6	45.7	0.04	0.3
South Asia	1.4	4.7	19.1	0.01	0.2
Developing	118.1	81.1	106.0	0.51	0.4
Developed	96.7	105.9	142.3	5.12	9.7
World	214.9	105.9	142.3	5.12	9.7

Source: FAO (2003).

Domestic trade in India

Large quantities of sorghum are traded within India from the major growing areas to urban centers, to non-sorghum growing areas and also between growing areas. The trade is mainly to meet demand for sorghum from urban consumers and to meet quality requirements of consumers from different income groups. For example, poor consumers prefer sorghum grown in the rainy season because it is cheaper than sorghum grown in the postrainy season, which is of superior quality. Sorghum is traded over long distances mainly for non-food uses like poultry feed, cattle feed, alcohol manufacture, etc (Marsland and Parthasarathy Rao 1999).

Prices

World market

At the global level sorghum is almost exclusively traded as feed grain and its market price is closely related to production and trade of other feed grains

Table 8. Millet imports ('000 t) in Asia.

Country/Region	1980	1990	2001
Asia			
Japan	47.4	26.2	12.9
Kuwait	1.1	0.1	0.4
Republic of Korea	1.0	0.1	15.4
Saudi Arabia	0.8	0.0	5.2
Thailand	0.6	1.8	3.9
Singapore	0.5	1.0	0.1
Malaysia	0.5	2.2	3.2
Philippines	0.035	0.3	1.8
China	0.00	3.6	4.0
Indonesia	0.00	1.6	7.6
Israel	0.00	0.3	1.1
Sri Lanka	0.00	0.0	2.3
Turkey	0.00	0.0	1.9
Region			
Asia	52.2	41.6	65.9
South Asia	0.002	0.4	2.9
Developing	114.5	38.4	108.1
Developed	170.1	164.4	152.4
World	284.6	202.9	260.5

Source: FAO (2003).

such as maize, wheat and barley (*Hordeum vulgare*). There are no published data on sorghum trade and prices for food use due to small volumes traded. The closest competitor for sorghum in most non-food uses is maize. Maize is preferred over sorghum when there is no price difference between the two crops. Generally international market prices of sorghum are lower than maize prices by 5-10% (Fig. 2). The price difference varies from year to year depending on production of maize in the major growing or exporting countries.

Domestic prices in India

Index of real wholesale prices of sorghum in India declined sharply until early 1990s and rose above the rate of inflation since 1995 (base 1981 = 100), perhaps indicating renewed demand for sorghum particularly for non-food

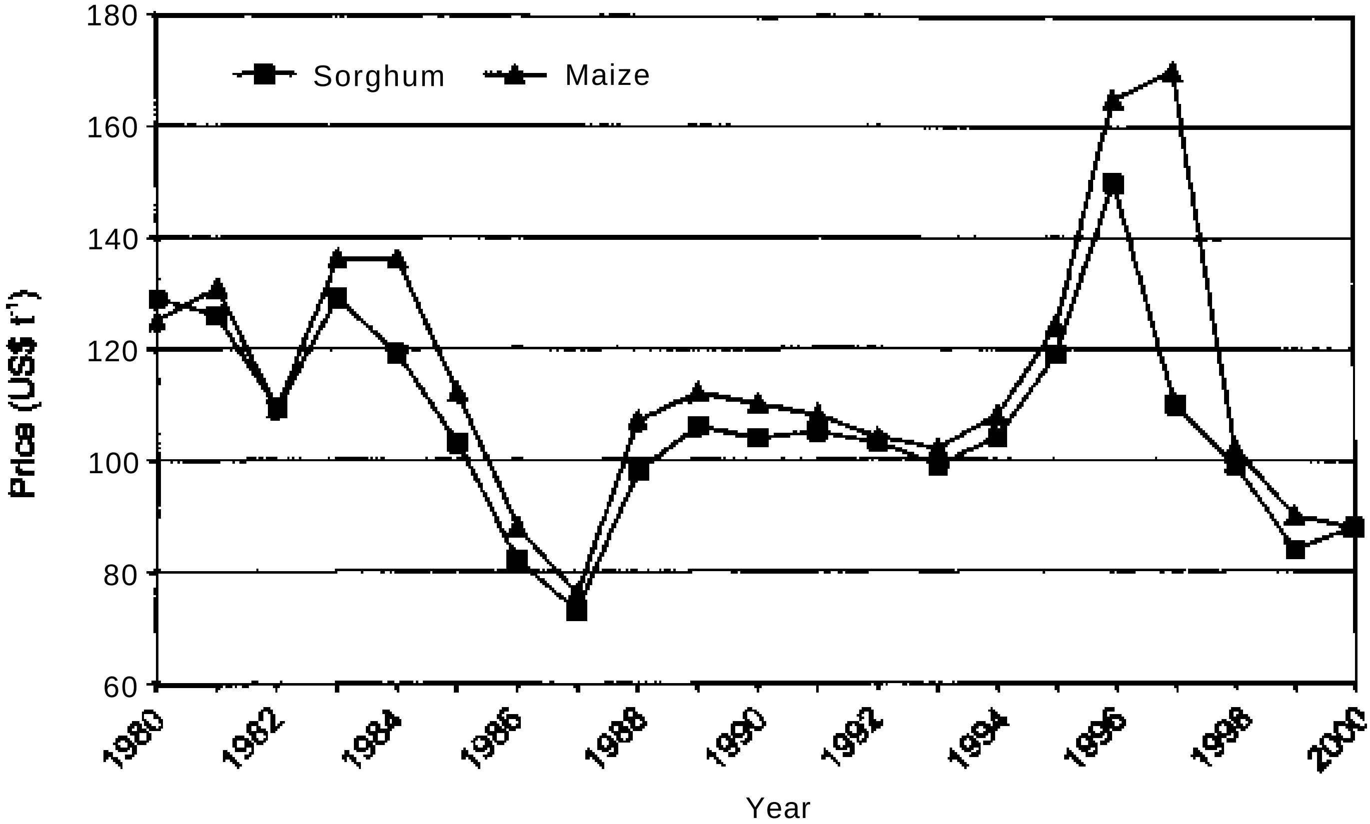

Figure 2. Average annual export prices of sorghum and maize at US Gulf ports.

uses. Since the mid-1990s real prices of rice and wheat (since 1997) have increased faster than the inflation rate. Due to an effective procurement price policy for rice and wheat, market prices are not a true indicator of demand for these crops. Sorghum prices are generally more volatile (large year to year fluctuations) compared to rice and wheat prices since its production is dependent on rainfall (Fig. 3a). In contrast, the real price of sorghum straw increased faster than the grain price leading to a sharp increase in the straw to grain price ratio over time, reflecting a growing demand for livestock feed, to meet the rising demand for milk and meat (Kelley and Parthasarathy Rao 1993). Compared to cereals, pulse price index increased sharply, with the index value around 135 in 2001 (Fig. 3b). The sharp rise in real prices of pulses has made it an attractive crop, with area under different pulse crops expanding, substituting area under coarse cereals.

As indicated earlier, maize is an important competitor for sorghum in alternative uses. As at the global level, even in India 10-15% lower market price for sorghum compared to maize is a minimum requirement for feed manufacturers and other industrial processors to partially substitute sorghum for maize. Wholesale market prices for sorghum and maize are assembled for

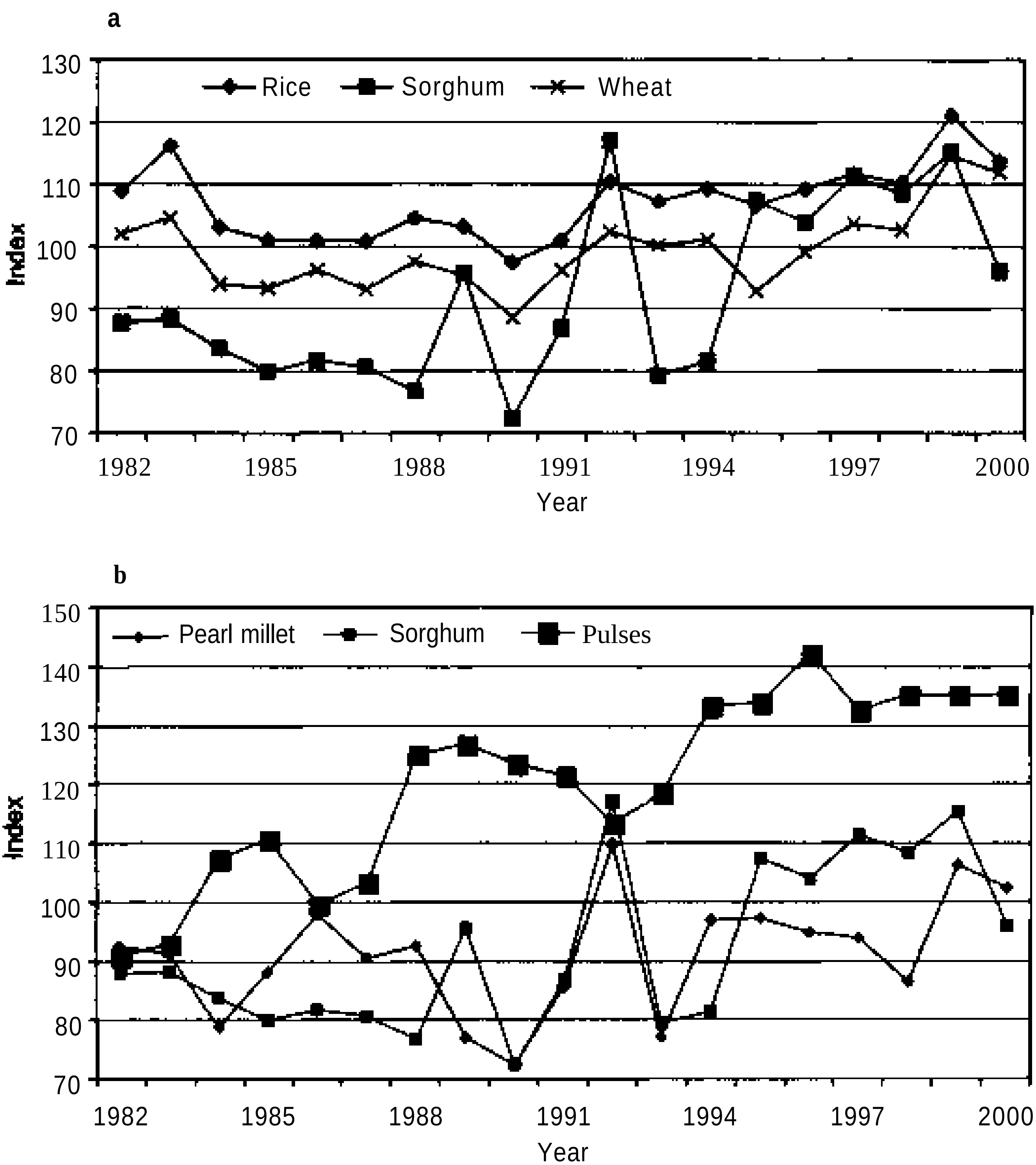

Figure 3. Index of real wholesale prices in India (base 1981 = 100): (a) Cereals; and (b) Cereals and pulses.

a few select markets in India and are shown in Figure 4. The ratio of sorghum to maize price is equal to or lower than maize prices in Bahraich, Chindwara, Kanpur and Calcutta markets in India except in few years when sorghum prices are higher than maize prices. If sorghum prices can be consistently lower than maize prices by 10-15% the prospects of substituting larger quantities of sorghum in non-food uses would be enhanced. According to industry sources, besides price, sorghum usage for industrial uses would depend on continuous supply throughout the year. According to industrial processors, maize supplies are more consistent in any given year.

Marketing in India

The marketing system for sorghum in India is generally free of major distortions and is not a constraint to marketing of sorghum as a food grain. Although linked or tied output and credit markets lead to distress sale by small

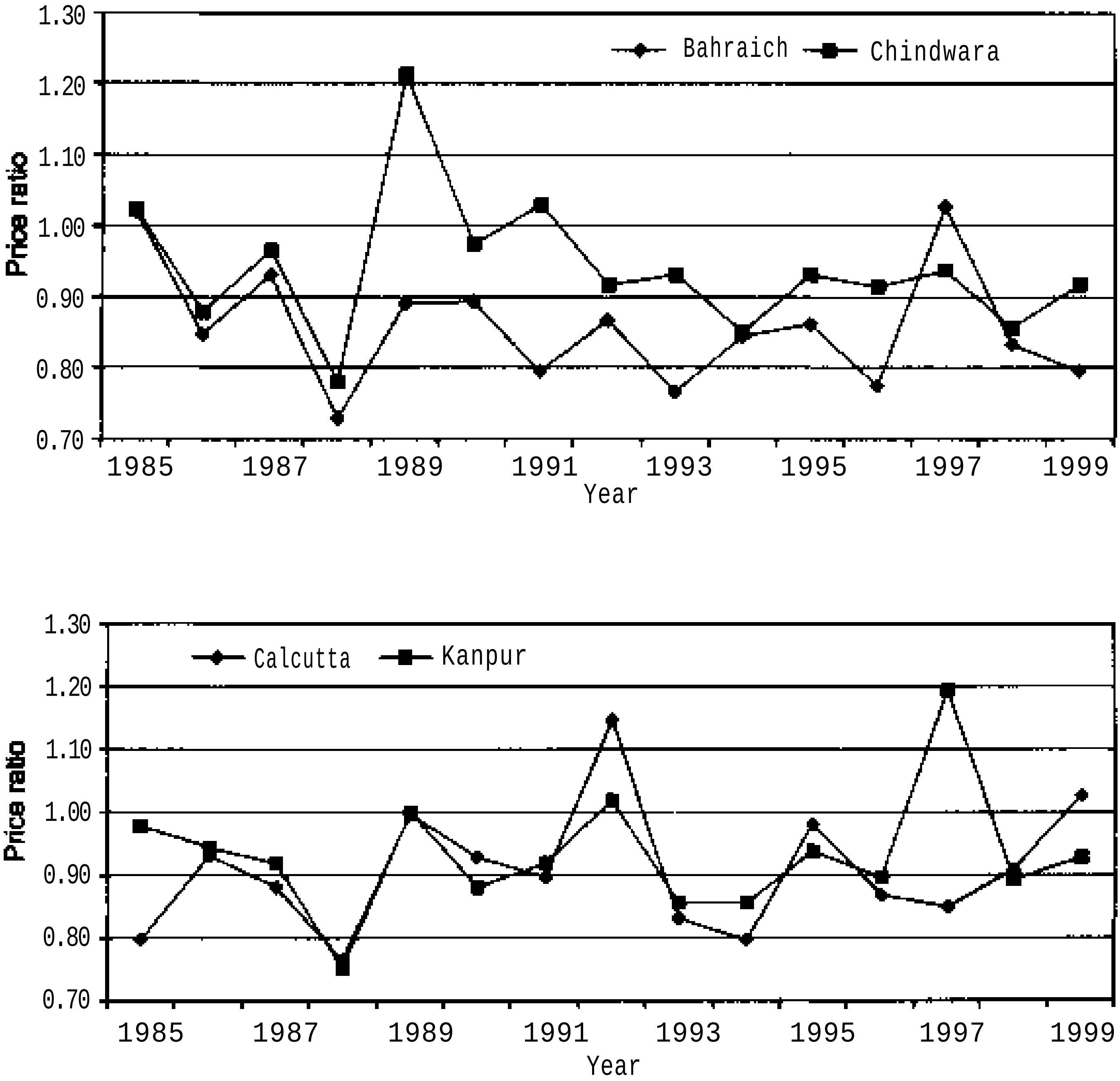

Figure 4. Ratio of sorghum to maize price in selected wholesale markets in India.

and marginal farmers, existing marketing arrangements may not be optimal for industrial users of sorghum and millet. Industrial users may wish to bypass the regular channels and obtain sorghum and millet more efficiently through new institutional arrangements. Thus, twin track marketing is envisaged for sorghum, one for food sorghum and another for industrial users (Marsland and Parthasarathy Rao 1999).

Promoting innovations in the coarse grain sector through science-industry coalitions

What clearly emerges from the trends discussed above is that sorghum and to a limited extent millet crops are making the transition from food to non-food markets. Supporting this transition with relevant postharvest interventions is a potentially important way of ensuring that new markets are found for a crop which farmers in marginal environments have little choice but to grow. The central empirical question concerns what the nature of that postharvest intervention should be.

Research and technology development in this area has had limited success. A major study of sorghum utilization in India (Hall 2000) concluded that increased utilization of sorghum in the industrial sector has happened despite any specific technical breakthrough in the formal public research sector. The same report goes on to emphasize that one of the critical weaknesses of current institutional arrangements is weak linkages between public and private sectors. This is unfortunate given the considerable amount of research that has been carried out on alternative utilization of coarse cereals.

Exploration of the potential role of the Indian private sector in relation to creating incentives for different coarse grain qualities reached a broadly similar conclusion (Hall et al. 2000). Again the recommendation from that study focused on the need for partnerships between industry and research as well as institutional innovations (such as contract farming) that link farmers to industry. While this constraint affects the postharvest sector in particular, it is a more general feature of the nature of relationships between the public and the private sectors in India (Hall et al. 2002).

Before going on to discuss how these issues could be resolved it is useful to briefly reflect on postharvest innovation systems. This allows us to investigate the implications these have for developing institutional arrangements that will simultaneously support industrial utilization of coarse cereals as well as ensure that the strategy also supports the livelihoods of poor farmers.

Postharvest innovation systems

Postharvest R&D seems to be placed uncomfortably in the conventional arrangements for agricultural research. Crop improvement research, for example, can clearly identify plant breeders (and increasingly molecular biologists) as the central scientific personnel. The product - new varieties - is well defined and the systems for disseminating this technology and the roles of extension services and seed supply agencies are relatively straightforward. The main client, the farmer, is clearly identified, as is the role of the client in applying this new input technology. In this view of agricultural research the number of players is fairly limited - scientist, extension workers, farmers - and their roles are clearly defined and mutually exclusive. While this is a stylized description of the R&D process and the way it is arranged, it is all too recognizable as the conventional model of agricultural research that persists in many parts of the world.

Postharvest R&D, on the other hand, cannot be so neatly categorized. Professionally the sector spans engineering, food science, pathology, marketing systems, economics and other disciplines. The postharvest sector is also characterized by its linkages and relationships between producers and consumers and between rural and urban areas, with markets playing a large role in mediating these linkages. The sector includes technology clients and intermediary organizations from the whole range of organizational types, from both public and private sectors and from an equally diverse set of stakeholder agendas and interests. Furthermore, postharvest technology applications often form part of complex techno-economic systems where many players are involved, each with different skills, responding to different incentives. As a result postharvest innovation is frequently embedded in a wider set of relationships and contexts than is implied by the conventional research-extension-farmers model of R&D. Managing postharvest innovation and doing so in ways that support a pro-poor policy goal is therefore challenging. It is increasingly argued that conceiving postharvest innovation as a process emerging from a system of supportive actors, relationships and institutional context, is a policy perspective that can be used to plan R&D more effectively (Hall et al. 2003).

A coalitions approach to postharvest innovation

To operationalize this concept of a postharvest innovation system, scientists from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India have recently begun experimenting with a coalitions approach to research. The approach involves investigating and strengthening the institutional context of the research undertaken, with a view to building local innovation system capacity. The focus of the coalition type project is specified in broad development terms (rather than narrow scientific terms) so as to articulate the identified problem in a way that includes the interests of both non-scientific as well as scientific stakeholders. Furthermore, instead of having a fixed workplan the approach uses an action research methodology whereby the program of work and the partners in the coalition involved can evolve along the way to match emerging circumstance and findings. The idea is that by building the right coalition of partners around an intervention task, the research element of the project becomes linked to and informed by those who will use and operationalize research products.

The focus of this experiment at ICRISAT is the promotion of sorghum by the poultry industry. The coalition, made up of breeders, economists, poultry scientists, poultry feed manufacturers and sorghum farmers, is testing new varieties in poultry rations. The project is exploring institutional arrangement that would allow a contract growing scheme to develop and in the longer term building a new relationship between sorghum breeders and the industrial sector that will increasingly determine the utilization quality characteristics of the crop. The novelty of this approach is not only the diversity of partners involved in the process, but also that the outcomes of the project are both technical and institutional.

While it is too early to predict the outcomes of this coalition experiment at ICRISAT, evidence from other postharvest interventions of this type suggest that it can bring about significant innovation and impact (Clark et al. 2003). Given what is already known about innovation process in the postharvest sector it is apparent that if the industrial utilization of coarse cereals in Asia will evolve in ways that support the livelihoods of poor producers, institutional development is likely to be as important as technological change. A critical part of institutional development will be stronger and more effective linkages between science, industry and farmers.

Conclusions

In recent years production, consumption and trade patterns for coarse cereals in Asia indicate a shift from food to non-food uses. Stronger coalitions of sector stakeholders should be promoted as a way of developing the non-food market and building stronger and more effectively linking farmers with new sources of demand for their crops.

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Demand-driven Sorghum and Millet Utilization: Failures, Successes and Lessons Learned

LW Rooney[1]

Abstract

Sorghum and millets have excellent quality for processing. However, generally, the grain available for processing from market channels has variable, poor quality. The key to producing profitable sorghum and millet products is a consistent supply of grain that can be processed into convenient, cost competitive, attractive products that provide an alternative for higher cost imported products.

The concept of supply chain management starts during development of new cultivars and continues through production, harvesting, storage, processing and marketing. There must be sufficient value added during the process to improve and share prof its with all participants. This system is difficult to initiate but is an essential need all over the world. The development of adequate supply chains from producers to processors will allow profitable production of new products.

Several myths about sorghum tannins and poor digestibility negatively affect the perceived nutritional and processing quality of sorghum, making many potential users afraid to use sorghum. Thus, the advantages and disadvantages of sorghum and millets must be clarified to potential users.

Development and marketing of value-added products from millet and sorghum is progressing. Demand is emerging, but systems linking seed and grain quality to production, food processing and marketing must be promoted. Many failures are behind us; the future looks promising if we can meet the challenges of providing a good quality grain supply at competitive prices.

Many fantastically good foods have been produced from sorghum *[Sorghum bicolor)* and millets in pilot projects conducted by numerous scientists and companies around the world. These grains can be processed into a wide variety of foods and food ingredients. However, most of the time the technology and products fail because there is an inadequate supply of grain that can be profitably processed.

Good products that were well accepted when they were made with good quality grain failed dramatically with consumers when grains from local markets were utilized. Basically, the situation "Which comes first, the chicken or the egg?" applies since an adequate supply of grain cannot be

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obtained until one produces and sells a good quality product that is competitive with existing products. Farmers cannot afford to preserve the identity and market good quality grain unless they are paid extra; processors cannot compete with imported foods without good grain supplies. Thus the cycle goes on. However, rising incomes and the need for convenience, good taste, proper texture, etc provide an opportunity for niche marketing that will grow dramatically.

Some of my experiences with sorghum and millet products over the past 35 years are summarized. Also, some thoughts about future research and development needs to improve their consumption in profitable foods demanded by urban consumers are presented.

Consumer demands

Urban consumers want food products that deliver convenience, taste, texture, color and shelf-stability at an economically competitive cost. However, up-scale sorghum and millet products that meet these requirements are usually not available in urban areas.

Our laboratory and collaborators in sorghum producing countries around the world have made excellent prototype products from sorghum and millet using existing technology and grain with good processing quality. However, acceptable value-added products cannot be made profitably by using grain purchased in the local markets.

The major constraints to sorghum and millet utilization are:

- Lack of consistent, uniform quality grain supplies
- Logistics/markets
- Subsidized imported cereals
- Extension of existing processing technology unavailable
- Few shelf-stable convenience foods
- Governmental policies, value-added tax on sorghum in South Africa
- Subsidized food systems based on maize *(Zea mays)*, rice *(Oryza sativa)* or wheat *(Triticum aestivum)*
- Poor image of sorghum and millet
- Nutritional myths, tannins and poor digestibility
- Grain molds

The greatest obstacle to utilization is the lack of a consistent supply of grain that can be processed into economically competitive products. Other constraints affecting the utilization of sorghum and millets, though serious, can be overcome once a supply of grain of consistent quality is available. In the past, opportunities were lost by governmental policy changes that discriminate against local cereals by easing import restrictions on foreign grain.

In spite of all these problems, local grain products are being profitably sold with increasing demand for export and domestic markets in some areas. This is especially true in Dakar, Senegal where a wide variety of high quality pearl millet (*Pennisetum glaucum*) products are marketed profitably. The products are based on local traditional products, eg, couscous and related products, a higher value yogurt containing pearl millet and puffed snacks.

These processors have learned to produce high quality products that are in demand by local consumers in spite of poor quality grain supplies. Their success is stimulating a demand for supplies of improved quality grain because they recognize the need to produce a quality product. These processors started with a very small niche scale operation and in some cases have expanded significantly. Other similar operations have failed because they did not provide quality products.

Thus, there may be more demand for sorghum products than we realize. For example, in South Africa, in spite of a local 14% value-added tax on processed sorghum products (Mabella Meal), significant amounts of decorticated sorghum are sold to consumers. The product made from local sorghums with red or brown grain color is consumed even though it costs more than white maize meal. In Botswana, white sorghum meal is preferred and has taken market share away from maize meal. Significantly greater decortication is required to make light colored meal and flour from red sorghums imported from South Africa.

Progress has been made in recent years in the United States to provide identity-preserved white food sorghums for use in domestic ethnic and dietary foods and for export to Japan for snacks and other products. Many new ethnic and special dietary recipes have been developed and published. The identity-preserved food sorghums have stimulated significant interest and demand for sorghum food products. Reasonable chances for growth of these markets exist, provided progress to produce good quality sorghum continues.

Value-added supply chain

The value added supply chain includes:

- Seed supplier (seed production) - quality and purity

- Grain producer
- Harvesting
- Storage
- Handling and transportation
- Processing into products
- Marketing

Developing a value-added grain supply chain is a challenge. All the components in some form or another are necessary to meet the needs for demand-driven food and feed products. More efficient methods of threshing and cleaning the grain to remove sand and other impurities are essential. Development of the supply chain involves extensive communications and promotion of good will and understanding among all the participants.

Simple methods to assess quality are required to facilitate supply chain management. A set of standards along with practical specifications for each important quality criteria is required. These specifications must be agreeable and practical to producers, grain traders and processors alike. Contracts are required along with credit systems to build grain storage facilities to hold grain throughout the year to assure a consistent supply of grain for the processor. Profit for all is necessary to make the scheme work.

Communications are critically important. It is inherently difficult for producers and processors to understand each other's needs and problems. A long-term relationship between producers and processors is required and must be developed over time. The best way to make it work is to start small and grow as experience is obtained. Efforts to work with large processors have failed since supply logistics are a major problem. Several large mills producing sorghum flour in Africa failed because obtaining and transporting large quantities of sorghum to and from a central location and urban areas were impossible to do profitably.

Some varieties and improved cultivars are available in most countries that have significantly improved processing quality. A supply chain management scheme would facilitate the introduction of new cultivars with improved quality and grain yields. In Mali, N'Tenemissa, a white grain, tan plant color photosensitive sorghum variety that avoids head bug and molds, has demonstrated excellent processing properties and has been identity preserved, stored, handled and processed into flours, decorticated rice-like products, and sold as clean whole grain. Farmers and consumers prefer the products made from N'Tenemissa over other local varieties.

Likewise, in Central America, farmers prefer certain white grain, tan plant color sorghum varieties for use in tortillas and baked products. In fact, some farmers are growing the tan plant varieties, storing the grain, milling it into flour and marketing the flour as bread, cookies and related products in urban areas. These vertically integrated operations are small but are providing opportunities for producers to enhance their profits. The linkage between crop improvement programs and processors is important. New cultivars will be adopted more rapidly if they can increase the profitability of farmers by increasing the value of the crop for transformation into food products.

Functionality of sorghum and millets

There are many different sorghums that can be used in various ways. Therefore, it is necessary to consider what sorghums are available and how to choose among them. The color and composition of sorghums vary from white food types to brown high tannin types. Each of these sorghum varieties has advantages and disadvantages for utilization. For example, our laboratory has documented that the brown, high tannin sorghums have levels of antioxidants equal to or higher than those of blueberries (Vaccinium corymbosum) and other fruits and vegetables. Over the years tannin grains have been eliminated from commercial production in the United States because they decrease the feed efficiency of livestock rations. However, tannin sorghums for use in specialty foods for dietary purposes may become important in the future.

Moreover, the flavor and color of the brown sorghums find applications in baked products where the natural colors are an advantage. It is possible that sorghum with tannins will find new applications in the food industry in many countries.

We have developed in our sorghum improvement program, white grain, tan plant color, food-type hybrid sorghums for use in food applications. Functional advantages for food sorghums include a white, light color, bland flavor, lack of GMO (genetically modified organism) contamination, and excellent processing properties for use in snacks, breakfast cereals and an array of flours, grits, meals and porridges. The bland flavor and light color of food-type sorghums affords a real advantage in functionality to sorghum. Sorghum does not contain gluten and is hydrolyzed slowly, making it attractive to diabetics, celiacs and ethnic groups. In addition, it is an alternative to rice for extruded, processed foods because of its bland flavor, light color and good expansion.

We recently reported that these white food-type sorghums can be extruded as whole grain in direct expansion extruders to produce snacks, breakfast foods and other products. In many areas, rice is sold at a much higher price than sorghum, so the white food-type sorghums can compete as food ingredients, replacing more expensive rice products. However, the quality of the grain must be excellent and the kernels cannot be molded or weathered.

Pearl millet has a strong flavor and dark color that is desired in millet consuming areas, which affords an opportunity for products with different characteristics. Some white and yellow grain types that exist in Namibia have functional advantages for processed foods with lighter color and milder flavors. Certain varieties in Senegal have better quality for use in composite bread flours, while others have significantly improved milling properties. These improved types will be used in Senegal if they can be introduced into the supply system for local processors. Over time this will happen because it can improve profitability for all.

Rice is considered a convenience food in many areas in Africa because it is available in different forms as ready-to-cook products. Similar products, eg, meal, couscous, flour, grits and snacks made from sorghum and millet are competitive with rice in these areas. There are several examples of small entrepreneurs in Bamako, Mali that profitably sell locally-milled maize, sorghum, millet and fonio products because they produce relatively high quality products free of sand, ready for cooking. Some of these business women are maintaining good consistent quality by securing supplies of high quality grain for processing. This market is limited in scope but it has continued for many years. During this time, I have observed some larger maize milling operations that failed quickly because they produced very poor quality products. The high cost of cleaning millet and sorghum increases prices, which limits the ability of the grains to compete with imported products.

Plant breeding and improvement of grain quality

The efforts to develop improved cultivars with built in quality for processing are critically important for successful utilization and increased profits for farmers as well. The goals of plant breeding programs must be considered in terms of yield of useful quantities of food produced per unit of land. The major objectives of sorghum and millet breeding programs are:

- Maximize yield of useful products per hectare

- Focus on economic grain yields and quality
- Develop genotypes with value-added characteristics and mold/head bug/ weathering resistance

Breeding for yield without regard for quality is a major mistake. Farmers in the semi-arid tropics have not planted many improved sorghum varieties because they are susceptible to weathering and head bugs, and have unacceptable processing and food properties. For example, women will not accept a thin pericarp sorghum because the work required to dehull it by hand pounding is increased by 50% or greater. Therefore, it is important that sorghum breeders recognize that food quality is critically important and is an essential part of grain yield. This is illustrated in Central America, where several white grain, tan plant color food-type sorghums are preferred by farmers because they have good tortilla-making qualities and can be used in a variety of baked products with superior quality. These sorghums are used in commercial bakeries to extend wheat flour for sweet breads and other products.

In the more humid areas of West Africa, a major priority should be to develop improved local varieties that have photosensitivity and good food quality (tan plant color, straw color glumes). Such varieties could be utilized for identity preserved sorghum production for value-added products. Until we obtain superior quality sorghums that consistently avoid damage by molds, sorghum food use in urban areas is doomed.

We do need to develop sorghum varieties that are resistant to molds and weathering. However, mold resistance is very difficult to select for because it is quite complex. Thus, in my opinion, the photosensitive sorghums are desirable since they can avoid at least some of the mold and weathering problems. Research to improve mold resistance is highly significant, but it is likely to be a long-term effort. In the meantime, the use of photosensitive varieties can be effective, as judged by the progress previously mentioned in Mali.

Food utilization of sorghum and millet

Proper sorghum and millet cultivars can be processed into a wide variety of very acceptable commercial food products. These grains can be extruded to produce a great array of snacks, ready-to-eat breakfast foods, instant porridges and other products. The flakes of a waxy sorghum obtained by dry heat processing can be used to produce granola products with excellent texture and taste. Tortillas and tortilla chips have been produced from sorghum and pearl millet alone or with maize blends. The sorghum products have a bland flavor while pearl millet products have a unique strong flavor and color. Again, the critical limitation is cost-efficient, reliable supplies of grain.

Neither sorghum nor millet have gluten proteins. Hence, to produce yeast-leavened breads, they are usually substituted for part of the wheat flour in the formula. The level of substitution varies depending upon the quality of the wheat flour, the baking procedure, the quality of the sorghum or millet flour and the type of product desired. In biscuits (cookies), up to 100% sorghum or millet flour can be used. The non-wheat flour gives the biscuit a drier more sandy texture and so the formula must be modified to make it more acceptable to consumers. White sorghum has a definite advantage over maize and millet in composite flours because of its bland flavor and light color. However, molds and discoloration are major constraints that must be recognized. Thus, we do not recommend that white food-type sorghums be grown in the Coastal Bend of Texas, or other similar humid areas, since molds are often significant problems there.

Dry milling quality

The milling quality of sorghum and millet is determined mainly by kernel shape, density, hardness, structure, presence of a pigmented testa, pericarp thickness and color. Kernels with a high proportion of hard endosperm, and a white, thick pericarp without a pigmented testa have outstanding dehulling properties. Soft floury kernels disintegrate during dehulling and cannot be milled efficiently. For hand dehulling, a thick starchy mesocarp layer in the pericarp reduces labor by 50% or more. Long, slender pearl millet kernels have very poor dehulling properties, while spherical kernels produce the highest yields of decorticated grain. The white grain, tan plant color food sorghums have significantly improved yields of light-colored flour and decorticated kernels.

Feed utilization of sorghum and millet

Both feed and food use of sorghum and millet are compatible; not all grains will have desirable food processing properties, so the poor quality grain will go into feeds. Obviously, care must be taken to avoid problems with mycotoxins.

Sorghum is a very good feed grain as long as it is properly supplemented for the particular species fed. Sorghums without a pigmented testa have 95% or greater the feeding value of yellow dent maize for all species of livestock.

Pearl millet has outstanding feed value for poultry and swine because of higher fat content and increased essential amino acid content. Animals fed rations containing high tannin sorghums usually consume more of the ration to produce similar weight gains, which reduces the feed efficiency significantly. However, the concern that animals will not consume tannin sorghums is erroneous.

Effect of molds, insects and weathering on quality

Molds discolor the grain, break down the endosperm and significantly deteriorate processing qualities. Mold damaged or weathered grain cannot be easily decorticated due to softness of the grain; the resulting flour or grits are badly discolored and cannot be used for food. This problem can be overcome by the production of photosensitive sorghums having white grain, tan plant color and straw-colored glumes. This is critically important in West Africa where most new improved types have been devastated by head bugs and mold. For example, N'Tenemissa recently released in Mali, is the first tan plant photosensitive sorghum released that has improved characteristics for processing into a wide variety of food products ranging from biscuits to decorticated rice-like convenience foods. Production of N'Tenemissa and related lines has led to improved quality food products. Systems to produce and supply the grain for value-added processing are evolving. The concept works and if a market exists that is profitable it will be adapted over time.

Mycotoxins

Unlike maize, sorghum does not develop aflatoxins prior to harvest. Sorghum contains *Aspergillus flavus* and other fungal species, but apparently the exposure of the grain to the atmosphere prevents significant levels of aflatoxin formation in the field. However, improper handling and storage can increase levels of aflatoxin significantly in sorghum. In addition, sorghum does not produce significant amounts of fumonisins compared to maize. The relative resistance to field contamination of sorghum by these important mycotoxins is a major advantage for sorghum over maize. As maize is grown under more marginal conditions, the risk of increased levels of mycotoxins to populations consuming maize should be considered. Sorghum definitely has fewer problems with mycotoxins than maize.

Sorghum image - tannins

The alleged 'poor nutritional quality' of sorghum due to the presence of tannins, resulting in poor protein digestibility, is a major problem as opined by some people. Often, key nutritionists, scientists and industry personnel believe that all sorghums contain tannins, and thereby scare potential users away. For example, a poultry nutritionist from India indicated he would only feed sorghum if it was priced at 60 to 70% the value of maize "because of the tannins in sorghum", even though most, if not all, Indian sorghums do not contain condensed tannins. The same is true of Central America where poultry producers are wary of using sorghum since "it has tannins". Even though tannins are not present, fear of them significantly affects the demand for sorghum.

The sorghums without a pigmented testa do not contain tannins and so they should be referred to as 'tannin free'. Often laboratories use general phenol assays to measure tannins, which results in erroneous information since all sorghums contain phenols but most do not contain tannins. The tannin sorghums (brown sorghums) have a very definitive pigmented testa, which is caused by the combination of dominant B_1-B_2-S- genes, and constitute a small proportion of the soybean (*Glycine max)* grown today. Such sorghums have significant levels of condensed tannins with resistance to birds and grain mold.

The tannin sorghums decrease feed efficiency by 5 to 20% when fed to livestock, depending upon feeding systems and livestock species; however, they have high antioxidant activities and may be a very good source of nutraceuticals. Thus we might someday use the sorghums with a pigmented testa and dominant spreader genes as potent sources of antioxidants that are more efficiently produced than fruits or berries.

Improving sorghum digestibility

Many people consider sorghum protein as indigestible and believe that sorghum should not be used in products like weaning foods. The combination of misinformation about tannins and poor digestibility often causes difficulty in gaining approval for sorghum foods. Sorghum is an excellent food that when properly processed, has good digestibility, and has sustained millions of people over the centuries. However, like all cereals it is deficient in lysine and other essential amino acids and must be processed properly for use in foods.

A significant body of knowledge indicates that sorghum proteins are only slightly less digestible than maize when measurements of digestibility other than pepsin protein digestibility are used. Also, the information using pepsin digestibility shows that digestibility is significantly improved when sorghum is cooked by extrusion or a combination of moisture and mechanical energy (such as the energy that occurs when porridges are stirred and beaten vigorously).

Soft, digestible sorghums are destroyed by molds in the field prior to harvest except in very dry areas like Sudan and Ethiopia. Thus, efforts to enhance digestibility of sorghum must be done with care. It is difficult to improve digestibility without enhancing the susceptibility of the grain to deterioration since sorghum kernels are exposed to ambient conditions during maturation, and are prone to attack by molds and insects.

Increasing the levels of lysine and tryptophan in sorghum is extremely valuable in terms of human and animal nutrition. Developing high-yielding sorghums with improved levels of lysine and trypotophan would greatly enhance its value for both humans and animals. With the increasingly widespread use of quality protein maize, the comparative protein quality (lysine and tryptophan) of sorghum will be significantly lower. Hence, more work is needed to improve sorghum protein quality.

Strategy for value-added products

The strategy for value-added products include the following activities or components:

- Identify up-scale products
- Promote niche markets (supermarkets)
- Develop sorghum and millet products
- Use low input, appropriate technologies
- Use identity preserved grain
- Specify variety and hybrids
- Educate farmers and producers
- Share the profits with members of the supply chain

The best strategy for developing convenient, shelf-stable sorghum and millet foods is to use identity-preserved grains to produce high-value products that can be priced slightly lower than imported products. The targets should be middle class and wealthy people who can afford to pay prices high enough to provide profits for all. There is no need to develop low cost, inferior quality foods that do not provide significant profits. The production of high quality products is working in Senegal where an expanded snack food is being sold profitably. The snack is a combination of pearl millet, maize and rice flour which is puffed, flavored, packaged and sold in small packets. Local supplies including packaging are used; the product sells so fast that it does not require costly imported long-term packaging material. Since shelf life is not a problem for this company, whole grains can be used for extrusion and puffing. This strategy works for the company. However, shelf life is a problem for some products. Innovative ways of extending shelf life can be developed through new technology or marketing strategies. Educational programs to promote and correct misinformation about sorghum and millet properties are necessary to promote acceptance by the food and feed industries.

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Effects of Mycotoxins on Cereals Grain Feed and Fodder Quality

F Waliyar, SV Reddy and RP Thakur[1]

Abstract

The mycotoxigenic mold fungi Aspergillus, Penicillium *and* Fusarium *were shoum to be associated with grain molds in sorghum and pearl millet. These fungi produce several mycotoxins, some of which can affect human and animal health. The most important mycotoxins that occur at biologically significant concentrations in cereals are aflatoxins, ochratoxinA, fumonisins, zearalenone, deoxynivalenol and* T_2 *toxin. Reports indicate that aflatoxin* B_1 *was associated with liver cancer, synergistic with hepatitis B virus and childhood cirrhosis in humans. Several outbreaks of aflatoxicosis in poultry and livestock were reported. The fumonisins were associated with oesophageal cancer and* T_2 *toxin with alimentary toxic aleukia in humans. Fusarial mycotoxins have been implicated as causative agents in various animal diseases such as leucoencephalomalacia, pulmonary edema, infertility, diarrhea, vomiting, reduced growth rate, drop in egg production and immunosuppression.*

Mycotoxin contamination of cereals can cause economic losses at levels of food and feed production including crop distribution, processing and animal production. Health risks associated with consumption of contaminated cereals were recognized and several countries have recommended permissible levels of mycotoxins. At ICRISAT, Patancheru, India, we have developed an enzyme-linked immunosorbent assay (ELISA)-based technology to detect aflatoxin B_1, *aflatoxin* M_1, *ochratoxin A and fumonisins in food and feeds.*

A large number of agricultural commodities are vulnerable to infestation by a group of fungi that produce toxic secondary metabolites called mycotoxins. Mycotoxins are a group of chemically diverse secondary metabolites that exhibit a wide array of biological effects. Some of the mycotoxins can be mutagenic, carcinogenic, embryo-toxic, nephro-toxic, teratogenic, oestrogenic or immunosuppressive. Among the various mycotoxins, aflatoxins, ochratoxins and fusarial toxins (fumonisins) assume significance due to their deleterious effects on human beings, poultry and livestock. The toxins are produced on cereal grains both in field and storage.

In sorghum *(Sorghum bicolor)* and pearl millet *(Pennisetum glaucum),* grain molds are important in relation to mycotoxin contamination. Grain mold fungi grow on or in seed (Williams and McDonald 1983). They affect sorghum

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and pearl millet grown in warm and wet conditions between flowering and harvest (Williams and Rao 1981, Williams and McDonald 1983). They are much more widespread in sorghum than in pearl millet because of the nature of the growing environments of the two crops. The problem of grain mold is encountered throughout the humid tropical and subtropical regions. It is particularly serious in areas where improved, short- and medium-duration cultivars that mature before the end of the rains have been cultivated. Under these conditions, the fungi such as *Aspergillus* spp, *Penicillium* spp and *Fusarium* spp can infect these crops and produce mycotoxins (Bandyopadhyay et al. 1988, Stenhouse et al. 1997).

According to Charmley et al. (1994), 25% of the world's food crops are affected by mycotoxins each year. The American Phytopathological Society (APS) reports that the loss in USA is estimated to be US$100 million per year (Source: APS Net). The most important mycotoxins that can frequently occur at biologically significant concentrations in cereals are aflatoxins, ochratoxins, fumonisins, zearalenone, moniliformin and trichothecenes (deoxynivalenol, nivalenol and T_2 toxin). These compounds can occur naturally in cereals, either individually or as specific clusters of two or more depending on the fungal species (or strain) implicated. These mycotoxins are associated with causative agents in various human and animal diseases. Mycotoxin contamination of crops cause economic losses at all levels of food and feed chain, including crop and animal production. Under certain environmental conditions the contamination of various cereal grains with mold fungi and mycotoxin is unavoidable. Therefore, the prevention of mycotoxin contamination of grain is the main goal of food and agricultural industries throughout the world. This report reviews some general information on the occurrence of toxigenic fungi and type of mycotoxins they produce in sorghum and pearl millet and their affect on human, animal health and economic losses. Most of the information has been accessed from the book 'Mycotoxins in agriculture and food safety' (Sinha and Bhatnagar 1998).

Toxigenic fungi on sorghum and pearl millet

Fungi that belongs to more than 40 genera are associated with molded grain including *Fusarium* spp, *Aspergillus* spp and *Penicillium* spp. These fungi produce mycotoxins in cereal grains and oil seeds (Fig. 1). The literature on toxigenic abilities of *Fusarium* species contain significant number of confusions, caused by usage of several taxonomic systems, wrong identification of toxigenic isolates or incorrect identification of mycotoxins (Chelkowsky 1989).

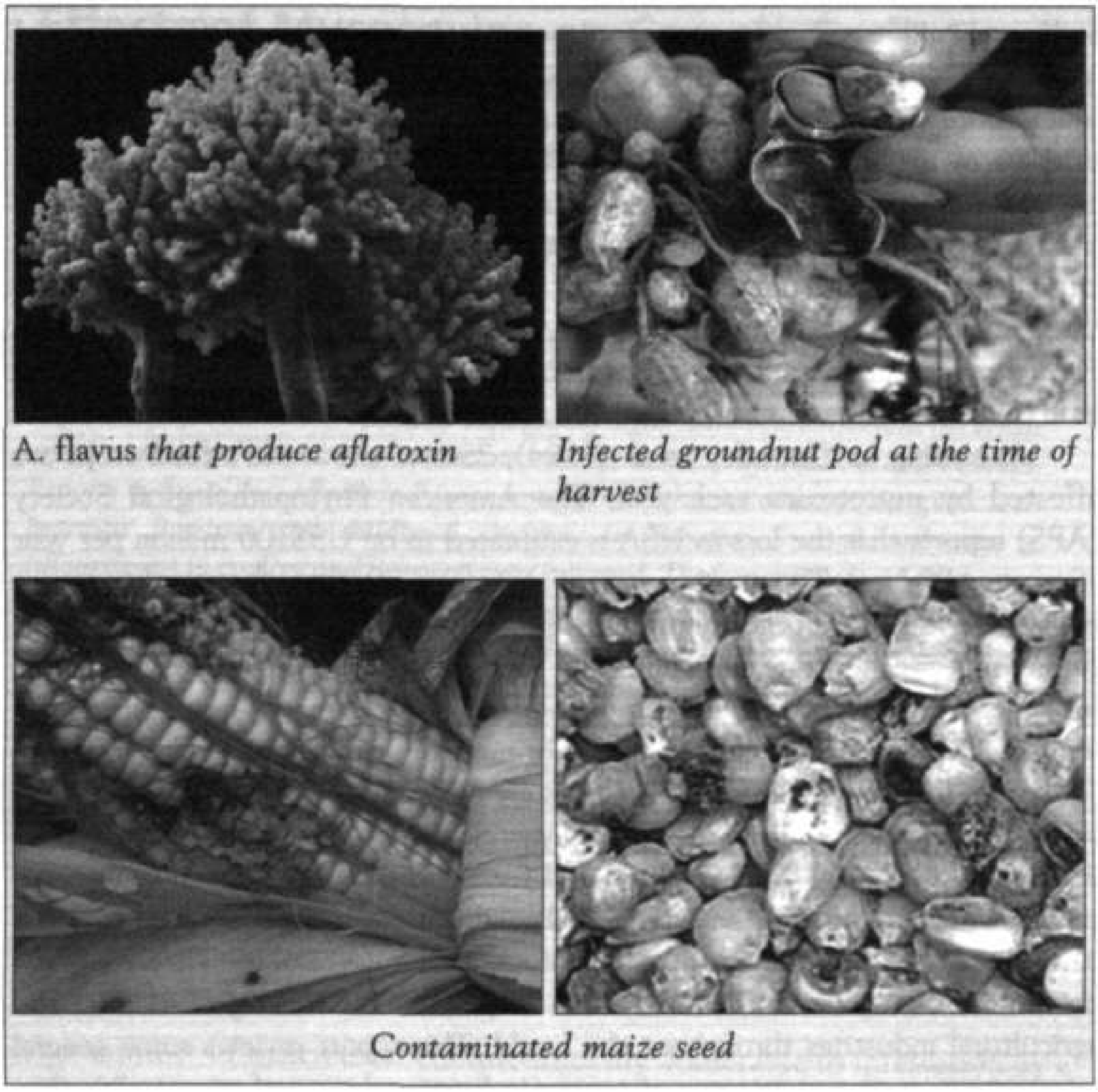

Figure 1. Groundnut and maize seeds affected by fungi that produce mycotoxins.

Effect of mycotoxins on human and animal health

Aflatoxins

Toxicologically, the aflatoxins, particularly aflatoxin B_1 (AFB_1) should be regarded as a quadruple threat, ie, as a potent toxin, carcinogen, teratogen and mutagen. AFB_1 induces liver cancer in several animal species, and has also been linked to liver cancer in human beings (Wang et al. 1996). Statistical correlations between contaminated food supplies and high frequencies of human hepatocellular carcinomas in Africa and Asia have implicated aflatoxins as risk factors in human liver cancer. All epidemiological studies of aflatoxins and liver cancer conducted in Africa and Asia involving populations subjected to hepatitis B virus (HBV) infection indicates possible synergistic effect of aflatoxins and HBV infection in the etiology of liver cancer (Van Rensberg 1986, Groopman and Kensler 1996, Montesano et al. 1997). Amla et al. (1974) presented circumstantial evidence to indicate that children exposed to aflatoxins through breast milk and dietary items may develop cirrhosis. They detected AFB, in 7% of urine samples from cirrhotic children.

No animal species are resistant to the acute toxic effects of aflatoxins. A wide variation in LD_{50} values has been obtained in animal species tested with single doses of aflatoxins. For most species, the LD_{50} value ranges from 0.5 to 10 mg kg^{-1} body weight. Animal species respond differently in their susceptibility to the chronic and acute toxicity of aflatoxins. Environmental factors, exposure level and duration of exposure besides age, health and nutritional status of diet can influence the toxicity.

Several outbreaks of aflatoxicosis in poultry have been reported from India. The disease symptoms included severe and sudden anorexia, loss of weight, staggering gait, convulsive movements, feed refusal and drop in egg production. Post-mortem examination of dead birds revealed liver lesions of varying severity (Char et al. 1982, Choudary 1986). An increase in blood clotting time increases the susceptibility of the carcass to bruising even at doses below that to have an effect on growth. In poultry, aflatoxins impair the availability of bile salts, which decreases vitamin D_3 production. This causes a decrease in the absorption of fat-soluble vitamins.

Several outbreaks of aflatoxicosis in cattle have been reported. The lesions were confined mainly to the liver, showing degenerative changes with biliary proliferation and finally leading to diffuse cirrhosis (Allcroft and Lewis 1963). Aflatoxin M_1 (AFM_1) is a major metabolite of aflatoxin B_1 found in milk of animals that have consumed feeds contaminated with aflatoxin B_1. The toxic and carcinogenic effects of AFM_1 have been convincingly demonstrated in laboratory animals and therefore AFM_1 is classified as class 2B human carcinogen. AFM_1 is relatively stable during pasteurization, storage and preparation of various dairy products. Therefore, AFM_1 contamination poses a significant threat to human health especially to children, who are major consumers of milk.

Ochratoxin A

Ochratoxin A has been implicated with a fatal human kidney disease referred to as 'Balkan Endemic Nephropathy' (BEN) characterized by contracted kidneys. Ochratoxin A has been found more frequently in food samples and in the serum taken from people in villages with BEN than in areas where the disease is unknown (Petkova-Boeharova et al. 1988). The toxin is nephrotoxic to most of the animal species and induces liver and kidney tumors. The renal lesions associated with diseases include degeneration of the proximal tubules and interstitial fibrosis in the renal cortex. Pigs fed with ochratoxin A, showed reduced feed intake, weight loss, increased water consumption, followed by polyurea diarrhea.

Fusarium toxins

Species of *Fusarium* are widespread in nature as saprobes in decaying vegetation and as parasites on all parts of plants. Many cause diseases of economically important plants. There are a number of species that produce mycotoxins, mostly fumonisins, zearalenone and trichothecenes (T_2 toxin, deoxynivalenol and nivalenol). A few common examples are discussed below.

Fumonisins

An outbreak of poisoning, characterized by abdominal pain and diarrhea, caused by the ingestion of fumonisin-contaminated maize *(Zea mays)* and sorghum in India was reported. People in 27 villages in Karnataka, India were affected and the disease was seen only in households which consumed sorghum or maize contaminated with fumonisin (Bhat et al. 1997). Consumption of fumonisin-contaminated maize has been linked to oesophageal cancer in humans in Transkei region of South Africa, China and other countries (Rheeder et al. 1992). Ingestion of fumonisin-contaminated maize has been associated with spontaneous outbreak of leucoencephalomalacia in horses, a neurological syndrome characterized by focal, often extensive, liquefactive necrosis of the white matter of the cerebrum, and white acute pulmonary edema in pigs. Although hepatic injury has been observed in all vertebrate species studied, a number of species-specific effects have been induced experimentally by the fumonisins on other target organs including renal injury and liver cancer in rats, immunosuppression in chicken, toxicity to broiler chicken and chicken embryos, nephrotoxicity and brain hemorrhage in rabbits (Marasas 1995).

T_2 toxin

Of the *Fusarium* trichothecenes, T_2 is the most toxic though less widely distributed than deoxynivalenol. The effects of the first trichothecene toxin, T_2, documented was in the 1940s where it was associated with an outbreak of alimentary toxic aleukia (ATA). At its peak, in 1944, the population in the Orenbury district and other districts of the then USSR suffered enormous casualties; more than 10% of the population was affected and many fatalities occurred (Joffe 1986). The term 'alimentary toxic' refers to the fact that the toxin is consumed in food and 'aleukia' refers to the reduced number of leucocytes or white blood cells in the affected person. Other symptoms included bleeding from nose and throat, and multiple, subcutaneous hemorrhages. The infected food in this case was millet, which made up a great part of the diet of the people in the region, and at times, during World War II, it was not uncommon to allow the millet to be left standing in the fields over winter because bad weather in the fall prevented its harvest at the proper time. During late winter and early spring the millet would become infected with various fungi, including *F. tricinctum,* and when the people gathered and ate this fungus, many were affected with what was diagnosed as ATA. Thousands were affected and many died (Joffe 1986).

In pigs, the clinical signs of T_2 toxicosis include emesis, posterior paresis, lethargy and frequent defecation. At low levels of contamination in the diet T_2 toxin causes reduced feed intake and animal performance. At high concentrations (>2 mg kg^{-1}) in the diet it produces diarrhea, emesis and feed refusal. T_2 toxicosis in poultry causes oral lesions, reduced feed consumption, reduced growth rate and egg production in laying hens. In ruminants the T_2 toxicosis results in a wide range of responses, such as feed refusal, leukopenia, depression, diarrhea, coagulopathy, enteritis and posterior ataxia. Reduction of humoral immunity is a common effect for pigs, poultry and ruminants and when exposed to low concentrations of T_2 toxin in the diet showed increased susceptibility to other diseases.

Zearalenone

Zearalenone and related metabolites pose strong estrogenic activity and can result in severe reproductive and infertility problem when fed to domestic animals in sufficient amounts. Pigs appear to be most sensitive; therefore, they are most frequently reported with problems caused by zearalenone, which include enlargement or swelling and reddening of the vulva in gilts and sows, swelling of mammary gland and atrophy, and prolapse of the ovaries, vagina and rectum. In young male pigs zearalenone can cause swelling of the prepuce, testicular atrophy and enlargement of the mammary glands, while in boars it causes reduced libido and marginal reduction in sperm quality.

Deoxynivalenol

Deoxynivalenol is also called vomitoxin and is the most important trichothecene because of its high incidence in cereals, but it is not one of the most acutely toxic of this group of mycotoxins (Rotter et al. 1996). At cellular level the main toxic effect is inhibition of protein synthesis via binding to ribosomes. In animals, the overt effect at low dietary concentrations (>2 mg g^{-1}) appears to be a reduction in food consumption and weight gain, while higher doses (>20 mg g^{1}) induce feed refusal, diarrhea and vomiting. Deoxynivalenol is known to alter brain neurochemicals, and serotoninergic system appears to play a role in mediation of the feeding behavior and emetic response. Animals fed low doses of toxin are able to recover from initial weight loss, while higher doses induce more long-term changes in feeding behavior. Pigs are more sensitive than other livestock to the presence of deoxynivalenol in their feed. Most of the clinical signs caused by the ingestion of deoxynivalenol are also observed with nivalenol, the latter being generally more toxic.

Economic losses caused by mycotoxins in sorghum and pearl millet

Some factors that influence the degree of fungal infestation and mycotoxin contamination in cereals are the prevailing weather conditions and the susceptibility of the crop to fungal invasion and mycotoxin contamination (Visconti 1996). During the seasons of extensive mycotoxin contamination, grain shortages may occur leading to elevated prices for grain and costs for livestock and poultry producers and consumers of grain products. Mycotoxigenic fungal infestation may reduce crop yields, seed germination rates, seedling vigor and grain quality. Mycotoxin contaminated grains are downgraded from food to feed, and additional cleaning and milling procedures may be required to reduce contamination, and export markets are affected.

Among all the mycotoxins, aflatoxin B_1 is the most toxic, carcinogenic and immunosuppressive agent to human beings and livestock. Mycotoxin exposure in humans increases medical and welfare costs, and reduces income potential of the individual. Consumer problems are related to less nutritious food, increased health risks in years of severe mycotoxin contamination, higher product prices and long-term chronic effects from low contamination.

Most economic losses due to consumption of mycotoxin contaminated diet by farm animals result from reduced animal production and increased disease incidence. Livestock producers are affected by increased production cost due to higher mortality rates, reproductive failures (abortions), reduced feed efficiency and overall quality loss. Presence of mycotoxins in poultry feed causes adverse effects on laying hen and broiler chicks. Moreover, consumption of feed containing a combination of toxins has a greater adverse effect on poultry than when feeds containing a single toxin are fed. Pigs are very sensitive to *Fusarium* mycotoxins in their diet. Deoxynivalenol can cause reduced feed intake, vomiting and reduced body weight gain. Delay in the time taken for pigs to reach the ideal marketing body weight or marketing pigs below normal weight can have serious economic consequences for pig producers. Economic implications of animal feed contaminated with fumonisins are significant, especially if contamination results in death of livestock.

Mycotoxin contamination in cereal and legume byproducts is hampered by strict regulation of many countries. Groundnut export was significantly reduced both in Asia and Africa because of very low permissible levels of aflatoxin B_1.Thus the reduction in the level of mycotoxins in agricultural products for food and feed is of high importance. Table 1 shows the permissible level of some of the mycotoxins in cereals.

Detection technologies

Several physio-chemical methods are available for estimation of mycotoxins. These methods are expensive and time consuming. At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, we have developed an ELISA (enzyme-linked immunosorbent assay)-based detection technique, which is cost effective and less time consuming. We have produced monoclonal and polyclonal antibodies for aflatoxin B_1 and determined the AFB_1 quantities in various foods and feed

Table 1. Worldwide recommended regulatory limits on *Fusarium* mycotoxins in cereals and cereal products.

Country	Mycotoxin	Commodity	Limit (ng g^{-1})
Austria	Deoxynivalenol	Wheat, rye/durum wheat	500-750
	Zearalenone	Wheat, rye, durum wheat	60
Brazil	Zearalenone	Maize	200
Canada	Deoxynivalenol	Uncleaned soft wheat (food)	2,000
	Deoxynivalenol	Diets for swine, young calves, lactating	1,000
		dairy animals, cattle, poultry	5,000
	All mycotoxins	Feedstuff for reproducing animals	0
France	Zearalenone	Cereals	200
Netherlands	All mycotoxins	Cereals (products)	0
Romania	Zearalenone	All foods	30
Russia	T_2 toxin	Cereals (wheat, hard and strong type), flour, wheat bran	100
	Zearalenone	Cereals (wheat, hard and strong type), flour, wheat bran	1,000
Switzerland	Fumonisins	Maize (products)	1,000
Uruguay	Zearalenone	Maize, barley	200
USA	Deoxynivalenol	Finished wheat products (food)	1,000
	Deoxynivalenol	Grains and grain byproducts for feed	5,000-10.000[1]
	Fumonisins	Maize (products) for feed	5,000-50,000[2]

1. 5,000 ng g^{-1} feed for pigs (not exceeding 40% of the diet); 10,000 ng g^{-1} feed for ruminating beef and **feed** lot **cattle** older than 4 months and for chicken (not exceeding 50% of the cattle or chicken total diet).
2. Feed for horses (5,000 ng g^{-1}), pigs (10,000 ng g^{-1}), and beef cattle and poultry (50,000 ng g^{-1}).

Source: FAO (1997).

materials. We have also produced polyclonal antibodies against aflatoxin M_1 and ochratoxin A, and developed technology to detect these toxins in milk, foods and feeds. We are in the process of refining the ELISA test for fumonisin detection.

Recently we produced polyclonal antibodies to fumonisin B_1. Like most of the mycotoxins, fumonisins are also low molecular weight compounds. Since the low molecular weight compounds do not stimulate the immune system in warm-blooded animals, it is essential to tag these compounds to a bigger protein molecule, such as bovine serum albumin (BSA). To produce polyclonal antibodies for fumonisin B_1, we prepared fumonisin-BSA conjugate (Feng-Yih Yu and Chu 1996). The rabbit was immunized 5 times (3 subcutaneous and 2 intra-muscular) each with 250 mg FBI-BSA conjugate and 8-9 bleedings were made for serum collection. High titered antibodies were obtained and an ELISA method was standardized.

Several animal feed samples were tested for fumonisin content using the antibodies produced. Different extraction methods were used. We faced some difficulties in extraction of fumonisin from crop residues. One hundred sorghum straw samples meant for cattle feed were collected from markets of Andhra Pradesh and analyzed for aflatoxins and fumonisin B,. All the samples were free from aflatoxins; however, 45% of the samples contained >100 ug kg^{-1} fumonisin B_1 (range 100-1600 ug kg^{-1}). As we have recently developed the test for fumonisins, we can now test many more samples to understand better the importance of fumonisin contamination and its implication on human and livestock health.

Conclusions

Mycotoxins are distributed widely in cereal crops, to the extent ubiquity in certain crops grown in specific regions and seasons. In cereals, grain quality as well as straw quality are important in relation to animal feed purpose. Mycotoxin contamination in sorghum and pearl millet grain was reported in different parts of the world. However, literature availability on mycotoxins in cereal straw is scanty. Since cereal straw is used for animal feed very extensively, it is essential to monitor the cereal straw for mycotoxin contamination. Moreover, after crop harvest, cereal straw in storage gets exposed to high temperature and high humidity that are conducive for the growth of mold fungi and subsequent mycotoxin production. To some extent, the presence of small amounts of mycotoxins in cereals and related food products is unavoidable. This necessitates monitoring of the food and feed samples at regular intervals. Some of the technologies available at ICRISAT can help different groups of people for better monitoring and analysis of their products for mycotoxins.

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Cereal Grain Procurement, Storage and Handling Systems for Commercial Use

S Sivakumar[1]

Abstract

For historical reasons, the grain procurement, storage and handling systems in India have evolved to suit a shortage economy. The focus has been on maximizing production, productivity and minimizing wastages in that order Supply-driven value chains built in such a context create a disconnect between the way a farmer sells (physical properties), a processor adds value (chemical properties) and a consumer buys (rheological and organoleptic properties). Aggregation of grain without preserving its identity while storing at FCl warehouses in the Government system, and while transporting from mandis *in the private marketing system creates the classical 'lemons problem'.*

Consumer-centric market economy must be supported by demand-driven storage and handling systems. The information related to the varied needs of multiple market segments needs to flow back seamlessly along the chain to enable producers deliver differentiated products to the consumers efficiently. Agribusiness firms in the developed world have met this need for identity preservation through models like vertical integration and contract farming. Large-scale replication of such models in India is not viable because the Indian farmers are fragmented, dispersed and heterogeneous. The problem is further compounded by weak infrastructure - physical, social and institutional.

However, by deploying information technology creatively through models like virtual integration, one can build efficient value chains even in India, notwithstanding above constraints. Information technology also helps in building traceability systems, which ensure visibility of the grain identity to the whole chain during the entire process of storage and handling from farmer to the consumer. Success of such a system depends heavily on linkages with the scientific community for decoding product chemistry from consumer perspective.

Grain procurement, storage, and handling systems in India have evolved to suit a shortage economy. Research and extension efforts of government organizations have primarily been oriented towards yield improvements and increasing total production by crop commodities. The Minimum Support Price Scheme for rice and wheat has eventually made the government the primary buyer. Grain procurement is facilitated through the Food

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Corporation of India (FCI). A combination of traditional and modern infrastructure exists for safekeeping and wastage reduction during grain storage and handling. Thus, the focus has been on maximizing grain production and productivity, and minimizing wastage.

The food value chain

The food value chain primarily has three elements (as shown in Fig. 1):

1. Primary production: High grain yields depend on favorable climate, soil and water resources, and other agricultural inputs, including high-yielding varieties.
2. Processing: Efficient methods of milling, curing and preserving are essential.
3. Retail: Quality products can be made available through efficient systems for grading, packaging and merchandizing.

The market functions include exchange (buying, selling), physical infrastructure (storage, transportation, processing), and facilitating (financing, information, risk bearing) functions.

Food economy in India and its implications

The supply-driven value chains differ in the exchange processes along the chain. For example, the farmer sells the product (grain) based on physical properties; a grain processor adds value based on chemical properties of grain;

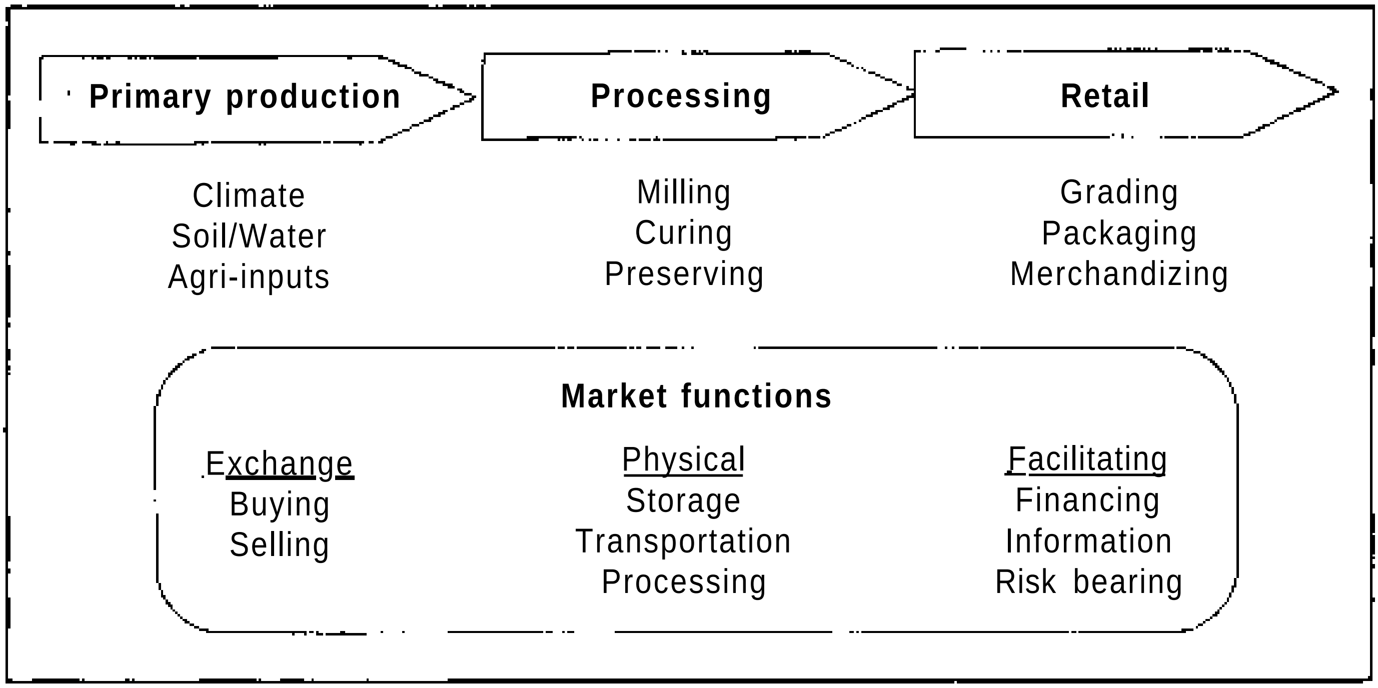

Figure 1. A diagrammatic representation of the food value chain.

and the consumer buys the products based on organoleptic properties. Farmers grow multiple varieties to suit different agroclimatic conditions (soil fertility, soil type, rainfall pattern, temperature, etc). However, the grain loses its source identity after aggregation while storing at warehouses by the government and transporting by village traders and the private sector. The aggregation of grain without preserving its identity results in the classical 'lemons problem'.

Consumer-centric market economy must be supported by demand-driven storage and handling systems. Consumers prefer different products to suit varied food preparations and individual tastes. The information on consumer preferences and requirements of multiple market segments need to flow seamlessly along the chain to enable producers deliver different products to the varying needs of different consumers efficiently. The infrastructure should be equipped with traceability systems to preserve identity of the source (of different varieties of the same crop).

Agribusiness firms in the developed world have preserved the source identity of the grain produced through models such as vertical integration of the food value chain and contract farming. Large-scale replication of such models in India is not viable because the landholdings of Indian farmers are small, fragmented, dispersed and heterogeneous. The social imperative of achieving global competitiveness in emerging economies like India is to bring the power of scale to the small farmers rather than displacing them. The problem is further aggravated by weak infrastructure (physical, social and institutional). Numerous intermediaries are present in the agricultural value chains of developing economies. These intermediaries or middlemen are a necessary evil. They are necessary because they not only make up for the lack of infrastructure but also block the information flow and market signals for their own benefit, thereby making the chain uncompetitive. Many 'middlemen' have exploited the small farmers by spinning a cycle of dependency starting with credit, leading to input sales and then on to output purchases. No matter whether the input is of spurious quality or the price bid for output is low, farmers have to go back to the same intermediary because the person offers the most flexible financing option. This environment has held the Indian food and agricultural chain at a low-level equilibrium, notwithstanding the potential upside, in light of the large arable land in multiple agroclimatic conditions as well as sound public agricultural research system.

Alternatives in market chain

Several alternatives have been tried from time to time to pull the sector out of this vicious cycle. Producers' cooperative has been one such system. While there are a few success stories among cooperatives, replication across different crops on a large scale has not been satisfactory. Further there are limitations in technology acquisition and marketing capabilities. The three-tier cooperative structure of Amul (the most successful among the producers' cooperatives in India, dealing with milk and milk products), led by small-farmer production, aggregated processing at the district level and a further aggregated marketing at the state level, is a supply-driven model that is more appropriate in a shortage economy. The transition to a demand-driven competitive market condition will be an interesting challenge to overcome, given the prevailing land ownership structure.

Contract farming is another viable solution although it has not been successful on a large scale due to credit risks and high costs. Theoretically, it is the most efficient link between the consumer and the farmer because the contracting company can provide the available inputs and best practices to the farmers, besides providing market linkages. The effectiveness is, however, limited to some crops (such as perishable, horticultural crops) that have natural reciprocal dependency in the value chain between the farmer and the company that provides an economic incentive for them to stay together in the long run. Large volume commodities such as grain crops are not the ideal candidates for contract farming because the natural reciprocal dependency is not very high.

Eventually, there is a need for the emergence of consumer-oriented business enterprises spanning the food and agricultural sector. But the current Government policies - notably high and multiple taxes, restrictions on movement of goods - benefit the unscrupulous players in the market chain because there are larger profits in tax evasion and adulteration, making the long-term oriented, consumer-focused businesses unviable.

The future

Despite the above constraints, efficient value chains can be built even in India by using information technology creatively through models like virtual integration. The value chain should be demand driven, with the farmer having a freedom of choice on farming decisions (contrasted with the exploitative cycle of dependency spun by the traditional intermediary and middlemen). The business model should be able to deliver effective service at low cost notwithstanding the fragmentation, dispersion, heterogeneity and weak infrastructure. The ITC Limited's eChoupal [a village group using information and communication technology (ICT)-based information sharing] is built on these very principles. It gives the farmer an end-to-end complete solution (information like commodity prices and local weather forecasts, knowledge on best farm practices, quality inputs, and access to credit and output markets). It empowers the farmer to transact sale of grain from home, instead of incurring transportation cost to the market-yard, as required in the traditional marketing system. Because the grain is bought directly from the farmer at the village, there is a source identity even as the products reach consumers. Information technology also helps in building traceability systems, which ensure visibility of the grain identity to the whole chain during the entire process of storage and handling, from the farmer to the consumer.

Long-term success of demand-driven value chain depends heavily on linkages with the scientific community for assessing product quality from a consumer perspective, using rapid testing equipment that can link physical properties with chemical properties of grain, as well as with the organoleptic properties, to eliminate the disconnect that exists in the supply-driven value chains.

Sorghum: A Potential Source of Raw Material for Agro-industries

RB Somani[1] and JRN Taylor[2]

Abstract

Adaptation to poor habitats, poor resource base and production and consumption by poorer sections of the society have made sorghum crop an indispensable component of dryland agriculture. It is a drought hardy crop, can withstand waterlogging and thus excels over maize; it is also ecologically sound and environment friendly demanding little pesticide use for crop management. Notwithstanding the moderate contribution of sorghum to the national food basket, this crop offers enormous advantages such as early maturity, wide adaptation, ease of cultivation and good nutritive value of both grain and fodder With the green revolution and availability of fine cereals in remote places, proper disposition by value addition and establishing food, feed, beverages, sugars and alcohol industries will not only generate employment potential but also improve the regional economy. Sorghum is a valuable food grain for many of the world's most food insecure people. Much of Africa and India is characterized by semi-arid tropical climatic conditions. Sorghum is undoubtedly and uniquely adapted in the Afro-Asian regions. Sorghum in Africa and Asia is processed into a very wide variety of nutritive food products. Documentation, standardization, popularization and commercial exploitation of traditional products need attention. A large number of accessions are available. Proper selection for the requirements of the end users is necessary. Use of new biotechnological tools such as anti-sense gene technology to incorporate desired traits is now possible.

Continuing focused fundamental and applied research is essential to unleash sorghum's capacity to be the cornerstone in food, feed, fuel and fiber sectors in Afro-Asian countries. Sorghum types of both the continents are different; in Africa it is 'milo' based whereas in the Indian subcontinent it is 'caudatum' type. More attention on dehulling and debranning of red sorghum and mold resistance in white sorghum is anticipated. The future for sweet sorghum or high energy sorghum is also bright. Combined efforts of research institutions, private seed sector, industry and the government are necessary for its commercial exploitation. So far, there was a concept of developing agro-based industry. However, we now have to think of industry-based agriculture.

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Cereal grains have been the principle source of calories in the human diet, with starch contributing 80% of human calories intake. Among cereals, sorghum (Sorghum bicolor) is rated very high for dry matter accumulation rate when compared on a daily basis. Similarly, sorghum has the highest food energy per unit cultural energy, exceeding maize (Zea mays) silage, sugarcane (Saccharum officinarum) and maize grains. Being a C4 species, it is one of the most photosynthetic efficient plant species producing directly fermentable sugars as well as grains. It is one of the most ideal crops for simultaneous production of food and energy that can be cultivated in both temperate and tropical environments due to its drought tolerance.

After USA, India is the second largest producer of sorghum grain. In India, sorghum is being grown in rainy and postrainy seasons. Areasonable level of stability in grain yield has been reached in the last decade in the state of Maharashtra, India. Introduction of photo-insensitive, short-duration and high-yielding hybrids on an acreage of >92% in rainy season resulted in higher productivity, ie, up to 1.8 t ha^{1}. However, even with the increase in human population, the consumption of this coarse cereal has not increased even in those regions where sorghum has been the traditional staple grain in the past. According to the National Sample Survey Organisation (1988), consumption of sorghum as food is 44.3, 31.7, 17.02 and 16.41% in Maharashtra, Karnataka, Gujarat and Madhya Pradesh, respectively. However, per capita consumption of sorghum has declined from 23.2 kg yr^{-1} in 1981 to 14.4 kg yr^{-1} in 1989. In Maharashtra consumption declined from 106 kg yr^{-1} in 1961 to 66.7 kg yr^{1} in 1989. A sample survey undertaken by the first author in Amravati division of Maharashtra during 1992-93 revealed further decline in consumption of sorghum, whereas there is a slight increase in demand in urban areas only for postrainy season sorghum. The fall in consumption even in remote areas could be attributed to price factor, status of the grain, easy availability of fine cereals such as wheat (Triticum aestivum) and rice (Oryza sativa) through Public Distribution System (PDS) and fine road network.

In Vidarbha, Marathwada and Khandesh regions of Maharashtra, southern Gujarat and western Madhya Pradesh, sorghum is usually grown in rainy season as a rainfed crop. The crop is usually caught in rains at grain-filling stage and the grains become discolored due to molds. The discolored grains cannot be stored for long periods and have low nutritive value. Considering these factors, producers bring their discolored produce immediately to the market and due to glut, it fetches very low price. However, farmers cannot switch over to some other more remunerative crops such as sunflower

(Helianthus annuus) and soybean *(Glycine max)* since there is no alternative/ substitute to sorghum in rainfed cropping system for dry fodder. Unless substitute for cattle fodder is suggested, sorghum has to be grown irrespective of market price of grain. Therefore, diversification of its uses for making this crop more remunerative is essential.

Since highly productive short-duration hybrids are under cultivation, prices come down when production exceeds the demand. There is thus no incentive for increasing sorghum production and many farmers tend to keep the production at subsistence levels, without any increase in input costs, even when output potential of the crop is quite high. Producers are influenced by two factors; one is the market price, which is often lower than wheat and maize. The second factor is that demand for sorghum has a degree of inflexibility, in that some buyers cannot easily change feed/food formulations.

In Africa, sorghum is still largely a subsistence food crop, but it is increasingly being used in bakery and beverage industries. Sorghum grains from South Africa have brown/red pericarp and some genotypes have colored testa. This is due to condensed tannins known as proanthocyanidins located in the testa and pericarp of the grain. Tannins confer considerable agronomic advantages. Tannin sorghums are less attractive to bird predation, a major problem in southern Africa. The tannins also protect these sorghums from insect pests and diseases. However, tannins bind with both the grain proteins and enzymes of the digestive tract and thus reduce the nutritional value of the grain. The tannins also adversely affect the quality of malt by reducing the enzyme activity. However, as a drought resistant crop, sorghum may enjoy a bright future, especially with genetic inputs to new food/feed grain strains. Sorghum is crucially important to food security in Africa as it is uniquely drought resistant among cereals and can withstand periods of high temperature. A yield trial of 30 entries in Zimbabwe (28 sorghum genotypes and 2 maize hybrids) showed that under irrigation the maize hybrids ranked 11 and 22 whereas under drought conditions they ranked 28 and 30. In fact, sorghum is not only drought resistant but also can withstand periods of waterlogging.

Diversification of crop use can make sorghum production more remunerative and can result in certainty of the market demand and price. The research should be oriented in this direction. The whole plant utilization concept and source of raw material for agro-industries need more attention. It is truly a 'F4' (food, fodder, feed and fuel) crop with additional prospects of being a good source of sugars (Somani 1996). Several potential areas where sorghum cannot be used are discussed in this paper.

Export

At present Japan, Mexico, West European countries, Israel and Taiwan are the major importing countries. Except in some Asian countries and Africa, sorghum is used as feed. Due to more emphasis on increasing meat production in China, Korea, former USSR, etc, the prospects for inclusion of sorghum in feed rations have brightened. In Vietnam, egg production has gone down due to higher feed prices; maize can well be replaced by sorghum to improve the situation. Sorghum production in Asia is around 20 million t (Table 1). Share of India and China to total sorghum production in Asia is 54% and 31% in 1988 and 69% and 20% in 2000, respectively. It is estimated that after 2000, Yemen (N), Pakistan and China will have deficit of sorghum supply and India will have surplus production (Kelley et al. 1991). Import demand of Iran and OPEC (Organization of the Petroleum Exporting Countries) will suddenly rise in near future to fulfill the requirements of sugars and dextrin. Considering the scope, feed type of sorghum needs to be encouraged for growing on larger areas. In India most of the high-yielding varieties and hybrids are dwarf and early maturing and fulfill the international criterion of feed and national requirement of food and fodder. Improvement of the trading sector and export agencies, both public and private, is essential to successfully utilize

Table 1. Projected production and consumption (million t) of sorghum in 2000 in selected countries in Asia.

Country	Production	Food	Feed	Total	Surplus/Deficit
India	13.74	10.47	1.34	11.81	+1.94
China	4.08	1.80	5.11	6.91	-2.82
Australia	1.04	0.03	0.85	0.88	+0.16
Yemen (N)	0.21	0.82		0.82	+0.60
Thailand	0.38	0.03	0.12	0.15	+0.23
Pakistan	0.19	0.22	0	0.22	-0.03
Taiwan	0.26	0.02	1.29	1.31	-1.05
Israel	0	0.05	0.16	0.21	-0.21
Japan	0		4.32	4.32	-4.32
Total Asia	19.91	13.44	13.19	26.63	-6.72

Source: Kelley et al. (1991).

the surplus. Attempts by the government to export had been made but the price fetched for discolored grains was US$68 t^{-1} in 1994. Hence, it was proposed for value addition rather than export. However, today the international rate is around US$130 t^{-1}; hence, export can be profitable. Since there are no tannins in Indian sorghums, its acceptance will be more at the international market; cultivars grown world over have much tannins in the grains (Somani 1996).

Food

Sorghum cultivars having high caloric value and no tannins are desired for food purposes. Total digestible protein should be sufficiently high and the endosperm should not be more corneous as milling is difficult and flour recovery is less (requires higher grinding energy). However, such quality grains are highly susceptible to grain molds. Therefore, development of cultivars with aforementioned desired traits and well adapted for postrainy season needs intensive research efforts. Such produce fetches good market price. However, rainy season produce has to be utilized for alcohol, glucose, high fructose syrup, etc, since hardly 2/5 of this produce goes for food purposes. Increasing purchasing power and elasticity of demand will be the driving forces behind the future increase in consumption of animal food products in India. It is predicted that the change in India's food consumption patterns will be similar to those experienced by other countries such as Japan and Korea (Mc Kinsey 1997). Normally cereal consumption declines and protein consumption goes up as per capita income increases. The National Statistical Survey confirms this for both rural and urban India (Table 2).

Table 2. Relative consumption (million t) of cereals and pulses in rural and urban India.

Commodity	1970	1990
Urban		
Cereals	36	26
Pulses	20	25
Rural		
Cereals	54	37
Pulses	15	21

Feed

Cultivars good for food are good for feed. Protein binder, ie, tannin is not present in Indian sorghums. With the increasing per capita income, demand for meat, eggs and milk has gone up. However, consumption as compared to other countries is low (Table 3).

Poultry feed

The demand for sorghum in poultry feed largely depends on price and availability of maize. Inclusion of sorghum up to 10% for layers and 15% for broilers is common. However, this rate goes up in the years of higher prices of maize. If sorghum has to be made more competitive, the price should be around 70 to 80% that of maize. Poultry sector is likely to grow at 8 to 10% per annum in the case of layers and around 15% for broilers. Thus, the increasing demand for sorghum from poultry feed sector is expected to result in deficit in energy source considering low availability of maize in the country and higher import price. It was also revealed during discussion with layer industry people in Andhra Pradesh, India that sorghum is less preferred than maize because of low carotene that gives less yellow color to yolk. However, supplementation using other cheaper carotene sources is possible. The gene for more carotene production could be incorporated through genetic engineering. Another misconception and misunderstanding with feed manufacturers is that sorghum grains contain more tannins and discolored grains contain more aflatoxins besides less energy value in comparison to maize. It is necessary to bring to the notice of entrepreneurs and extension workers some facts about sorghum grain. The technology for primary processing of sorghum has been already developed. All cultivated white- grained sorghums contain practically no tannins and there are less chances of aflatoxin contamination. Samples analyzed at various national and international laboratories did not reveal

Table 3. Per capita per annum consumption of milk and poultry products in 1992.

Commodity	India	China	USA
Milk (kg)	65	3	104
Eggs (pieces)	26	163	181
Poultry meat (kg)	0.5	4	40

Source: World Bank (1996).

presence of aflatoxins. Studies undertaken by the Natural Resources Institute (NRI), UK revealed mycotoxins below tolerance levels in all samples and very interestingly, the levels decreased during storage, whereas in all other grains the trend was generally reverse. It might be due to aconitic acid present in the sorghum grains (Hodges 2000); however, it needs confirmation. Sorghum is more or less at par with maize as regards to energy. Maize has more oil as compared to sorghum; calorific value for the fat is compensated by higher starch and protein in sorghum. In case of moldy grains, there is reduction in starch content; however, protein is unchanged and change in amino acid profile was in desired way.

Near Pune, India two persons who graduated from Edinburgh, UK are using solely sorghum as poultry feed for a long period without any adverse effect on production of eggs and meat. Saxena (1994) also opined that sorghum shall be preferred over maize and the Universities shall come out with the data to impress upon the poultry feed industry. Whatever information the industry has is based on milo-based sorghums. Some see it as a good energy alternative to maize, whereas others consider the energy level in sorghum as low. These disparities may be due to the quality of sorghum examined. The Project Directorate on Poultry, Hyderabad, India reported that apparent metabolizable energy of sorghum is much higher than maize and pearl millet (*Pennisetum glaucum).* Composition of layer mash used on commercial farms included 21% sorghum (Saxena 1994). Pathological studies on feeding of highly discolored sorghum grains to broilers at Akola, Maharashtra indicated that maize can be replaced up to 75% without any adverse effect on body weight, hematological and biochemical parameters when compared to normal sorghum; however, maize has shown better response than sorghum (Joshi and Joshi 1996). But with the modern tools of genetic engineering it is possible to manipulate and incorporate desired trait considering that sorghum is an established traditional crop in the rainfed agriculture system. Washed and sun-dried, highly discolored sorghum grains when fed to poultry birds improved humoral and immune response when compared with normal sorghum and maize grains (Joshi and Joshi 1996).

Animal feed

In India on an average, 250 g grains are consumed per dairy animal. Consumption of sorghum grain by dairy cattle is highest in northern India and lowest in southern India. Considering the population of animals and the

Government policy for white revolution, the requirement of grains by feed industries will be quite high. Total feed production had gone up from 0.48 million t in 1974 to 2.9 million t in 1996-97. The World Bank estimates deficit of 2.6 million t in concentrate feed and 251 million t of roughages. According to Dairy India (1997), the annual growth rate of milk production was about 5% during 1980s and 1990s. During 1998-99, 4 million t of dairy feed was produced by the commercial sector. The standard dairy ration comprises 10% grains, which corresponds to 0.4 million t of grains per annum. Assuming annual growth rate at 3%, the requirement will be around 0.44 million t by 2002.

In sorghum-growing areas, sorghum in substantial quantity is consumed on farm by small-scale dairy farmers. Besides cost, availability and quality of sorghum the common problem for feed millers is grain storage. Feed manufacturers are more keen about the price rather than the quality and hence prices for 'Disco' grade are usually quoted and supplied. Such moldy grain cannot be stored for long periods as it deteriorates further under storage conditions. In the 1990s the Maharashtra State Government auctioned deteriorated grains stored in their godowns at very low price and the feed industry people in Gujarat purchased them. Maize is more prone to deterioration as compared to sorghum and mycotoxin level goes down in sorghum during storage. Hence, it is advantageous for incorporation of sorghum in animal feed formulations. The utilization of sorghum as feed in North America is 97% as against 27% in Asia.

Considering the nutritional value of sorghum (Table 4) and probable shortage of grain and roughages and limitations of maize cultivation in the country, there will be wide scope for more inclusion of sorghum in feed formulations. If comparative price trend of *kharif* (rainy) season sorghum over

Table 4. Nutritional values of grains for dairy cattle[1].

Grain	Dry matter (%)	Protein (%)		TDN (%)	Energy (k cal kg^{-1})		Ca (%)	P (%)
		Total	Digestible		Digestible	Metabolizable		
Barley	90	8.7	6.9	79	3483	-	0.06	0.33
Pearl millet	89	11.9	5.1	61	2665	2185	0.12	0.46
Sorghum	87	15.2	7.3	86	3772	3093	0.12	0.44
Maize	89	8.9	6.8	81	3571	2928	0.02	0.31
Oat	89	11.8	8.8	68	2998	2458	0.10	0.35
Wheat	89	13.0	10.1	78	3449	2820	0.50	0.40

1. TDN = Total digestible nutrients; Ca = Calcium; P = Phosphorus.

years is considered, its price was 10 to 30% lower than that of maize. It is available in sufficient quantity during October-January at much low rate and thereafter, the rates increase. Nevertheless, the price will be lower than that of maize (Table 5). Thus considering the demand of grains in feed and limitations in importing maize, sorghum has a bright future. Unless there is good demand for sorghum, farmers in rainfed agriculture system are not prepared to increase inputs for increased production.

Processing

Sweet sorghum

A well grown sweet sorghum crop harvested at physiological grain maturity yields about 1-2 t of grains, 10-15 t of fresh leaves and tops and 40-50 t of stripped stalks. The crop maturity is attained in 125-130 days. The juice can be extracted by crushing stalks using roller mills commonly used in sugar mills to crush sugarcane or diffuser. The juice extraction rate is 40 to 45% with two-roller extractor; however, it can be up to 55% with cane crusher. The juice is acidic having pH 4.5-5.2 due to presence of aconitic acid. Brix reading is 14 to 21 and specific gravity is 1.05 to 1.08. The juice also contains starch ranging from 0.5 to 2.0%. The ratio of sucrose to reducing sugars ranges from about 10:1 in high sucrose type to about 3:1 in low sucrose varieties. Crystallization of sucrose is a bit difficult due to presence of aconitic acid and starch. The technology has already been perfected to get crystallized sugar in the laboratory. Use of amylases reduces starch which mostly interfere with crystallization. Invertase activity is fast under central and southern Indian conditions. However, excellent results have been obtained in Iran (Kulkarni et al. 1995). Technology for sugarcane purification can very well be utilized to get excellent crystal clear syrup which can replace cane sugar in many commercial products, viz, beverages, confectionery and ice cream. The process has also been developed to convert both cane juice and sweet sorghum stalk juice to glucose syrup.

Table 5. Indicative average price (Rs t^{-1}) of maize and sorghum grain paid by feed industries in India.

Crop	1993-94	1994-95	1995-96	1996-97	2001-02
Maize	2370	4980	5130	5200	5340
Sorghum	2020	4730	4680	4500	4700

The juice can also be fermented to get good quality alcohol. The yield of alcohol can be estimated by using the formula:

(Brix -3) x specific gravity x 0.59

The effluent generated is less with low biological oxygen demand and chemical oxygen demand as compared to that generated in sugarcane molasses-based unit. Interestingly, the yeast strains for converting cane juice or sorghum grain are not efficient to convert sweet sorghum juice. Acidification of juice and heating converts starch to simple sugars; also, no sterilization is necessary. The process has been standardized and ready for commercialization. When the whole stalks are subjected to the extraction process, the impurities in the rind and the leaf sheath (silica, waxes, phenol compounds, pigments, proteins, etc) also get extracted from the rind. If juice is extracted from the pith (without rind) the impurities will automatically be eliminated. It is necessary if crystalline sugar or syrup is to be produced.

Bagasse can be used for fodder purpose or for silage or good nutritive feed can be prepared by taking 40-60% of finely chopped or powdered bagasse to which 40% molasses, 5% cereal grains and pulse mill waste and 10% minerals are added. Compressed blocks can be prepared for easy storage. Bagasse sprayed with 2% urea is good feed for animals. Good quality particle board can also be prepared and the process has been developed at Carlsberg Research Laboratory, Denmark.

Grain processing

Except for much smaller size and generally oval shape the structure of sorghum grain is remarkably similar to that of maize. Both grains have floury and horny endosperm and fat-rich germ. Neither grain has a true hull. This means that processing technologies such as methods of dry and wet milling applied to maize can be applied to sorghum. Pericarp of sorghum grain appears to be more friable. It is disadvantageous in dry milling as the flour can become contaminated with bran. The friable nature of the pericarp may be due to presence of starch granules. Sorghum proteins like those of all cereals except wheat, do not have the ability to form a gas-holding, viscous elastic dough. However, leavened bread-type products have traditionally been produced in Africa using sorghum. Similarly, in India too, some of the traditional products prepared from sorghum are organoleptically good. Standardization on documentation and commercial exploitation is necessary.

Sorghum grain is usually processed by dry milling to make flour for bread. Other processing methods include rolling, steaming, flaking, popping, parching, malting and fermentation. Dehulling (pearling) is practiced only in some parts of the country particularly, the southern Indian states. Dehulling is commonly done by hand pounding, which is laborious and time consuming. Mechanical dehullers not only save time but large quantity of grains can be processed with uniform and better quality. Several types of mills have been developed in India for dehulling; however, these mills have not become popular among the consumers. Tangential abrasive dehulling device (TADD) is commonly used worldwide. Dehulling removes coarse fibrous outer coat so that the product is more appealing to consumers. It is very useful in removing the outer black coat (due to grain molds) of grains damaged by rains. However, good amount of starch is lost in dehulling. Prairie Research Laboratory (PRL) dehuller was first developed in Canada and is very commonly used in the subcontinent. The drawbacks of the PRL dehuller for industrial milling is that the batch size is rather small. Besides, milling losses can be very high up to 30%. To overcome these problems, a small roller mill has been developed. This mill consists of 2 or 3 pairs of rollers and a vibrating screen sieving device to remove bran from the flour. Typically, such mills have a capacity of 500 kg h^{-1}. Research has shown that with moderate pre-conditioning (to 16% moisture), milling with such a roller mill can consistently produce sorghum meal of higher extraction, and slightly lower ash and fat content compared to debranning and hammer milling.

In India dry milling of grains for bread purpose is carried out in small quantities always, since staling of flour is common. This may be due to aconitic acid or some free fatty acids. Sorghum flour is commonly used in preparation of red *'Kankoo'* since its plasticity is less at ambient temperature as compared to other cereal grains. Indian sorghums have white grains and are susceptible to grain molds resulting in enormous losses. The colored-grain sorghums can also be grown since they are resistant to grain molds and deterrent to birds. The tannins can be removed by various processes. The grains are more floury and waxy and thus have advantages in industrial uses. Pigment from colored glumes was obtained (Somani 2000). This color can be used in food preparations also. China is now producing a good quantity of natural color from non-tan stalk sheath and glumes.

Grit production

Information on dry milling of sorghum is scanty and currently available technology is inadequate. Sorghum is harder than wheat. More corneous grains on dehulling can be processed for semolina production. The sick wheat rolling machines in Maharashtra can be used for semolina production with little change in sequence of processing. The semolina is in good demand in southern states for uttapa and other similar preparations. However, only good grains can be processed for the purpose. The recently developed hybrid SSH 1 has been found to give more grit output. Grits can be used as adjunct in beer making.

Starch production

Grain sorghum is similar to maize in its composition and properties (Table 6). Hence, the technology developed to extract starch from maize can be used for sorghum with slight modifications. The technology developed in Germany for maize processing failed to give desired results when used for starch extraction from sorghum. The work done in the past at the International Crops Research Institute for the Semi-Arid Tropics (1CRISAT), Patancheru, India and other institutions on starch extraction yielded off-white starch. However, the modifications in steeping, coarse grinding and fiber washing system have yielded good quality of absolutely white starch. Few starch industries in Gujarat and Madhya Pradesh are using sorghum when either maize is in short supply or the cost is relatively very high as compared to sorghum. Sorghum starch before drying is mainly used for starch powder or liquid and glucose production. Dextrin produced from sorghum has shown superiority over maize.

Table 6. Chemical composition of maize and sorghum grains.

Constituent	Sorghum	Maize
Starch (%)	70	68.5
Protein (%)	9	6.2
Fats (%)	3.6	4.6
Ash (%)	1.94	1.7
Crude fiber (%)	1.90	1.9
Starch granule size (mm)	6-25	10-30
Amylose content (%)	23-28	24
Oil in germ (%)	52	52-58
Oil extraction (on grain weight basis) (%)	2-2.3	3.4
Color of oil	Dark red	Pale
Starch extraction rate (%)	50-54	57-61
8% starch solution viscosity (Brabender unit)	630-858	650-865
Viscosity at 95℃ after 1 h (Brabender unit)	370-550	375-575
Viscosity at 50℃ (Brabender unit)	938-1075	930-1110
Viscosity at 40℃ (Brabender unit)	1078-1580	1075-1580

Of the three methods tried, adding lactic acid (1%) during steeping or addition of lactic acid bacterial culture gave comparatively higher starch yield and good quality white starch. Viscoamylograph of sorghum starch thus extracted has shown similar trend to that of maize starch. At present, some industries in Gujarat and Madhya Pradesh are utilizing sorghum for starch extraction. There is a misconception amongst users that the starch of sorghum is not as good as that of maize. In fact, actual users could not differentiate sorghum starch and maize starch. Sorghum starch has good application in dextrose monohydrate, liquid glucose, dextrin and sorbitol production besides its common utilization as binders, glue, thickeners, and for adsorption of radioisotopes from effluents generated in heavy water plants and in synthetic polymers. Sorghum germs are small and recovery of oil is also less as compared to that from maize germ. The color intensity of sorghum oil is much higher and hence less preferred by users for edible purposes. At present, it has application in soap industries. Oil contains low levels of stearic acid (4%) and palmitic acid (10%).

In starch separation process, a good amount of pentosan-like material is separated which can be exploited to produce high quality glue, xylose and xylitol. Research is also necessary to lower the color value of germ oil since there is no market demand for intense colored oils.

Sugars

If the production of sugars, viz, glucose and high fructose syrup (HFS) from sorghum is successful, it is estimated that sugars from cereals may replace 30-40% of cane sugar in bakery, confectionery, biscuits and beverages. Traditionally, starch is first separated from the grains and then acid hydrolyzed (pH 1.8-2.0). Dehydration occurs within the dextrose molecules giving rise initially to 5-hydroxymethyl furfuraldehyde, with further transformation taking place to yield levulinic acid or polymers of hydroxymethyl furfuraldehyde. A recombination of dextrose also occurs to form disaccharides having 1-6 alpha and 1-6 beta linkages. The rate of formation of degradation product increases with the strength of acid, concentration of starch and reaction temperature. For economic reasons, a sufficiently high concentration of starch has to be used to avoid the removal of large quantities of water at a later stage. The major limitation is the completely random nature of acid hydrolysates which makes the sugar composition solely dependent on the degree of hydrolysis. This makes it difficult to adopt the properties to the highly diversified requirements of modern food industries.

Liquid glucose, glucose powder and dextrose monohydrate are usually produced universally by starch industries. Starch slurry prior to drying is subjected either to acid hydrolysis for production of low dextrose equivalent (DE) liquid glucose, or to acid-enzyme or enzyme-enzyme process to get high DE liquid glucose. High DE liquid glucose is usually converted either to glucose powder or dextrose monohydrate or fructose syrup. However, for starch extraction, moldy grains cannot be used and thus disposal of moldy grains remains a problem.

A process has been developed by Somani et al. (1995) wherein no starch separation is required and whole grains of any quality can be used to convert to sugars. However, in this method yield of sugars is high. In case of sorghum, much of the starch is present in the mesocarp and it is lost along with the effluent since no efficient system had so far been available to separate it. In the technology developed at Dr Panjabrao Deshmukh Krishi Vidyapeeth (PDKV), Akola, Maharashtra, the whole starch present in the grains, irrespective of its distribution, is converted and conversion efficiency is more than 95%. Moreover, high DE liquid glucose is obtained. The patent for the process is pending.

A mini (pilot) plant has recently been erected at Akola and trial run will be taken very shortly. However, testing of all sections of the mini plant has been done and found satisfactory. The whole unit will be run shortly. Samples will be sent to end users to know their reaction. The process may be modified to suit the requirement of various industries utilizing liquid glucose. If this process proves to be successful, small independent units can be commissioned and grains of any quality could be used. The yield of liquid glucose, however, would depend upon the quantum of starch present in the grains.

Grain spirit

India had been producing ethanol from molasses that was the cheapest source due to controlled price and regulation of supplies by the Government of India. But decontrol of price and supplies resulted in escalation of price from merely Rs 144 t^{-1} to Rs 2000 t^{-1} in Maharashtra and up to Rs 4000 t^{-1} in other states. This has increased ethanol prices to Rs 18-20 L^{-1} in different states from only Rs 6.60 L^{-1} in 1994. This has resulted in partial capacity utilization of existing distilleries in India. The molasses-based distilleries hardly run for 150 to 170 days a year.

The ongoing economic liberalization in India has made it obligatory on the part of Indian liquor industries to improve the quality of ethyl alcohol so as to compete globally. Ethyl alcohol obtained from molasses contains sulfur and hence the quality is inferior to that from non-molasses alcohol even after purification. Moreover, the process is not eco-friendly as it generates more effluents. In the developed countries, ethanol is made from maize, wheat and rye (Secale cereale). In China, maximum ethanol production is from sweet sorghum. In Brazil, ethanol is produced mostly from cane juice followed by sweet sorghum. Now most of the leading breweries have signed a Memorandum of Understanding (MOU) to manufacture world famous brands in India. Hence there is a new market for good quality alcohol from feed stocks other than molasses.

Superiority of alcohol from sorghum grains has attracted many foreign investors and liquor manufacturers since the cost of production is less in India. The alcohol produced from grains is neutral alcohol and needs very less refinement to meet international standards whereas that from molasses is rectified spirit and needs much refinement even though it would not be of high quality. The technology was developed and demonstrated at PDKV and a simple single compact column to yield more than 90% strength alcohol was also developed. An effluent treatment process using vaccuoporation technology was also developed. Around 22 to 26% distillers' grains containing 27 to 28% protein is also obtained, which is an excellent feed. Soluble solids are concentrated using multiple vacuum evaporator and mixed with distillers' grains and dried; the product has export potential too.

The advantages of preparing neutral alcohol from sorghum grain over molasses are given below:

- Alcohol production from sorghum can be a farm-based industry. Micro distilleries can be established.
- Only 3 to 4 columns are required as against 7 to 9 in molasses-based industry for extra neutral alcohol.
- Aroma and purity of alcohol is far better than from molasses. All over the world, grain spirit is only used for potable purposes, pharmaceuticals and perfumery since it does not have sulfur odor.
- Industry can run round the year as distillery in sugar industry runs only for 150-170 days yr^{-1}.
- Storage of molasses, acid resistant equipment and more pollution are the disadvantages in the sugar industry. However, in sorghum-based industry, there is no storage problem and high pressure or acid resistant equipment is not required.

- Quantity of spent wash is around 1/4 of that in molasses-based unit. Chemical oxygen demand, biological oxygen demand and color of spent wash are very less in grain-based distillery.
- Raw material is easily available round the year. Grains of any quality can be used; rain-damaged and moldy grains also can be processed.
- Excess rainy season production and blackened grains can well be disposed off by value addition.
- In India there is no price restriction on the sale of grain spirit whereas there is restriction for molasses-based alcohol.

No license is necessary for manufacturing alcohol from non-molasses. The Government of Maharashtra has been empowered to take the decision for permitting alcohol production from sorghum grains. Selection of yeast strains and conditions for maximum yield have already been worked out at PDKV The machinery for all the products is indigenously available. Considering the utilities of the sorghum crop, it can be said that it is a F4 (food, fodder, feed, fuel) crop and is an excellent raw material for many industries. Need-based research is necessary so that menu-made sorghum can be delivered (Somani 2002).

Sweet sorghum has enormous potential where bagasse can be used for particle board, or feed or for pulp purposes. In short, sorghum has a bright future and research should be oriented to improve the quality considering the requirements of industries. Rainy season sorghum, which is usually damaged due to rains, can well be disposed off to produce value-added products. In case producers get good price for their produce that will be an incentive for intensive cultivation with more farm inputs to increase output and thus India may be a leading country in exporting not only grains but also grain-based products.

Traditional sorghum foods and beverages

The importance of sorghum in Africa can be adjudged from the fact that there is an almost bewildering variety of African traditional sorghum foods and beverages. These include: whole grain rice-type products, breads and pancakes, dumplings and couscous, porridges, gruels, opaque and cloudy beers, and non-alcoholic fermented beverages.

A characteristic of many African sorghum foods and beverages is that as part of their production, they undergo a lactic acid fermentation by lactic acid bacteria, generally of the genus *Lactobacillus.* These so-called 'fermented foods' are appetizingly sour in taste. The fermentation is also of critical importance with regard to shelf life and safety of food in Africa. The production of lactic acid lowers pH of the food, which slows down or prevents its spoilage. Apart from food safety issue, many other nutritional advantages of lactic acid fermentation have been found and claimed. Fermentation increases in vitro carbohydrate availability and starch digestibility. Similarly, sorghum protein in vitro digestibility is improved. The B vitamins, particularly thiamine, are increased. Even though fermentation does not change the quantity of minerals, there is probably some improvement in their availability, since the quantity of phytate (myoinositol hexaphosphate), a powerful chelator of divalent metal ions present in sorghum and other cereals, is substantially reduced by fermentation. Two fermented food and beverage products, injera and sorghum beer, are described to illustrate the importance and potential of traditional sorghum foods in Africa.

Injera

Injera, a large circular, fermented pancake-like bread, is the staple food of Ethiopia. It is produced from a number of cereal flours, but primarily teff (*Eragrostis tef)* and sorghum, either singly or in combination. Although neither of these grains contain gluten, injera is a leavened bread with attractive spongy texture.

To make injera, the grain is first debranned, then ground into a fine flour using disk mill. The flour is mixed with water in 50:50 ratio and kneaded to form dough. Starter culture from a previous fermentation is added to initiate fermentation. The dough is covered and allowed to stand for 2-3 days. A portion of the dough, about 5%, is mixed with water. This slurry is added to the dough and cooked to make a gruel. The gruel, which contains gelatinized starch, acts as a binder and provides viscosity. When the foam collapses the batter is spread on a hot griddle and baked covered. Good injera is so flexible that it can be folded or rolled.

Recently, there has been a rapid growth in Africa in many 'modern-type' fast foods, including flat breads and 'wraps' containing fillings. Injera has huge potential for commercialization in this market. In addition, the technology of gelatinizing part of the flour to make a viscous batter, the so called 'custard' process has also successfully been applied to make conventional leavened pan bread from sorghum.

Sorghum beer

Throughout sub-Saharan Africa, sorghum is the grain of choice to produce traditional cloudy and opaque beers. The key ingredient of these beers is sorghum malt, which provides hydrolytic enzymes (especially amylases to ferment sugars to ethanol and carbon dioxide), starch (the source of fermentable sugars), yeast nutrients and beer flavor and color substances.

Malting

In southern Africa, malting sorghum for opaque beer brewing has developed into a large-scale commercial industry with some 150,000 t of sorghum being commercially malted annually. This figure includes a small amount of sorghum malted for the production of a sorghum malt breakfast cereal 'Maltabela'. Sorghum is also malted on large-scale in Nigeria for the production of lager beer and stout and for nonalcoholic malt-based beverages. The quality criterion is malt with high diastatic activity.

The sorghum malting process, both traditional and modern commercial, is split into three unit operations: steeping, germination and drying. Steeping is immersing the grains in water until it has imbibed sufficient water to initiate the metabolic processes of germination. Besides, it is helpful to remove tannins and broken grains by washing and floatation. Inactivation of tannins by soaking sorghum grain for 4-6 h at the beginning of steeping in a very dilute solution of formaldehyde is widely used. However, dilute alkali seems to be safer and is now being used instead of formaldehyde.

Germination involves seedling growth in warm water-saturated air. In floor malting, the steeped grains are spread out on a concrete floor, in a layer 10-30 cm deep. The germinating grain may be covered with a sack or shade cloth to reduce moisture loss. The grain is watered at intervals. In South Africa, nearly 100,000 t of sorghum are malted annually by this process. Pneumatic makings are used to produce sorghum malt for industrial brewing. They comprise rectangular or circular chambers 1-1.5 m deep and up to 100 m long. The germinating grain rests on a slotted, steel false floor, below which is a plenum (chamber). The grain is aerated by fans blowing air through the plenum and up through the bed of malt. During germination the grain is watered by spraying and turned by helical screws which traverse the chamber frequently.

Drying involves reducing the moisture content of grain sorghum malt to around 10% to produce shelf-stable product. Drying is generally carried out in a box with a perforated floor, similar to germination box but is rather deeper. Warm air is blown through the green malt. The air temperature should not be more than 50°C. In some outdoor floor malting, the malt is sun-dried.

Large-scale commercial brewing of opaque beer now takes place in many countries in southern, central and eastern Africa. However, only in South Africa, Botswana, Zimbabwe, Namibia and Swaziland brewing is carried out in the traditional way using sorghum malt. In other countries, food-grade industrial enzymes are used as the source of hydrolytic enzymes. Total opaque beer production in southern and eastern Africa is around 1,700 million L yr^{-1}. At least twice this volume is home brewed using commercially manufactured sorghum malt. In South Africa, there is strong evidence that as consumers become more affluent they prefer lager beer to sorghum beer.

A modern, efficient sorghum beer brewing process - the split sour, double cook process - is described. There are considerable variations in processes depending on regional tastes and the equipment available in a particular brewery. The lactic acid fermentation known as souring is an integral part of the brewing process. Souring involves incubating 8-10% slurry of sorghum malt at a strictly controlled temperature of 48-50°C for a period up to two days. The lactic acid bacteria culture is maintained. Adjunct cooking involves boiling slurry of cereal for 1.5-3 h at atmospheric pressure, or for a rather shorter time under pressure. These long periods both gelatinize and solubilize the starch. A portion of the sour is cooked together with the adjunct and a second portion of sour is added during mashing; hence the name 'split sour'. The first portion of the sour lowers the pH of the mash to around 4.5, close to the optimum for the sorghum malt amylases. The serial mash is then cooled using plate or tubular heat exchangers. Mashing or as it is known in opaque beer brewing, 'conversion' is then carried out, and a quantity of conversion malt (about 25% of cereal adjunct) is added. Conversion is at constant temperature for approximately 1.5 h. Mashing aims to solubilize and enzymatically hydrolyze the cereal to create a fermentable wort. At the end of the mashing period, the second portion of sour is added to bring the pH to the desired pH of the beer, around pH 3.8. The whole mash is then cooked again; hence the name 'double cook'. This gelatinizes all the conversion malt and second sour starch. This step greatly improves the efficiency of the process. To obtain the desired viscosity, a short mashing period of about 15 minutes at around 60°C is performed after cooking. A small quantity of malt or industrial amylase is added to thin the mash.

The spent grain is removed by a process known as straining. The mash is strained at elevated temperature using high-speed centrifugal decanters. Decanters separate primarily on the basis of gravity and remove insoluble material such as raw starch insoluble protein and fiber. After decanting, the wort is invariably passed through fine vibrating screen to remove coarse material of low density such as malt pericarp.

The wort is then cooled to 30°C by heat exchange and pitched with active dried yeast. The pitched wort is then either fermented in bulk for draught sale or packaged into containers. A wide range of sizes of containers are used, from 1 to 20 L, and differ in type from non-returnable cardboard cartons and low-density polyethylene bottles to returnable high-density polyethylene bottles and drums. All the containers have in common small slits or vents in the top to allow the escape of carbon dioxide from the actively fermenting beer. Opaque beer is distributed and consumed while actively fermenting.

Non-traditional food and beverage products

Sorghum instant soft porridge

'Morvite', a product of King Food in South Africa (part of the Tiger Foods group) is pre-cooked sorghum with added vitamins (hence the name), plus citric acid, sugar and other sweeteners. It is a dry powder to which one simply adds either hot or cold water or milk to make an instant breakfast porridge or beverage. Morvite (100 g) makes a substantial contribution to the recommended dietary allowance (RDA) for protein, vitamins A, B, C, D and E, and minerals such as calcium, phosphorus, iron and iodine.

Morvite was originally developed as an easy to prepare and consume mid-shift nutrient supplement for miners. Later, it was adopted by provincial governments in South Africa for school meals. Perhaps most interestingly, Morvite has found a place on the supermarket shelves. Since 2000, annual production has increased by 20% and is now about 12,000 t, which is 15 to 20% of South Africa's entire commercial sorghum milling production. Morvite is such a success that King Food is investing in additional manufacturing capacity and is bringing out flavored varieties.

An instant sorghum porridge like Morvite is relatively simple to manufacture. In addition to the normal dehulling and milling machines, it requires equipment for dry cooking, such as an extrusion cooker or gun puffer and a ribbon blender to mix the dry ingredients. Due to its ease of manufacture, Morvite is sold in the supermarket at about half the price of oat *(Avena sativa)* porridge and one-third the price of cornflakes. Hence, this type of value-added sorghum product is an attractive choice for both the manufacturer and consumer.

Malt beverages

In Nigeria, a wide variety of non-alcoholic malt beverages are very popular. These include both bottled 'brewed' non-alcoholic malt drinks such as 'Malta' products of the Guinness and Heineken companies and hot, malt and cocoa, powder-based drinks such as 'Milo', a Nestle product. Traditionally these products are produced using barley (*Hordeum vulgare)* malt extract. Malt extract is a sweet, sugar-rich wort (unfermented beer), which can be concentrated by evaporation to a dark-colored, richly flavored syrup or dry powder. In 1988, the Nigerian government banned the import of barley and other cereals, to save foreign exchange. This forced food and beverage manufacturers to develop local cereal alternatives. Suitable sorghum cultivars, such as the white Farafara for beer brewing and yellow Short Kowrie for malt beverages have been selected and now cultivated on large scale. Sorghum malting in Nigeria has now become a major industry both for lager and stout beer brewing and for malt beverage manufacture, with approximately 15,000 t of sorghum being malted annually.

To completely gelatinize and solubilize the starch and to conserve (3-amylase activity of the sorghum malt, which as stated is rather low, special mashing processes have been developed. These are based on the principle of decoction, whereby a portion of the mash containing the starch is removed, cooked to gelatinize the starch and then added back to the rest of the mash to be enzymatically hydrolyzed into sugars. Decoction may be carried out in a single step, or in a number of steps of progressively increasing temperature. The latter method provides more optimum conditions for different malt enzymes. Technologies have also been developed to roast sorghum malt for malt beverages to produce the required color and a complex, nutty, sweet chocolate aroma, characteristic of barley malt.

Despite the fact that the ban on cereal import has long since been rescinded, local sorghum has become the grain of choice in Nigeria for both beer brewing and malt beverage manufacture. These developments have benefited local farmers and led to industrial development as well as saving the cost of unnecessary imports.

Lager beer

As described, sorghum brewing in Nigeria started out of necessity. However, because of its cost-effectiveness and unique properties, sorghum is being used for lager brewing elsewhere in Africa. The South African Breweries-Miller group, which runs many breweries throughout Africa, after much development work, has begun commercial brewing of sorghum lager beer in Uganda. The Uganda story will be described as it is anticipated that it will serve as a model for similar schemes in other African countries where the use of barley is uneconomical.

Development of local commercial sorghum farming is the major aim of the project which began in 2001 with selection of a suitable local variety for brewing. Epuripur, a tannin-free, corneous endosperm, white-grained variety was selected. It was developed by the Serere Animal and Agricultural Research Institute in Uganda and first released in 1995. It has a yield potential of 2.5-3.0 t ha^{1}. In January 2002, seed multiplication started. Sorghum is now being grown in Soreti and Kumi districts that previously grew cotton (*Gossypium* sp) but have for many years been without a cash crop. Farmers growing this sorghum variety under contract for Nile Breweries can expect a good guaranteed price of US$ 150 t^{-1}. It is anticipated that any surpluses will be readily sold to food aid organizations such as the World Food Programme, as Epuripur is a high quality food-grade sorghum. Interest from farmers has been almost overwhelming, with applications from every area in Uganda from nearly 1000 farmers or farmer groups.

Although the details of the brewing process are not reported, it is known that sorghum grain (not malt) is used and the process involves conversion with industrial enzymes. What is particularly interesting is that sorghum was selected, rather than maize, because it was found that there is no fat rancidity problem with sorghum. The beer, which is called Eagle Lager, was launched in January 2003 and so far sales are exceeding all predicted estimates. It is anticipated that the annual requirement for sorghum will shortly be around 3,000 t. It is clear that brewing lager beer with sorghum in this way can result in a quality product, which is much more affordable than beer brewed with barley malt. Increased demand resulting from affordability will lead to greater requirement for sorghum bringing direct benefit to local farmers.

A report on "An overview of the potential of sorghum and millets for industrial uses in India" has been prepared for NRI, wherein the present utilization and scope have been highlighted (Somani 1996). Recently a joint survey by NRI, ICRISAT PDKV and the National Research Centre for Sorghum (NRCS), Hyderabad was taken up to study the difficulties in utilizing sorghum in various agro-based industries. This survey and questionnaires revealed that there is some misunderstanding with the feed industries and variations in the policies of the State Governments. It is necessary to capitalize this crop for improving rural economy especially in rainfed agriculture system.

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Processing of Sorghum and Pearl Millet for Promoting Wider Utilization for Food

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Abstract

Sorghum and pearl millet, the major coarse grain cereals in Asia and Africa, are being predominantly used for food purposes after conversion to traditional products. Although sorghum is now emerging as an important feed material, pearl millet has still remained a food crop in India and Africa. Diversified utilization of these crops for food, feed and industrial purposes is expected to promote their increased production and utilization in the future. Absence of appropriate primary processing technologies to yield shelf-stable flour/products has been the major limiting factor in their utilization for diversified food uses and development of value-added products. Some recent works have shown this possibility. Technologies for production of shelf-stable refined flour, grits and semolina from sorghum and millet have been developed and laboratory studies have demonstrated their successful utilization and incorporation into various traditional foods (idli, dosa, chakli, papad, *etc) and newer convenience health products (*vermicelli*, noodles, plain and ready-to-eat flakes, extruded products, weaning and supplementary foods, and bakery products). Efforts are needed for popularization and wider adoption of the successful technologies to promote these grains for diversification of their utilization among the non-traditional urban population.*

Sorghum *(Sorghum bicolor),* maize *(Zea mays),* pearl millet *(Pennisetum glaucum)* and other millets are classified as coarse grain cereals, perhaps because of their hard grain texture (Murty and Kumar 1995). While sorghum and pearl millet are important staple food grains in Asia and Africa, they are used as the main component in feed formulations in other parts of the world. Grown generally in non-irrigated and rainfed lands, with very little agricultural inputs as compared to wheat *(Triticum aestivum)* and rice *(Oryza sativa),* they are important for food security in Asia and Africa.

Both sorghum and pearl millet complement well with lysine-rich vegetable (leguminous) and animal proteins and form nutritionally balanced composite foods of high biological value. Carbohydrates of sorghum and pearl

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millet comprise a large proportion of starch (65-70%) and a good amount (16-20%) of non-starchy polysaccharides (NSP). The NSP, which constitute nearly 95% of the dietary fiber of the grain, are derived not only from bran but also from the endosperm cell walls. There are no reports of any adverse effects of regular consumption of sorghum and millet, especially in the Indian subcontinent. On the other hand, incidence of diabetes mellitus and gastro-intestinal disorders are minimal among the population using these grains as staple food.

Constraints in processing and wider utilization

Although sorghum and pearl millet are nutritious and staple foods for millions in the under-privileged section of the society, their increased utilization and diversification is impeded by problems mostly related to milling and storage characteristics (Varriano-Marston and Hoseney 1983). These grains are known for their high (3-7%) fat content; the kernel, bran and germ contain a major portion of the lipid material (Serna-Saldivar and Rooney 1997).

Relatively less work has been carried out on the nutritional quality of pearl millet. The protein efficiency ratio (PER) of pearl millet is higher than that of sorghum or wheat (Rao et al. 1964, Pushpamma et al. 1972, Oke 1977). The nutritional quality of sorghum is generally affected due to the presence of tannin and poor protein digestibility. Tannin in sorghum reduces digestibility and efficiency of utilization of absorbed nutrients by 3 to 15% and hence animals that consume brown or high tannin sorghum at the same or slightly higher rates do not gain as much weight (Waniska and Rooney 2000). The content of tannin can be reduced by processing such as decortication, malting, fermentation and cooking.

Another anti-nutritional factor is the presence of phytic acid and phytates in the aleurone layers, and to a lesser extent in the germ of sorghum. Phytic acid forms complexes with the essential minerals making them unavailable for absorption (Lasztity and Lasztity 1990, Beneto and Miller 1998). Phytate content can be reduced by abrasive milling, which removes the pericarp and aleurone (Doherty et al. 1981, 1982). Fermentation and malting are other effective methods to decrease the content of phytic acid. Malting of pearl millet reduces the content of oxalic acid, an anti-nutritional compound shown to form an insoluble complex with calcium, and thus reduces its bio-availability (Opoku et al. 1981, Whitney et al. 1987).

Another major limitation in utilization of sorghum worldwide is the occurrence of molds (and weather damage) that reduces grain yield and quality which further affects the physical properties, processing, nutritional value and market value (Glueck and Rooney 1980). Mold or weather-damaged grains cannot be decorticated, since the flour and grits are badly discolored and cannot be used for food and brewing. Kumar et al. (1991) have shown that milling and popping of mold-infested grains reduced the intensity of seedborne microflora. Excessive consumption of pearl millet has been implicated in the occurrence of endemic goitre in some areas of Sudan (Osman and Fatah 1981). The phenolic flavonoid compounds, C-glycosyl flavones and their metabolites, are the factors responsible for causing goitrogenecity (Birzer and Klopfenstein 1988, Gaitan et al. 1989). The compounds are also shown to be responsible for the gray color and off-odors (Reddy et al. 1986). Anti-thyroid properties of pearl millet can be reduced by autoclaving and decorticating the millet grains.

Traditional foods from sorghum and millets

Various foods from sorghum and pearl millet are traditionally prepared and consumed over centuries in the Indian subcontinent, Africa and in Central America. Majority of them are made from flour, either from the whole grain or partially decorticated grains. These include unleavened pancakes from fermented or unfermented dough, stiff or thin porridges, snack foods, deep-fried products, sweet or sour opaque beer, non-alcoholic beverages and boiled (as for rice) decorticated grains (Fig. 1). Table 1 gives the list of these foods with specific names prevalent in the countries where they are normally consumed (FAO 1995, Rooney and Waniska 2000).

A decline in the consumption of sorghum and millets has been noticed in the past two to three decades in the countries known for their production and traditional consumption and this is true in both urban as well as rural households in India also. This has been ascribed to increase in the family income and the purchasing power accompanied by increased availability of wheat and rice (FAO 1995). In some parts of India, this trend has resulted in decline in the nutritional status of population belonging to lower socioeconomic status.

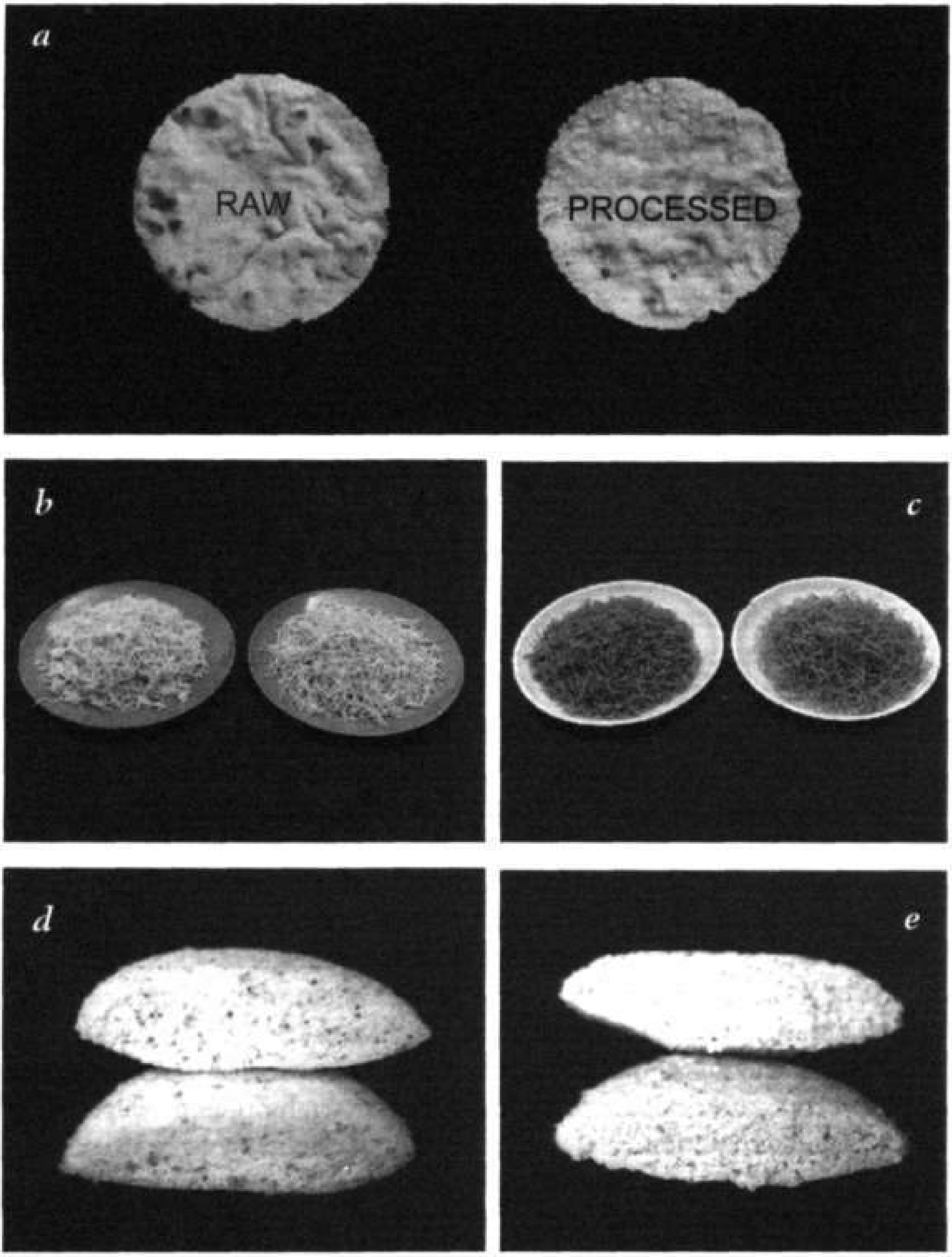

Figure 1. A few products from sorghum and pearl millet: (a) sorghum roti; *(b) sorghum noodles; (c) pearl millet noodles; (d) processed sorghum* idli; *and (e) processed pearl millet* idli.

Table 1. Traditional foods made from sorghum and pearl millet.

Type of food	Common names	Countries/Region
Sorghum/Pearlmillet Unfermented pancake	*Roti*	India
Thick (stiff) porridge	*Ugali, tuwo, saino, dalaki, aceda, atap, bogobe, ting, tutu, kalo, karo, kwon, nshimba, nuchu, to, tuo, zaafi, asidah, mato, sadza, sankati*	Africa, India, Mexico, Central America
Thin porridge	*Uji, ambali, edi, eko, kamo, nasha, bwa, kal, obushera, ogi, oko, akamu, kafa, koko, akasa*	Africa, India, Central America
Steamed cooked products	*Couscous, degue*	West Africa
Snack foods	Popped, *sandige, papad, chakli*	India
Sorghum Nixtamalized pancake[1]	Tortilla	Mexico, Central America
Boiled rice-like foods	*Annam, acha*	Africa, India, China, Mexico
Sweet/sour opaque beers	*Burukutu, dolo, pito, talla*	West Africa
Sour opaque beers	*Marisa, busaa, merissa, urwaga, mwenge, munkoyo, utshwala, utywala, ikigage*	Sudan, South Africa, India
Non-alcoholic beverages	***Mehewu, amaheu, marewa, magou, leting, abrey, husawa***	Cameroon, South Africa, Sudan, Uganda, Zambia, parts of Tanzania

1. Nixtamalization is an Aztec word that refers to the cooking of maize and sorghum in lime solution or leachate of wood ash. The resulting product is called masa, which is pressed into circles and cooked into flat unleavened breads. It originated in southern part of North America. This process increases the bioavailability of calcium and niacin.

Processing for food purposes

Traditional methods

In India, traditional grinding stones were used to prepare flour from sorghum and millets. But nowadays the grains are custom milled in mechanized disc mills located even in remote villages in the country. Wet milling of these grains is done traditionally by soaking the grains overnight. The soaked grains are ground between two stones to form a batter or paste instead of flour. This method is usually adopted when products requiring fermentation have to be prepared. Traditionally, in most places of Africa, sorghum is first debranned by hand pounding after sprinkling sufficient quantity of water on the grains, followed by winnowing or sieving to remove bran and fine grain particles. Subsequently, dry, moistened or wet grains are pounded with a wooden pestle in a wooden or stone mortar. Usually grains are moistened by adding 10% water which results in moist flour. It is estimated that one woman must spend an hour to mill 1.5 kg grain, which may be required for the preparation of the day's food for the family (Perten 1983). Pounding gives a non-uniform product with poor keeping quality.

Recent advances in processing and value addition

Milling and decortication

Milling of sorghum and millet results in decortication or debranning of the kernels for use similar to that of rice, and also in reduction of size similar to that of wheat for semolina, grits and flour. The grains are normally pulverized and a small portion of coarse bran is sieved off to use the flour for traditional foods such as unleavened bread *(roti),* thin porridge *(ambali)* and stiff porridge (*mudde)* (Pushpamma et al. 1972). Sorghum milling has received considerable attention and it has been reported that incipient moist conditioning of the grain facilitates separation of the seed coat in the abrasive or friction type mills to prepare decorticated grains (Desikachar 1975). On the other hand, by incipient moist conditioning fragmentation of the seed coat is minimized and hence, major portion of the bran can be separated by sifting or aspiration of the pulverized material. This principle is utilized to produce refined flours from sorghum and millets in roller mills at industrial scale in Nigeria and also for custom milling purpose. The Mini Grain Mill, developed at the Central Food Technological Research Institute (CFTRI), Mysore, India is a small capacity mill that works on this principle to prepare refined flour and semolina from sorghum and millets (Shankara et al. 1985) (Fig. 2). Decortication of sorghum is also carried out by abrading the kernels in a series of emery-coated discs (Desikachar and Malleshi 1987). However, decortication of sorghum with or without moist conditioning does not separate the embryo efficiently and the presence of embryo affects the storage stability of the sorghum products although the proportion of embryo in sorghum is insignificant. Recent studies at CFTRI have shown that the decortication or debranning of sorghum or millet without any pre-treatment is possible in an abrasive type mill (such as carborandum discs). Decortication or debranning after incipient moist conditioning is achieved effectively in a friction type mill. Although moist conditioning grinding and sieving minimize pulverization of the seed coat, the method has limitations because the germ also gets pulverized and mixed with the milling fractions which affect the shelf life of the product (Hadimani 1994).

Figure 2. A mini grain mill developed at CFTRI, Mysore, India.

In pearl millet, especially in traditional varieties, glumes form part of the seed coat, and being a non-edible component of the kernel, necessitates its separation. Hence, pearl millet decortication involves degluming in addition to debranning. While the millet could be deglumed in friction type mills (huller), debranning could be efficiently achieved using an abrasive or friction type mill.

Very recently, a new method for improving the shelf life of sorghum and millet products has been developed at CFTRI (Meera et al. 2002). The process involves moist heating of the grains followed by drying to about 10-12% moisture content and decortication to the desired degree, or pulverization as such. This process improves the milling characteristics of sorghum and pearl millet varieties even with high proportion of floury endosperm and also enables to prepare grits/semolina from the grains which may serve as a substitute for wheat semolina. The meal or the flour prepared from these grains by following this process has a longer shelf life. Figure 3 shows the changes in the development of free fatty acids (FFA) of the flour from sorghum and pearl millet with or without prior wet heat treatment of the grains, packed in low density polyethylene (LDPE) bags and stored at ambient conditions. The flour from wet heat treated and decorticated sorghum could be stored for about 8-10

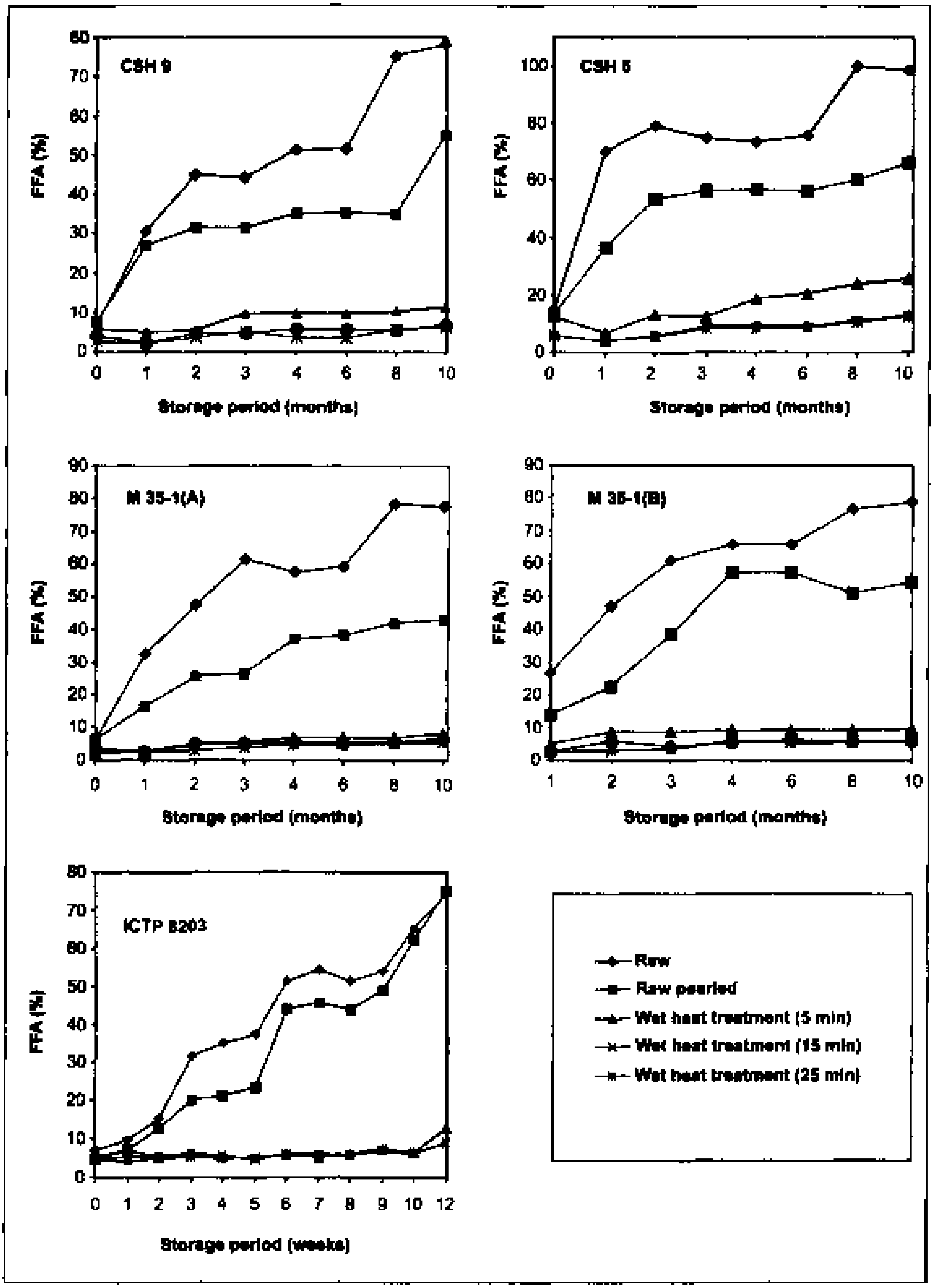

Figure 3. Development of free fatty acids (FFA) during storage (at ambient conditions) in flour of raw and treated sorghum and pearl millet grains.

months, and that from pearl millet for about 3-4 months, during which the FFA content remained below limit of perceptible deteriorative condition (10%). The oxidative rancidity also remained low, as the flours are refined. The technology can be adopted at industrial level and is simple enough for adoption at household level as well. The process was demonstrated to a large number of consumers and entrepreneurs. This method makes it possible to market the flour/semolina commercially, particularly in urban areas. Lack of such shelf-stable and marketable flour/grits may be one factor, which forces the people to switch over to readily available flour/semolina from wheat. Further, this development also makes it possible to prepare a variety of products for commercial marketing. Another advantage of this process is that the microbial load on the grain surface is drastically reduced. Table 2 shows the effect of wet heat treatment on the level of microbial infestation before the treatment and also at various stages of processing after treatment.

In pearl millet, the characteristic odor and the dark gray pigments also hinder the acceptability of the products. Improvements have been made possible by treating the partially decorticated millet with mild organic acids such as acetic, fumaric and tartaric acids, and also by the extracts of natural acidic material such as tamarind *(Tamarindus indica)* (Hadimani and Malleshi 1993). Soaking the grains for a few minutes in the aqueous tamarind extract, or such other organic acids improves the product quality by reducing polyphenols and other anti-nutritional factors and thus increases the consumer acceptability (Fig. 4).

Wet milling of sorghum is practiced to a small extent as compared to maize, mainly to prepare starch, that too from low-grade sorghum but wet milling of pearl millet is scanty. Since wet milling facilitates separation of the germ, which is

Table 2. Effect of processing on fungal infestation (%) in grain of two sorghum varieties[1].

Process	CSH 5 (A)[2]	CSH 5 (B)[2]	M 35-1
Raw, as is	100	15	1
Raw pearled	12	2	Nil
Steamed 5 min, pearled	3	Nil	Nil
Steamed 15 min, pearled	Nil	Nil	Nil
Steamed 25 min, pearled	Nil	Nil	Nil

1. After surface sterilization tested by blotter method.
2, Samples are from two different sources, A and B.

an oil- and mineral-rich component, as a separate entity, it may be a valuable byproduct that could find application in various food industries.

Even though India is one of the major producers of sorghum and pearl millet, there are no dedicated custom/industrial level mills for these commodities. This aspect needs attention to improve the economy and marketability of these crops.

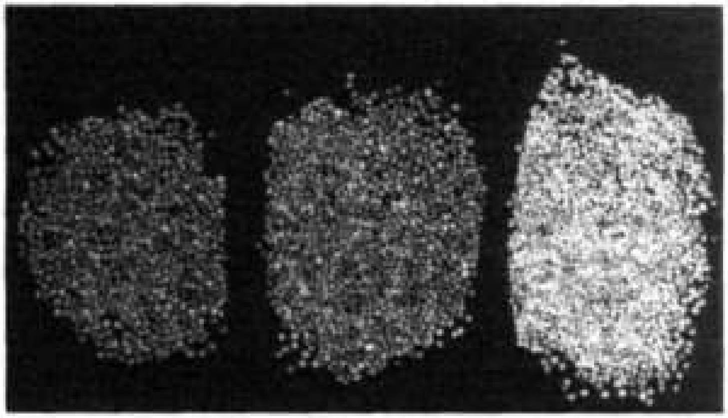

Figure 4. Pearl millet grains: whole grain, untreated (left); milled, untreated (center); and milled, treated with tamarind extract (right).

Flaking

Flaking of cereals is one of the traditional methods for preparation of convenience foods in the Indian subcontinent and to improve the digestibility of feed in the developed countries. Flaking essentially involves hydrating grains followed by steaming and bumping or pressing of the steamed grains. Extensive work has been carried out on sorghum flaking at CFTRI and various process parameters such as soaking time and temperature, and also the conditions of wet heat or dry heat treatment have been standardized (CFTRI 1985). The grain soaked to its equilibrium moisture content is steamed or roasted to fully gelatinize the starch, dried to about 18% moisture content, conditioned, decorticated and then flaked immediately by passing through a pair of heavy-duty rollers. Efforts to hand pound or flaking in an edge runner (used in cottage level industry for flaking of rice in India) have achieved little success. The thickness of sorghum flakes could be adjusted to 0.4-1 mm, depending on the end use. Proper drying after flattening minimizes the buckling and retains the shape of the flakes without any fissuring or breakage. The thinner flakes are suitable for preparation of traditional snack foods like *uppitu* after boiling and seasoning. The thicker flakes could be deep-fried or dry toasted to prepare expanded crunchy snack products. The flakes could also be coated with requisite additives including vitamins and minerals to improve their nutritional quality. The oil absorption of sorghum flakes is comparable to that of rice flakes. The deep-fried sorghum flakes, seasoned with spices, is an excellent snack and scores higher than a similar product from maize.

Wet heat treatment of sorghum is known to lower its digestibility. This characteristic feature could perhaps be used to market sorghum flakes as diabetic flakes. During flaking process, the starch undergoes retrogradation leading to formation of resistant starch or enhancing the dietary fiber contents (Mangala et al. 1999). This added advantage may have great potential in exploiting sorghum flakes in the dietary management for the diabetics.

Results of exploratory studies on flaking of pearl millet following the method adopted for sorghum have been promising. Millet flaking would be a new avenue for its widespread utilization, since the millet flakes will have better shelf life due to stabilization of the oil during flaking. Also, the bran separated as a byproduct of the flaking industry could serve as a source of the edible oil similar to that of rice bran oil. Deoiled bran from millet and sorghum would have less ash and silica content as compared to that of deoiled rice bran and hence could be efficiently used as a source of dietary fiber. Unlike sorghum bran, pearl millet bran contains high proportion of soluble dietary fiber and could be tapped for hypocholestomic and hypoglycaemic effects. Hence, fiber regulated sorghum and millet flakes, expanded by hot air or sand, could be an ideal snack or supplementary food for the obese and calorie conscious people (Hadimani and Malleshi 1993).

Popping

Grain popping is one of the ancient technologies to process the cereals by dry heat (roasting) methods. Generally, fine sand is used as heat transfer medium for popping at household- and cottage-level industries. Although hot sand as a heat transfer medium is very effective in expansion, it affects the consumer acceptability because of the adherence of fine sand in the crevices of the expanded endosperm. Popped sorghum is also marketed in Maharashtra and Rajasthan states of India as a proprietary food. Since popping involves formation of steam and development of pressure inside the kernel, optimum moisture level and popping temperature play an important role in quality of the popped cereal. Varietal variations exist largely with respect to popping characteristics and special sorghum varieties, viz, 'pop sorghum', are cultivated and marketed. Most of the sorghum varieties could be popped to an expansion volume of about 20 ml g^{-1} by suitable pre-treatments. The optimum conditions for grain popping are equilibrating sorghum and millet to about 16% moisture and subjecting the grains to high temperature; ie, short time treatment at about 230°C for a fraction of a minute in an air popper developed at CFTRI (CFTRI 1985). The machine is highly suitable for value addition to sorghum and millet by popping (Fig. 5).

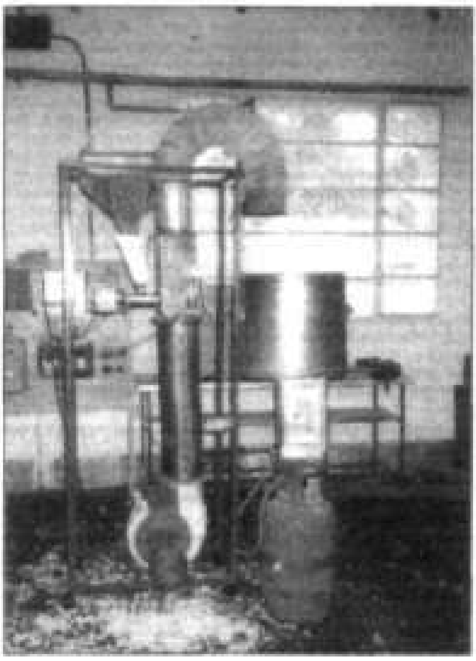

Figure 5. Popping machine developed at CFTRI, Mysore, India.

Popping of pearl millet is not very popular but the popped millet is a good source of energy, fiber and carbohydrates and the expansion volume of the popped millet is about 7-10 ml g^{-1}. The varieties with hard endosperm and medium thick pericarp (Fig. 6) exhibit superior popping quality (Hadimani et al. 2001). The lipolytic enzymes are denatured during the process of popping. The nutritional advantage of the popped millet is utilized in developing formulations for supplementary foods or weaning foods for children and lactating mothers (Bhaskaran et al. 1999). Popped millet could be consumed in the form of *laddu* or *sattu* and *chikki*. Popped millet flour blended with popped or toasted legumes, such as puffed chickpea *(Cicer arietinum)*, and jaggery or sugar makes delicious and nutritionally balanced convenience foods for growing children and lactating mothers. The product has the advantage of low cost and permits addition of other flavoring ingredients [eg, groundnut *(Arachis hypogaea)* and coconut (*Cocos nucifera)]* for improving the taste and nutritional quality.

Nutritious food supplements based on popped sorghum and millets could be served to mothers and children in the nutrition intervention program. Since sorghum and pearl millet are rich sources of micronutrients and phytochemicals, such products may score over similar products from rice and wheat.

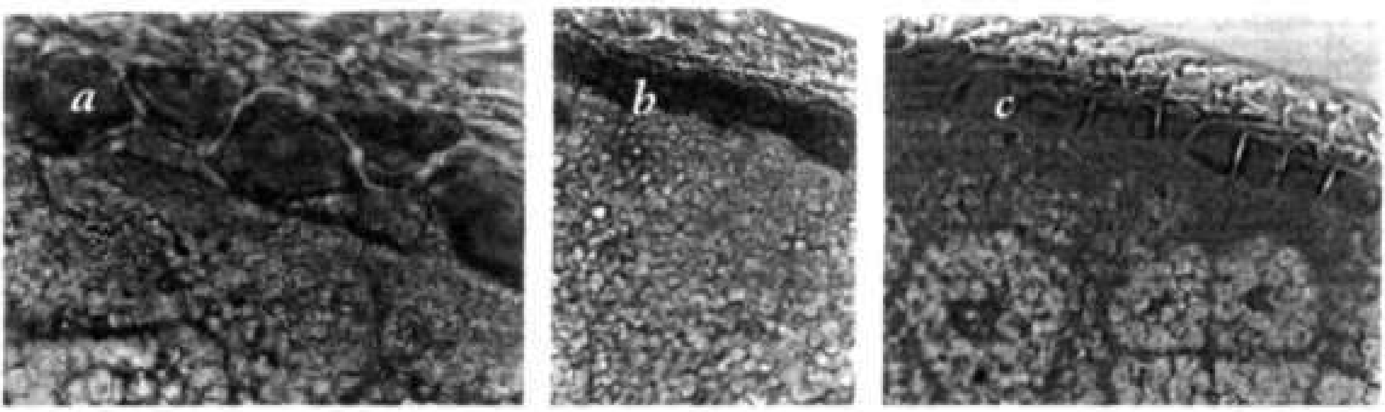

Figure 6. Pericarp thickness in different varieties of pearl millet: (a) thick pericarp; (b) medium pericarp; and (c) thin pericarp.

A nutritious blend, containing popped sorghum or pearl millet, with chickpea, soybean (*Glycine max)* and jaggery and pressed into a pellet or *burfi*-like product was developed at CFTR1, and has proved to be a convenient nutritious food. About 70 g of the product supplied in the form of 3 pieces of *burfies* provides 300 calories and 12 g protein, which is recommended as the nutritional supplement to undernourished children. Popped sorghum and millets could also be utilized as adjuncts in brewing. As popping largely destroys seedborne microflora, it may be advantageous to utilize the technique to process microbially infected sorghum and millet (Kumar et al. 1992).

Malting

Malting is one of the early biotechnological processes that man adopted for cereal processing for food and brewing. Although barley *(Hordeum vulgare)* malting is common, sorghum malting is also practiced at household and industrial scale in Africa, especially for the preparation of lactic acid fermented brew.

The ratio of a- to β-amylases elaborated during germination of sorghum is lower than that of barley. Hence, sorghum malt requires supplementation of amylases from external source to prepare yeast fermented lager beers. Alternatively, sorghum malt is used as an adjunct in industrial brewing based on barley. Wide varietal variations have been reported for malting characteristics of sorghum. Malted sorghum has better nutritional characteristics than the native sorghum (Malleshi and Desikachar 1986). However, caution is needed for use of sorghum malt for food purposes because of the presence of durrin, a cyanogenic compound in the rootlets. Hence it is necessary to remove the rootlets completely from the sprouted sorghum. Moreover, sorghum is susceptible to mold infestation during germination; thus it may require application of chemical or natural anti-microbial agents during steeping and germination. Use of sorghum malt (prepared after removing the rootlets and the pericarp) in formulation of weaning food has been successfully demonstrated (Malleshi et al. 1989). Weaning foods based on malted sorghum exhibit good growth promoting qualities compared to those from roller dried and popped sorghum. Pearl millet malting has not been promising because of the presence of the active lipase enzyme and due to mold growth during germination. However, the ratio of a- and β-amylase in millet malt is highly favorable in comparison to other tropical cereals. If malting conditions are suitably adopted, millet malt could be a good raw material for nutrient dense specialty foods. Utilization of malted sorghum in bakery products has also been reported.

Application of modern processing technologies

Extrusion cooking

Extrusion cooking is a very versatile, modern food processing technology followed throughout the world for preparation of snacks, supplementary foods as well as pet foods. Voluminous literature is available on extrusion cooking of maize, wheat and rice, but such information on sorghum and millets is scanty. The available data reveal that sorghum grits as well as millet flour could be extruded to prepare ready-to-eat products. Since the seed coat or the bran affects the expansion ratio and also the eating quality of the products, it is desirable to use grits and flour, preferably of less than 40 mesh size, prepared from decorticated or debranned grain. Equilibrating the flour to about 18% moisture content and extruding in a single- or twin-screw extruder at about 150°C and 200 rpm, produces products with an expansion of 1.5-2 times. The products have crunchy texture and could be coated with traditional ingredients to prepare sweet or savory snacks. Alternatively, the grits could be mixed with spices and condiments prior to extrusion to obtain ready-to-eat snacks of desirable taste. Acid-treated pearl millet yields products of better acceptability as compared to those from decorticated millet. Sorghum and millets, blended with soybean or protein-rich ingredients such as legumes or groundnut cake, on extrusion give nutritionally balanced supplementary foods (Malleshi et al. 1996). The low-cost dedicated extruders used in nutrition intervention programs in several developing countries could be conveniently utilized for the preparation of diversified, value-added extruded products from these grains. The dietary bulk could be reduced and texture of the extruded foods could be improved by mixing a small proportion of cereal malt and warming the slurry. This improves the taste of the product also. Although the investment on extrusion cooking machinery is high, the low processing cost and small capacity extruders that are nowadays readily available, makes the process viable for commercial exploitation. This technology could be utilized to prepare pellets which can be flaked to yield high quality flakes from these grains.

Vermicelli-noodles

Noodles and pasta-like products, in spite of their ancient origin, have undergone considerable evolution and migration as the products became increasingly globalized. There is a phenomenal increase in the consumption of noodles in India also. While wheat noodles are very common throughout the country, rice noodles are popular in southern India. Utilization of sorghum and pearl millet for vermicelli-noodles is very rare. Sorghum and millet are unique with respect to taste and aroma and also provide dietary fiber. Research work was undertaken on their use for noodles and a process has been successfully developed (Sowbhaghya and Ali 2001a). The noodles on cooking in water retained the texture of their strands and firmness without disintegration and the solid loss was less than 6% (Sowbhaghya and Ali 2001b) (Table 3). Noodles from both sorghum and pearl millet were readily acceptable in the form of savoury and sweet. Since the present trend of the population is towards low fat and high fiber foods, noodles from these cereals have a great future not only in the domestic market but also for export to other developed countries.

Conclusion and future perspective

Being mainly rainfed crops and grown with marginal agricultural inputs, the value of sorghum and millets for stretching the availability of food is well established. With increasing realization that water is becoming a limited resource, these crops will assume higher significance in future. Considerable crop production knowledge base has been created for future application. The knowledge base on grain quality, processing and value addition needs to be

Table 3. Composition and physico-chemical properties of sorghum and pearl millet flour and noodles[1].

Samples	Crude fiber (%)	Fat (%)	Ash (%)	Protein (%)	Amylose (%)	Solid loss (%)	Texture[2] Firmness (%)	Texture[2] Elastic recovery (%)
Pearl millet								
Flour, whole	0.57	5.24	1.35	12.2	25.8			
Flour, debranned	0.19	3.34	0.92	9.8	29.6			
Noodles	0.18	1.58	2.12	8.6	26.8	9.7	45	20
Sorghum								
Flour, whole	1.38	3.36	1.42	10.4	26.8			
Flour, debranned	0.26	2.45	1.11	10.2	29.1			
Noodles	0.12	0.88	2.12	8.3	28.7	6.5	50	30

1. Composition based on as is condition.
2. Chopin-Inra Viscoelastograph, an instrument, used to measure the texture.

addressed although efforts in this direction are now increasing with recent R & D work across the world. Special features of sorghum and pearl millet, in comparison to rice and wheat, have been established that could form the basis for their future exploitation for value addition and widening the scope of their utilization. Feasibility of production of shelf-stable flour from pearl millet and sorghum has been established which would pave the way for commercial production of flour and semolina for promotion of bulk usage for urban as well as rural population. There is a great scope for these grains to be utilized for increased alternative food uses.

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Alternative Uses of Sorghum - Methods and Feasibility: Indian Perspective

CV Ratnavathi, PK Biswas, M Pallavi, M Maheswari, BS Vijay Kumar and N Seetharama[1]

Abstract

In India, sorghum is traditionally consumed in the form of unleavened flat bread (roti). *In southern India, it is consumed in the form of* sankati, annam *and* ganji *(thin porridge). Popped sorghum and sorghum noodles are eaten as breakfast or snack foods. The rainy season grain sorghum consumption has declined during the last decade mainly due to grain deterioration by molds. Therefore, rainy season sorghum grain is priced lower than maize; hence it can replace maize as a raw material in many of the alternative uses.*

The possible promising alternative food products from sorghum are bakery products, maltodextrins as fat replacers in cookies, liquid or powder glucose, high fructose syrup and sorbitol. Malted sorghum can be a good alternative for baby weaning foods.

The industrial products made from sorghum grain include alcohol (potable grade) and lager beer. Commercialization of alcohol production from grain is already in practice. Other technologies such as production of glucose, maltodextrins, high fructose syrup and cakes from sorghum are yet to be scaled up. The sweet sorghum with its juicy sweet stalk has potential as a bio-energy crop. Ethanol can also be produced from sweet sorghum stalk juice. Sweet sorghum products like syrup and jaggery have received good attention from dryland farmers. Shelf life and nutritive value of syrup and jaggery made from sweet sorghum and sugarcane are similar. Attempts for scaling up the technology for alcohol production from sweet sorghum were successful, but more work is needed to integrate the current production with potential market.

Sorghum *(Sorghum bicolor)* is an important food and fodder crop of the semi-arid tropics (14-24° N to 70-82° E). India is the third largest producer (7.06 million t) of sorghum in the world after USA and Nigeria (FAOSTAT 2002), and has the largest area under this crop (9.5 million ha). The rainy season sorghum grain is often damaged due to mold; so it fetches a low price in the market. However, it has high potential for use in the non-food and industrial sectors for various value-added products.

1. National Research Centre for Sorghum (NRCS), Rajendranagar, Hyderabad 500 030, Andhra Pradesh, India.

At present, most of the sorghum produced in India is consumed as human food in the form of *roti, bhakri* or *chapati* (unleavened flat bread). The sweet sorghum with juicy sweet stalk has enormous potential as a bio-energy crop. Sorghum is known to have high dry matter productivity rate (50 g m^{-2} day^{-1}) and is reported to surpass the productivity of sugarcane *(Saccharum officinarum),* another C_4 plant (Somani et al. 1997).

Alternative uses of sorghum encompass utilization of grain and sweet stalk in food and non-food sectors for the production of commercially valued products, such as alcohol (potable and industrial grade), syrups (natural and high fructose), glucose (liquid and powder), modified starches, maltodextrins, jaggery, sorbitol and citric acid (downstream products from starch).

Global and domestic demand for animal and poultry feed is rapidly rising. Sorghum can be a prominent energy source in poultry and animal feed (Kleih et al. 2000). Similarly, demand for starch and industrial and potable alcohol is increasing. However, sorghum always has competition from maize *(Zea mays)* for various industrial uses. Demand can also be created for sorghum in beverage industries as malt and adjunct (unmalted cereal component used for beer preparation). The gradual shift from traditional uses to potential use of sorghum as value-added food and non-food industrial products is discussed.

Traditional food products of sorghum and their commercialization

The most preferred traditional food form of sorghum is *roti, bhakri* or *chapati* (unleavened flat bread) mainly in the states of Maharashtra, Karnataka and parts of Andhra Pradesh in India. *Roti* can be stored for several days in the crisp dehydrated form without loss in quality. It is consumed along with different kinds of dishes (food) depending on the socioeconomic status of the consumer (Subramanian and Jambunathan 1980).

There is a decline in the consumption pattern of sorghum mainly due to the urbanization and availability of subsidized rice *(Oryza sativa)* and wheat (*Triticum aestivum)* at a cheaper price. In the recent past, there is a growing awareness among the urban population that sorghum is an excellent health food for diabetics. A survey conducted in 2003 by the National Research Centre for Sorghum (NRCS), Hyderabad, Andhra Pradesh has indicated that nearly 20 t of grain $month^{-1}$ are being consumed in the form of *roti* in small hotels in Hyderabad. The other traditional sorghum preparations like *annum* (cooked, same as rice), *sankati (toh)* and *ganji* (gruel) are popular with farmers as a preferred diet (Murty and Subramanian 1981). Noodles made from sorghum are not very common. Although the acceptability of sorghum noodles was not a problem, it was not given adequate attention. The technology for noodle preparation from sorghum makes the product cheaper and healthier as sorghum products are known to have higher levels of vitamin B and dietary fiber (Hulse et al. 1980).

Alternative commercial grain products of sorghum

The alternative commercial products include both food and non-food products. The main food products are bakery and industrial products.

Bakery products

Common bakery products such as bread, cakes and biscuits were prepared and tested at NRCS. Finely ground sorghum flour equal to the consistency of fine wheat flour *(maida)* was made from pearled rainy season sorghum grain using 300 um sieve. This flour in combination with *maida* was used for the preparation of various bakery products like bread (made only from sorghum), mixed bread [from sorghum, finger millet *(Eleusine coracana)* and pearl millet *(Pennisetum glaucum)* in 2:1:1 ratio], cakes and biscuits. The methodology for the preparation of these bakery products is similar to that used with wheat flour.

Bread

Finely ground sorghum flour was mixed with *maida,* salt, sugar, fat and bread improvers and was made into dough. Baker's yeast was added to the dough and allowed for fermentation for a longer time (10-12 h) than for the normal wheat bread; after fermentation, the dough was baked for an hour. For improved leavening and softness of the bread, compared to wheat bread, more yeast and external gluten were added. A mixture of 30 to 40% *maida* and 68% sorghum flour resulted in tasty bread (Fig. 1).

Cakes

Preparation of sorghum cake is similar to cake prepared from *maida.* Fine sorghum grain flour was used for the preparation of cakes. Finely ground

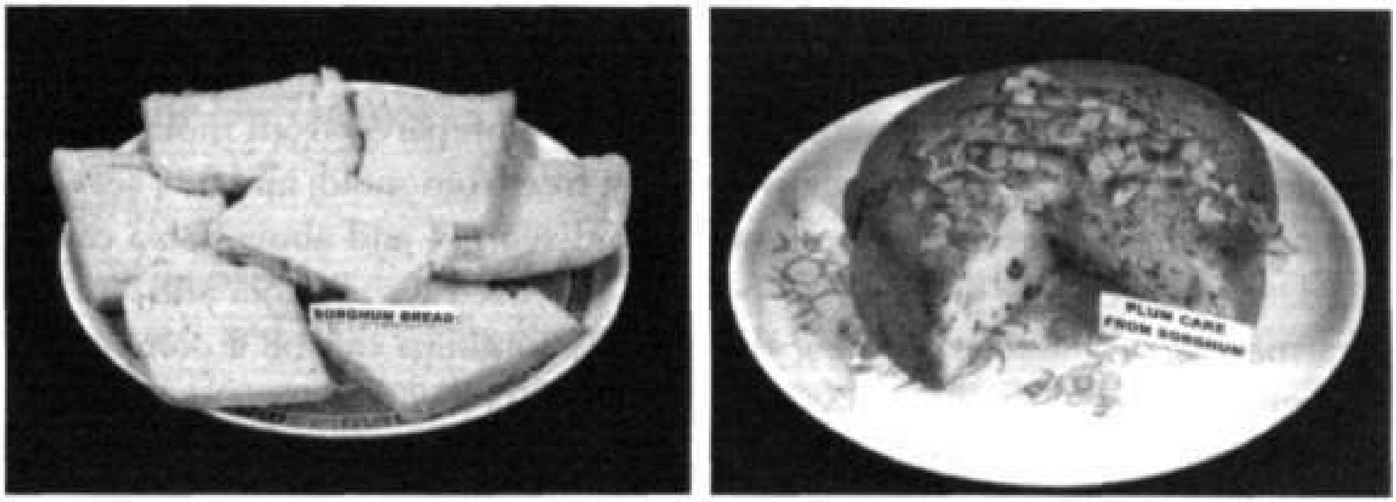

Figure 1. Bakery products from sorghum: bread (left) and plum cake (right).

sorghum grain flour was mixed with required quantities of sugar, egg, emulsifiers and fat. The dough was made slightly soft and nuts were used to decorate the top. The dough along with the mold was kept in an oven for an hour for proper baking (Fig. 1). Sorghum flour was comparatively superior to wheat flour (in terms of taste) for cake preparation. The requirement of sugar was also less as the sorghum grain was sweeter than wheat grain.

Biscuits

Biscuits were prepared from 80% sorghum flour and 20% *maida.* Sorghum flour was mixed with *maida,* vegetable fat, sugar, baking powder and essence. The mixed dough was then compressed in a mold and baked at the required temperature (225°C). Studies on the parameters such as compressibility and breaking strength showed that sorghum biscuits had lesser breaking strength than wheat biscuits. The panel score in terms of quality and taste was high for cakes and biscuits made from sorghum compared to wheat.

Pilot studies are in progress in collaboration with Modern Food Industry, Uppal, Hyderabad. Non-stickiness upon eating is a special trait of sorghum bakery products. Studies on the shelf life, a key factor directly related to the economy of bakery industry, indicated that the shelf life varied from 24 to 72 h for bread, 7-12 days for cakes and more than 30 days for biscuits and was comparable with wheat products.

Industrial products

The various industrial products prepared from sorghum grain currently are potable alcohol, glucose, high-fructose syrup, modified starches, maltodextrins and starch downstream products like sorbitol and citric acid.

Alcohol

Commercially viable and potable alcohol can be prepared from molded grain (mold score above 3.5, on a scale where 1 = free from mold; and 5 = severely molded grain). Severely molded grain (mold score 4 and above) also can be used. This alcohol, graded as potable, is used as liquor and in the pharmaceutical industry. Among the cereals, sorghum can be a competitive raw material for alcohol production because of its low grain price. A number of industries are currently using sorghum in alcohol production. The use of sorghum alcohol production in different distilleries is 17520 kl yr^{-1} in Kedia industries, 16060 kl yr^{-1} in Square D&J Singh, 3650 kl yr^{1} in Amar industries and 3540 kl yr"^{1} in G Galeon industries. With modern technology, the inclusion of sorghum in alcohol production does not have any major technical constraint. Industries buy molded grain at low price. Alcohol made from grain sorghum, though not very economical when compared with that from molasses, can be a good alternative to produce ethanol for blended petrol (gasohol); in addition, the grain is processed in brewing industry to produce alcoholic beverages. The alcohol recovery from grain is 400-410 L t^{-1} and the byproduct can be used as cattle feed. Sorghum varieties or hybrids with high starch and moderate protein content in the grains are most desired by the industry. A study conducted by NRCS with Seagram R&D Institute, Nasik, Maharashtra revealed that CSH 16 and CSH 18 are the superior hybrids for alcohol production (Seetharama et al. 2002).

The alcohol industry is quite eager to explore alternative sources of raw material following the Government of India's policy to include ethanol in petrol (initially 5% and may increase up to 10% or more). So far, sugarcane molasses is the major raw material for ethanol production, for both potable and industrial purposes. It is projected that there would be a short supply of molasses in some states, and sorghum finds a niche.

Starch and starch byproducts

Sorghum grain contains 63.4-72.5% starch, 17.8-21.9% amylase, 7.9-11.5% protein, 1.86-3.08% fat and 1.57-2.41% fiber (Ratnavathi and Bala Ravi 2000). The recovery of starch from sorghum grain is 5-8% less than maize, but is equally good in quality. Increasing grain size and reducing protein and fiber **contents** can increase the recovery. Sorghum being a cheaper source for the production of starch and starch byproducts can substantially replace maize. Liquid glucose and high-fructose syrup can be prepared from starch.

Maltodextrins prepared from sorghum starch are used in the preparation of low-calorie low-fat cookies in the baking industry (Anonymous 2002).

Sorbitol

Sorbitol is used as a syrup base in the pharmaceutical industry. Starch is hydrolyzed and chemically converted into sorbitol using Raney Nickel as catalyst. The conversion percentage from glucose to sorbitol is 90% (Anonymous 2003). However, attempts are being made to use micro-organisms to convert starch into sorbitol (Rainer and Silveira 2003).

High-fructose syrup

High-fructose syrup can be prepared from sorghum grain. This is a highly valued product in the pharmaceutical industry. It is 1.6 times sweeter than sucrose (common sugar). It can be utilized as a sweetener in pharmaceutical, soft drink and food processing industries. It was successfully prepared by using native invertase enzyme in NRCS laboratory. The sweet sorghum variety RSSV 9 was best suited for the preparation of high-fructose syrup (Anonymous 2003). The standardized technology is available with the Marathwada Agricultural University, Parbhani, Maharashtra.

Glucose

Liquid and powder glucose can be prepared economically from sorghum grain. Glucose also can be produced from starch enzymatically. The standardized technology is available with Agro-Product Development Centre, Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra and the Department of Food Technology, Marathwada Agricultural University, Parbhani (Anonymous 2003).

Malt

Commercially, malt is prepared from sorghum grain and this malt is used in the preparation of baby food and beverages. Milo is a sorghum drink prepared from sorghum malt. The diastatic activity of sorghum is 80% of that of barley (*Hordeum vulgare).* The optimization of conditions for sorghum malt preparation was carried out at NRCS (Bala Ravi and Ratnavathi 1991). The diastatic activity measured in Sorghum Diastatic Units (SDU) varied with genotypes tested: 144.5 SDU in IS 14387, 151 SDU in SPV 824 and 200 SDU in WS 1297. A malting loss of 27-39%

recorded in these genotypes can be minimized by reducing air and water supply. Micro-malting technique of sorghum grain (sample 10 g) was established for rapid screening of germplasm lines and elite breeding lines for diastatic activity (Jaya et al. 2001).

Adjunct

Grain sorghum flakes are used as an adjunct in the brewing industry. Sorghum can be a cheaper raw material compared to maize. Presently maize flakes or broken rice is being used in the brewing industry. A study conducted by NRCS in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh revealed that sorghum cultivars CSV 11, CSV13 and CSH 5 are best suited as adjuncts (Ratnavathi and Bala Ravi 2000). A further study in collaboration with a commercial brewery at Mumbai, Maharashtra revealed that three recently released cultivars of sorghum (CSH 13, CSH 14 and CSH 17) can be used as efficient adjuncts and pilot studies in this direction would definitely encourage higher sorghum grain usage in breweries.

Alternative uses of sweet-stalk sorghum

Sweet-stalk sorghum is a potential raw material for the preparation of jaggery, syrup and ethanol. Production of jaggery from sweet sorghum is identical to sugarcane and the jaggery obtained from sweet sorghum is comparable to sugarcane jaggery. Cultivation of sweet sorghum is economical in rainfed areas where sugarcane cultivation is not possible. The seed rate and sowing pattern recommended for grain sorghum can be adopted. However, a fertilizer dosage of 120 kg nitrogen ha^{-1} and 60 kg P_2O_5 ha^{-1} is suggested for increasing the sweet sorghum cane yield.

The variety SSV 84 has yielding ability of 40.4 t ha^{-1} green cane (with an average brix value of 18.4%) and 1.38 t ha^{-1} grain. Sweet sorghum cane juice has 5 pH, 12 to 13% sucrose, 0.8 to 1.8% reducing sugars and 0.6 to 1.8% starch. Thus, it consistently produced a minimum of 12% sucrose or at least 15% total fermentables with 50-60% juice recovery.

Ethanol as biofuel

Sweet sorghum stalk with 65% juice recovery is a competitive raw material for the production of ethanol. Most of the sweet sorghum varieties mature between 115 and 125 days during rainy season. Stalks can be harvested along with grain, or 4-5 weeks after harvest of panicles for grain. The green cane yield varies from 30 to 50 t ha^{-1} and grain yield from 0.8 to 2.0 t ha^{-1} with a brix value of 16 to 23%. Sweet sorghum varieties and hybrids bred at NRCS have potential to produce biomass up to 48 t ha^{-1}, 1.5 to 2.9 t ha^{-1} grain with brix value of 14 to 18% (Table 1). Sweet sorghum can be grown throughout the year, with minimum irrigation requirements and purchased inputs, which is an advantage over sugarcane.

Five sweet sorghum genotypes [Keller, SSV 84, BJ 248, Wray (varieties); NSSH 104 (hybrid)] were evaluated for total sugar, alcohol production and fermentation efficiency (Fig. 2). Extractable juice and sugar content results showed varietal differences. Extractable juice (per five plants) varied from 1080 ml (Wray) to 1790 ml (SSV 84). Total sugar content varied from 4.66 t ha^{-1} to 7.35 t ha^{-1}. Among the five genotypes, SSV 84 showed high juice extractability (34.4 kl ha^{-1}). The brix value was high in Keller, and therefore high ethanol production was obtained from the juice of this variety. Reducing sugar content of the juice varied from 1.10 to 2.80% (w/v).

Table 1. Promising sweet sorghum genotypes for ethanol production.

Genotype	Plant height (cm)	Cane yield (tha^{-1})	Grain yield (tha^{-1})	Extraction (%)	Brix (%)	TSS[1] (%)	RS[2] (%)	Sucrose (%)
RSSV 59	317.8	48.44	2.24	50.1	17.7	15.1	1.5	13.6
RSSV 46	293.9	47.68	2.80	42.5	16.2	13.1	1.7	11.3
RSSV 24	343.5	45.67	1.50	46.7	16.1	13.1	1.4	11.2
RSSV 45	347.6	45.48	2.01	39.1	16.8	14.1	1.8	11.9
RSSV 57	317.1	45.29	2.48	45.7	16.6	13.7	1.3	12.0
RSSV 44	276.4	44.49	2.63	43.1	15.9	13.2	1.3	12.3
SSV 84	273.9	43.58	1.77	47.1	16.5	14.1	2.1	11.8
RSSV 58	299.8	42.42	2.17	46.1	17.2	13.3	1.4	11.9
NSS 219	282.2	40.51	2.05	42.3	16.6	14.1	2.0	12.0
NSS 216	306.4	39.16	2.74	41.3	16.2	13.8	1.9	11.7
NSS 218	279.7	38.57	2.24	39.4	16.9	13.0	2.2	10.6
NSS 209	293.3	38.11	1.76	46.3	16.9	13.6	1.5	11.6
NARISS 41	295.5	34.49	1.94	48.8	14.2	12.9	1.3	9.5
AKSS 01-03	282.3	28.72	2.91	44.8	14.9	11.6	1.9	9.6
NARISS 83	238.7	27.85	2.28	41.1	16.2	14.4	1.9	12.3

1. TSS = Total soluble sugars.
2. RS = Reducing sugars.

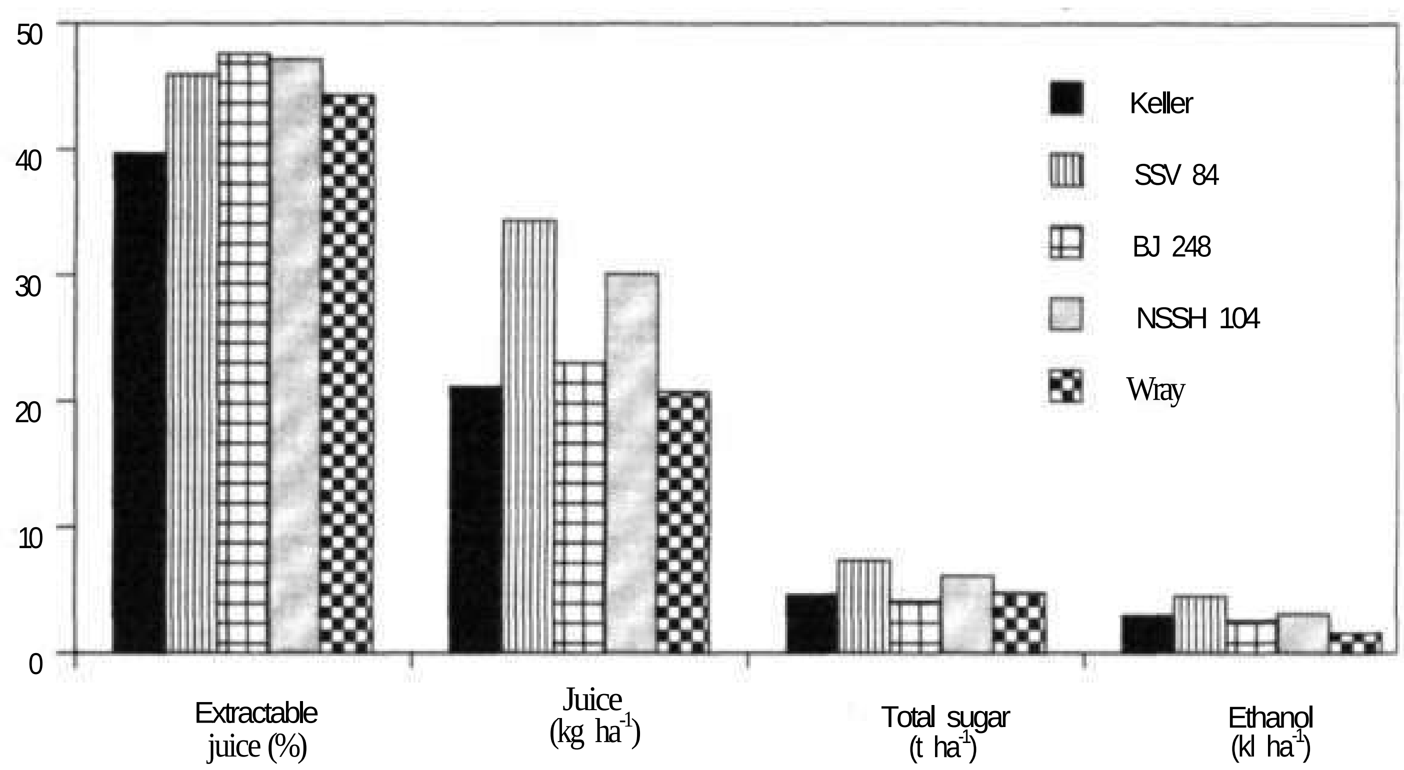

Figure 2. Total sugar and ethanol production yields from five sweet sorghum varieties.

The presence of reducing sugars in sweet sorghum prevents crystallization. Fermentation of juice from SSV 84 yielded 4.5 kl ha^{-1} ethanol whereas high fermentation efficiency (ie, the efficiency of yeast to produce alcohol per unit of juice) of 91% was observed with genotype Keller. High biomass production was observed with variety BJ 248.

The finished product of the fermentation, ie, ethyl alcohol (C_2H_5OH) has high commercial value. Ethanol is a 'clean burning fuel' with high octane rating and the existing automobile engines can be operated with petrol blended with 20% ethanol (80% petrol) without need for engine modification. The sweet sorghum juice can be used as a raw material to produce alcohol.

A pilot study in collaboration with a sugar factory in Karnataka was conducted successfully for the production of alcohol using sweet sorghum juice from variety SSV 84. Total fermentable sugars were enough to achieve maximum fermentation efficiency for alcohol production. Sweet sorghum cultivars have 90% fermentation efficiency. Pilot studies showed that recovery of alcohol from sweet sorghum cane juice economically is about 9%. Pilot production studies are encouraging and indicate cost effectiveness of sweet sorghum raw material for ethanol production.

Natural syrup

Sweet sorghum cane juice is concentrated and sterilized to make natural syrup, which can be used in confectionery industry as a sweetener. The syrup can also be used instead of honey with breakfast foods (Fig. 3). Syrup from sweet sorghum juice was also prepared commercially in Kentucky and Alabama in USA (University of Kentucky 2003). 'MADHURA, syrup from sweet sorghum juice, is being marketed by Nimbkar Agricultural Research Foundation, Phaltan, Maharashtra at US$1 for 400 ml. The chemical composition of sweet sorghum syrup is nutritionally equal to that of honey. It is very rich in calcium and iron (Anonymous 2003).

Jaggery

Sweet sorghum juice can be concentrated to make jaggery using the same technology used for making sugarcane jaggery (Fig. 4). The yield is 3 to 3.5 t ha^{-1} and is economical compared to sugarcane jaggery. Jaggery preparation is mainly dependent on the invertase activity. Some genotypes with very low invertase in the stalks do not get inverted. The genotypes NSSV 6, NSSV 7 and NSSV 8 have been identified as good for jaggery crystallization. Jaggery from sorghum may be better for diabetic patients due to rich fiber content. Sugars in sweet sorghum stalk include sucrose, glucose and fructose. Among the six cultivars of sweet sorghum evaluated for jaggery quality, NSSV 6 yielded good quality jaggery with best crystallization followed by NSSV 7. Jaggery prepared from NSSH 104 and

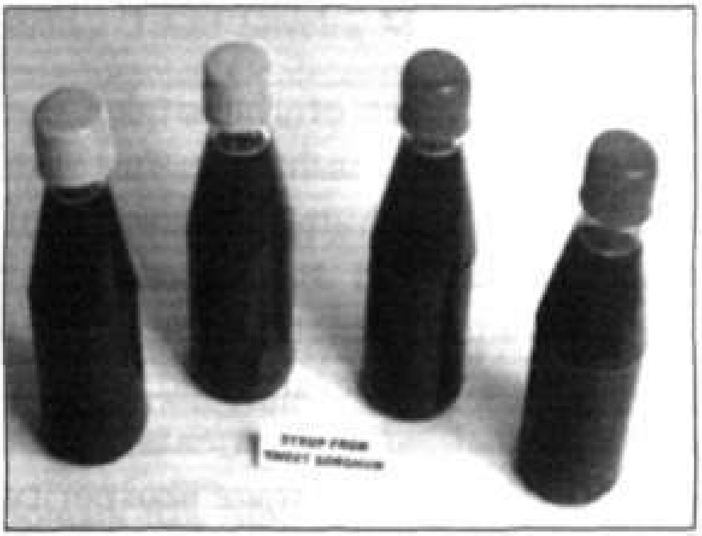

Figure 3. Syrup from sweet sorghum.

Figure 4. Jaggery from sweet sorghum.

SSV 84 had good confectionery taste. However, maximum jaggery was produced from SSV 84 (7.67% of cane weight) followed by NSSV 6 (5.88% of cane weight).

Institutional alliances necessary for scaling-up technology

The main industries that can use either grain sorghum or sweet sorghum are food industries for bakery products, starch industry, brewing industry and alcohol industry (both grain-based and molasses-based). Maize is the main competing grain for starch and food products. Sugarcane molasses is the competing raw material to sweet sorghum for alcohol production. Industries are generally interested in cheaper raw material without losing the benefits of byproducts and quality of the final product. In case of grain-based alcohol industry, this is quite possible. However, for the scaling-up of any technology the following aspects should be considered:

- Need for machinery modification
- Location of industry near raw material available zone
- Coordination between industry, research institute and the farmers

Contract farming may be taken up by industries to ensure the assured supply of sorghum at reasonable price. This would benefit both the farmers and industries. Price incentives similar to sugarcane should be given to farmers to encourage them to grow sweet sorghum for ethanol production. There is a proposal from the industry to procure grain from the farmers for a fixed price with the support of R&D organizations and state agricultural universities involved in sorghum research. This type of a liaison from the industry is much needed for the benefit of farmers.

Food industries are mostly based in the states of Karnataka and Tamil Nadu in India. Grain sorghum uptake by food industries in these states would certainly enhance the utilization of sorghum. The uptake of sorghum by industries at cheaper price compared to maize would certainly improve the farmer's net returns and ultimately the loss of sorghum area to some other competing crops can be arrested. Public institutions should encourage technological developments with necessary support either to farmers or industries to encourage prosperity to poor farmers in dry areas.

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Alternative Uses of Sorghum - Methods and Feasibility: Chinese Perspective

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Abstract

China, one of the major sorghum producers in the world, ranked fifth in harvested area and sixth in production during 2000-02. According to incomplete statistics, there are more than 40 types of traditional sorghum foods in China. Now sorghum is grown mainly for liquor and vinegar production, and only a small part is used as staple food. Around 2.6 million t of sorghum per year is used for liquor production. New products such as popped food and sorghum pigment are being commercialized. Rut more attention needs to be paid to the development of other products.

Archaeological research shows that sorghum (*Sorghum bicolor)* has been cultivated for at least 40-50 centuries in China. It used to play an important role in promoting crop production and guaranteeing food security, especially in the arid, semi-arid and waterlogged areas in China. In the early 20th century, sorghum area accounted for 10-26% of the total crop area, and ranked third after rice *(Oryza sativa)* and wheat *(Triticum aestivum)* (Song Renben et al. 2002).

Since the founding of the People's Republic of China in 1949, great changes have taken place in sorghum production, with the improvement of living standard, readjustment of agricultural production structure, and transformation from planned economy to market economy. Sorghum area and production has also been changing with social demands.

In 1952, sorghum area was historically highest (9.4 million ha), accounting for 7.5% of the cultivated area of all crops. The average yield of sorghum was 1.19 t ha^{-1}. Since then sorghum area gradually decreased, dropping by 34.4% in 1965 compared to 1952. During this period, sorghum had been grown mainly for staple food.

During 1966-76, sorghum area further decreased to 4.33 million ha in 1976, declining by 29.6% compared to 1965. But production increased greatly (8.7 million t), and yield was around 2.0 t ha^{-1}. Sorghum was still grown mainly for staple food, but a higher proportion was used as feed or raw material for liquor production.

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During 1977-88 when China reformed and was open to the outside world, agricultural production developed quickly and living standards improved greatly. Sorghum area decreased sharply although it slightly increased in some years. However, yield continued increasing and was 3.15 t ha^{-1} in 1988. Proportion of sorghum used for staple food decreased gradually until 1988 when its uses for food, feed and brewery was almost similar.

Sorghum area continued to decrease during 1989-2000. Also, the production decreased; however, yield increased. More and more sorghum was used for producing liquor. Currently sorghum area is around 0.7-0.8 million ha, with a slight increase in production (Fig. 1). About 90% sorghum is used for brewery, and less than 10% for food or feed. It is an indispensable raw material for producing high quality Chinese liquor and the most important source of income for farmers in sorghum production areas.

Traditional sorghum grain products and their commercialization

Since ancient times sorghum grain has been used in China as food and as raw material for Chinese liquor, starch, vinegar and Kaoliang Yi (caramel). For many centuries, sorghum was staple food for the population in the arid and

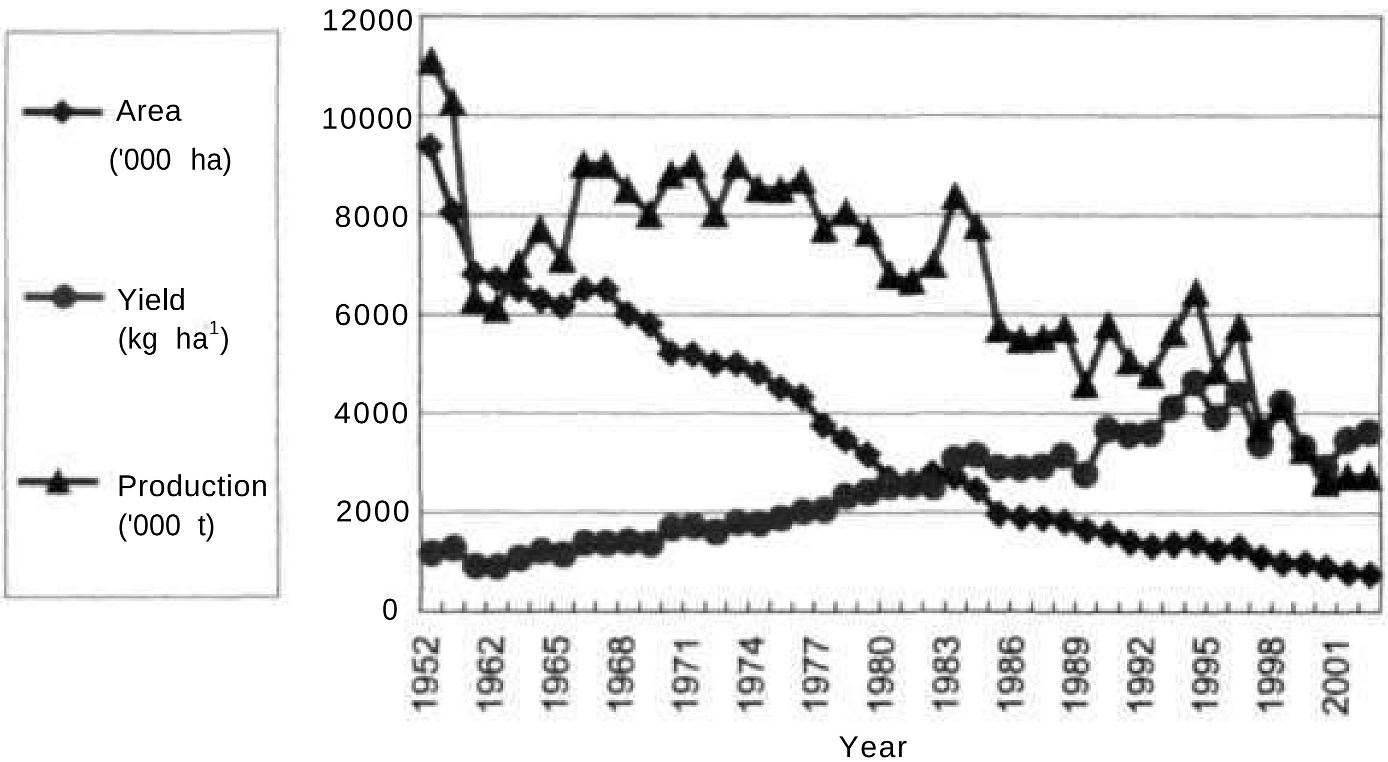

Figure 1. Changes in area, yield and production of sorghum in China (1952-2002) (Source: FAO 2003).

semi-arid areas. Later, for many years people did not eat sorghum. Increasing number of people are now eating it, not as staple food, but as healthy foods for balanced nutrition.

Traditional foods

There are many traditional sorghum foods in China, with various processing methods. According to Zhao Shukun (1987), it was found that there were around 40 traditional sorghum foods, which could be sorted into three groups based on raw materials and processing methods: polished grain foods, flour foods and popped foods (Table 1). Some of the important foods are: sorghum *hele* (a kind of vermicelli), cut noodles, planed noodles, steamed bread, dumpling, sorghum-vegetable roll, leavened cake and batter cake (Lu Qingshan 1999).

Table 1. Traditional food products of sorghum grain in China.

Category	Description	Typical products
Polished grain foods	Cooked grain meal	Cooked sorghum with less water, cooked sorghum washed with cold water, cooked sorghum with other cereal grain or legumes
	Conjee	*Conjee* of whole polished grain, *conjee* of mashed grain, *conjee* of sorghum grain and legumes, alkali *conjee*
Flour foods	Dough made with cold water	*Hele* (a kind of vermicelli made from sorghum powder), fried dumpling, Chinese pancake, cut noodle, planed noodles
	Dough made with hot water	Dumpling, steamed bread, steamed roll, fish-like noodle, lump soup, flapjack
	Glue flour paste	Fried dumpling, fried bread, batter cake
	Dried flour	Parched flour, *conjee*
	Moist flour	Soft cake
	Leavened dough	Cake (steamed or toasted), sour soup, rolled bread three-color cake
	Sticky flour	Sticky cake, sticky steamed bun filled with bean paste, sticky baked cake, sticky fried cake
Popped products	Popped grains	Popped shortbread, puffed sorghum grain

Cooked foods

Sorghum *hele.*

- Prepare dough with 5 kg sorghum flour, 0.25 kg elm bark powder, a little wheat flour and 2.5 L water.
- Boil water in a pot.
- Place a *hele-bed* [a wooden board with many holes (3 mm in diameter)] above the pot with boiling water. Press prepared dough on the *hele-bed* to form noodles, which directly drop into boiling water. The cooked noodles are called *hele* in Chinese.
- Prepare thick gravy of personal favorite.
- Mix cooked noodles with thick gravy and serve.

Cut noodles.

- Prepare dough with 5 kg sorghum flour and 2.5 L water (as above).
- Roll the prepared dough with a rolling pin into a flat shape.
- Cut with a knife into noodles.
- Follow the steps as in *hele* preparation for cooking and serving.

Planed or flat noodles.

- Prepare dough as above with sorghum flour.
- Hold the dough with one hand, and cut the dough with a sharp knife into thin, flat noodles
- Follow the steps as in *hele* preparation for cooking.

Steamed foods

Steamed bread.

- Prepare dough as above with sorghum flour.
- Make the dough into a bun-like shape with a hole in the bottom.
- Steam the shaped dough.

Dumpling.

- The preparation is similar to wheat dumpling.
- Prepare dough with sorghum flour and cold water or hot water.
- Take a small piece of dough and roll it using a rolling pin into a round flat shape (8-10 cm in diameter).
- Prepare filling with various vegetables, meat and seasoning.

- Make dumplings by placing the filling in the flat dough and covering the filling.
- Cook or steam as desired.

Leavened cake.

- Blend sorghum flour (5 kg) with water (approximately 3 L), then leaven it.
- Add appropriate dose of sodium bicarbonate and mix thoroughly.
- Put the dough in a steaming box, 6-7 cm thick, and steam.

Steamed twisted vegetable-sorghum flour roll.

- Prepare dough with sorghum flour.
- Prepare vegetable filling.
- Roll the dough to about 2-3 mm thin pieces.
- Spread a layer of oil and vegetable filling.
- Roll up the dough, cut into segments with filling and then steam.

Baked foods

Batter cake.

Batter cake is one of the most popular foods in China. The ingredients used are: 5 kg polished sorghum grain, 0.25 kg maize *(Zea mays)* flour, a little soybean *(Glycine max)* flour, a little cooked rice and 3.5 L water. The preparation process involves the following steps:

- Soak polished sorghum grain in water overnight and discard the water.
- Mix soaked grain with other ingredients.
- Grind with millstone into a paste.
- Pre-heat a cake pan and spread a layer of oil.
- Take a scoop of paste onto the pre-heated cake pan, and then swiftly extend it on the full surface.
- After 1-2 minutes, the cake is ready for eating, either plain or with filling.

Traditional secondary products of sorghum grain

Chinese liquor

China has thousands of years of history in producing liquor with sorghum; a characteristic taste has been formed since a long time. Experience of liquor making shows that only sorghum grain can turn out highest quality liquor. All famous Chinese liquors are produced by using sorghum as main raw material.

In recent years, around 2.6 million t of sorghum has been used annually to produce liquor. Thus, sorghum has played an important role not only in revenue but also in providing employment. It is estimated that there are about 40,000 breweries across China, which employ more than two million workers, most of them farmers.

The following characteristics of sorghum make it an ideal raw material to produce high quality liquor: (1) high starch content; (2) tannin and anthocyanin could be turned into fragrant aroma that is characteristic in the liquors; and (3) crushed sorghum grain remains loose after cooking, which is good for production.

Through years of practice, Chinese liquors have been made with different special technologies, by which different flavor and brand types of products have been formed. The most favorite brands are: Maotai, Wuliangye, Fenjiu, Luzhoulaojiao, Yanghe, Jiannanchun and Dongjiu. The features of four top brands of liquors are discussed.

Maotai. Maotai is well known at home and abroad. The earliest brewery was built in 1704. It used to be a national liquor served at receptions of senior foreign guests. It is made with local sorghum as main raw material, through fermentation using wheat starter. Maotai is sauce-fragrant type with complicated aroma components; total aldehyde content is higher than other famous brand liquors and alcohol content is around 53% (v/v).

Wuliangye. Wuliangye liquor is being produced for more than 1000 years. It is made from sorghum mixed with rice, sticky rice, wheat and maize through fermentation for a long period of 70-90 days. The fermentation silos now used were built during Ming dynasty. This liquor has excellent quality with special flavor and color. It tastes pure mellow and is sweet and refreshing. It belongs to strong fragrant type with high content of ethyl butyrate.

Fenjiu. Fenjiu liquor is being produced for more than 1500 years. It is made with local common sorghum as raw material, using barley (*Hordeum vulgare)* or pea *(Pisum sativum)* starter. The main aroma component is ethyl succinate (1.36 mg $100ml^{-1}$, thrice as high as in Maotai). Fenjiu is colorless, fragrant and refreshing. It belongs to traditional delicate fragrant type.

Luzhoulaojiao. Luzhoulaojiao liquor is being produced for more than 400 years. It is made from sticky (glutinous) sorghum using wheat starter, and filling with rice husk. It is strong mellow type with main aroma component of ethyl hexanoate. It is cool and refreshing, with strong apple fragrance.

Vinegar

Vinegar is a traditional condiment in China. In southern China, edible vinegar is made from sticky rice. In the north, edible vinegar is usually made from cereals. Sorghum is one of the best raw materials. Sorghum vinegar is very popular in northern China.

Kaoliang Yi (caramel)

Kaoliang Yi is caramel made from sorghum starch and sugar. It is a traditional sorghum food.

Alternative commercial products of sorghum grain

Chinese sorghum beer

Chinese sorghum beer was first made with sorghum as main raw material in the Institute of Sorghum, Shanxi Academy of Agricultural Sciences in early 1980s based on traditional technology for barley beer. Amino acid content in sorghum beer is higher than common beer, especially lysine content, which is 30% higher than common beer. Total sugar and lactoflavin contents are same as common beer, with flavor typical of common beer.

Popped food

Popped sorghum is a newly developed food in recent years. Crisp and popped sorghum made with special popping machine is popular.

Sorghum pigment

Sorghum pigment (red) is chemically a derivative of flavone-like compound, which is a natural pigment with no toxicity or flavor. Usually it is a red powder or lumpy solid, and can also be processed into liquid or paste as needed. It can be dissolved in water. Sorghum pigment can be widely used for coloring processed meat and fish, soybean products, cake, drinks, candy, medical capsules, etc.

Potential for commercializing alternative sorghum grain products

Sorghum beer

There is a great potential for the development of sorghum beer. Beer is becoming increasingly popular in China with the improvement of living standard. But in recent years, barley, mainly imported, has been used in beer production. The cost of beer production is increasing, which has affected beer market. Research has shown that sorghum can substitute barley, keeping flavor similar to common beer but with higher nutrition. Sorghum is much cheaper than barley, so it could be predicted that sorghum beer would have a great potential in the future.

Sorghum pigment

Sorghum pigment has been used in food industry and paramedical industry. Because it can be produced with simple technology, the production cost is relatively low. Sorghum pigment is a natural product with no toxicity and no side effect. So it is more popular than artificially synthesized pigments.

Institutional alliances necessary for technology up-scaling

Because sorghum has not drawn as much attention as rice and wheat, institutional alliances become more important for research and technology up-scaling. In China, an institute alliance has been formed since 1960s. Research fund mainly comes from the government, with a limited proportion coming from industries. Fund shortage has affected the routine research work on sorghum.

Because sorghum is not as popular as rice and wheat, and seed companies are reluctant to manage sorghum seed, it is not easy for farmers to get new sorghum varieties or relevant technologies that are desired. Sometimes research results cannot meet requirements of winery. So it is necessary to establish a coalition of research institutes, producers and processing companies.

Significance for improved livelihood and income generation

In the past, sorghum was grown mainly for staple food. But now it is an important industrial crop and people consume it as healthy food. Although it is not as popular as rice and wheat, it still plays an important role in the improvement of livelihoods of farmers in the arid and semi-arid areas. Sorghum has even become an economic mainstay in some sorghum-growing areas.

In recent years, local governments in some regions have attached much importance to sorghum production due to its high yield, resistance to drought, and higher price than maize. For example, in Wanzhou district and Jiangjin city, Sichuan province and Xinzhou district, Shanxi province, the local governments have put sorghum production on their work agenda. But sorghum production is far from what it should be. To promote its development, wide international cooperation is needed in breeding, crop production and developing new products.

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Alternative Uses of Cereals - Methods and Feasibility: Pakistani Perspective

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Abstract

The six cereals produced in Pakistan are wheat, rice, maize, sorghum, millet and barley. Wheat is in the leading position while sorghum and millet rank fourth and fifth, respectively. Sorghum and millet contribute 3% in area and less than 1 % in total cereal production. In the dryland areas, however, they are the leading food and fodder crops. Sorghum production remained unchanged while its area slightly declined in the last two decades. Millet area and production also slightly declined. The yields have shown marginal improvements. Sorghum is mainly consumed as a food grain (87%) while only 5% of it goes into feed. Sorghum is the most important summer fodder crop with increasing importance in the irrigated areas near towns. Millet is also an important fodder crop specially in the dryland areas. About 45% of millet is used in human food while about 50% is used in rural poultry and cattle feeding but not in commercial poultry rations. Both the commodities are utilized at the village level and are not industrially processed, and thus have no alternative uses. The fodder utilization of both can be improved further provided ensilage is adopted by the rural farmers. With the current level of production and utilization in Pakistan, there is not much scope of industrial processing and non-conventional utilization of sorghum and millet in the near future. They will continue to play a significant role in fulfilling the food, feed and fodder requirements in the dryland areas. Therefore, they deserve more attention by researchers, extension workers and policy makers.

In Pakistan, six cereals are produced. Wheat *(Triticum aestivum)* is in the leading position followed by rice *(Oryza sativa)* and maize (*Zea mays)* (Table 1). Sorghum (*Sorghum bicolor)* and millet rank fourth and fifth, respectively. In the semi-arid regions, these are the most important staple foods. Because of their ability to grow in harsh environments where other crops do not grow well or produce poor yields, they will continue to significantly contribute to the household food security and nutrition of the inhabitants of these areas. These crops are still the principal sources of energy, protein, vitamins and minerals for millions of the poorest and the

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Table 1. Area, production and yield of the cereals grown in Pakistan in 2002.					
Cereal	Area ('000 ha)	Share in total area (%)	Production ('000 t)	Share in total production (%)	Yield (kg ha[1])
Wheat	7983	67.39	18475	69.86	2314
Rice	2040	17.22	5776	21.84	2831
Maize	992	7.95	1664	6.29	1766
Sorghum	357	3.01	222	0.84	632
Millet	417	3.52	216	0.82	531
Barley	107	0.90	92	0.35	860
Total	11846		26445		

most food-insecure people in these areas. Therefore, improvements in production, utilization and other aspects of these poor people's crops will significantly improve the livelihood of many smallholder farmers in the low rainfall and drought-affected agro-ecoregions in Pakistan and other similar regions. This paper presents an overview of the production and utilization of cereals in Pakistan with special reference to sorghum and millet. It also reflects on the alternative uses of these cereals in Pakistan.

Area and production trends

Like many developing countries, the available data on production and utilization of sorghum and millet in Pakistan are less accurate because these are primarily grown in outlying areas as subsistence crops. Also, in the hot and dry agro-ecoregions, they are grown as dual-purpose crops, where both grain and stover are highly valued outputs. This further complicates the situation making it even difficult to accurately record the grain and fodder production of these two crops. Because of their least contribution in total cereal production, no specific surveys have been conducted for accurate estimation of the area, production, productivity and utilization.

Sorghum, locally known as *jowar,* is an important *kharif* (rainy) season crop grown in most districts south of latitude 34° N. It is particularly important in the districts of DG Khan, Rahim Yar Khan, Rawalpindi, Attock and Jehlum (Punjab); Sukkar, Khairpur, Dadu, Nawabshah and Sanghar (Sindh); Nasirabad, Lasbela, Kacchi, Kalat and Sibbi (Baluchistan); and DI Khan, Bannu and Kohat (NWFP) (Kambal 1988). Grain sorghum is grown on 375,000 ha of land with a total production of 222,000 t and an average yield of 632 kg ha^{-1} (FAO 2002). Sorghum production in Pakistan has literally remained unchanged during the last two decades (Fig. 1). During the same period, sorghum area has declined from 390,000 to 350,000 ha. Sorghum yields have shown signs of marginal increase from 569 to 622 kg ha^{-1} in the last two decades (Anonymous 1981-2002).

Millet is grown in Pakistan on an area of 417,100 ha, with a total production of 216,400 t, and a yield of 519 kg ha^{-1} (Fig. 2) (FAO 2002). Millet in Pakistan is a dominant crop in the districts of Tharparker, Sanghar and Hyderabad (Sindh), DI Khan and Karak (NWFP); DG Khan, Sargodha and Rawalpindi (Punjab); and Kacchi, Sibbi and Gowader (Baluchistan). During the last two decades, millet area and production have shown a slight decline from 438,000 to 418,000 ha and 220,000 to 216,000 t, respectively. The yields during the same period slightly improved from 502 to 517 kg ha^{-1} (Anonymous 1981-2002).

The contribution of both sorghum and millet towards total cereal production in Pakistan has been progressively decreasing. This is in contrast to annual increases in the area, production and productivity of other major cereals, ie, wheat, rice and maize (Fig. 3) (Anonymous 1981-2002).

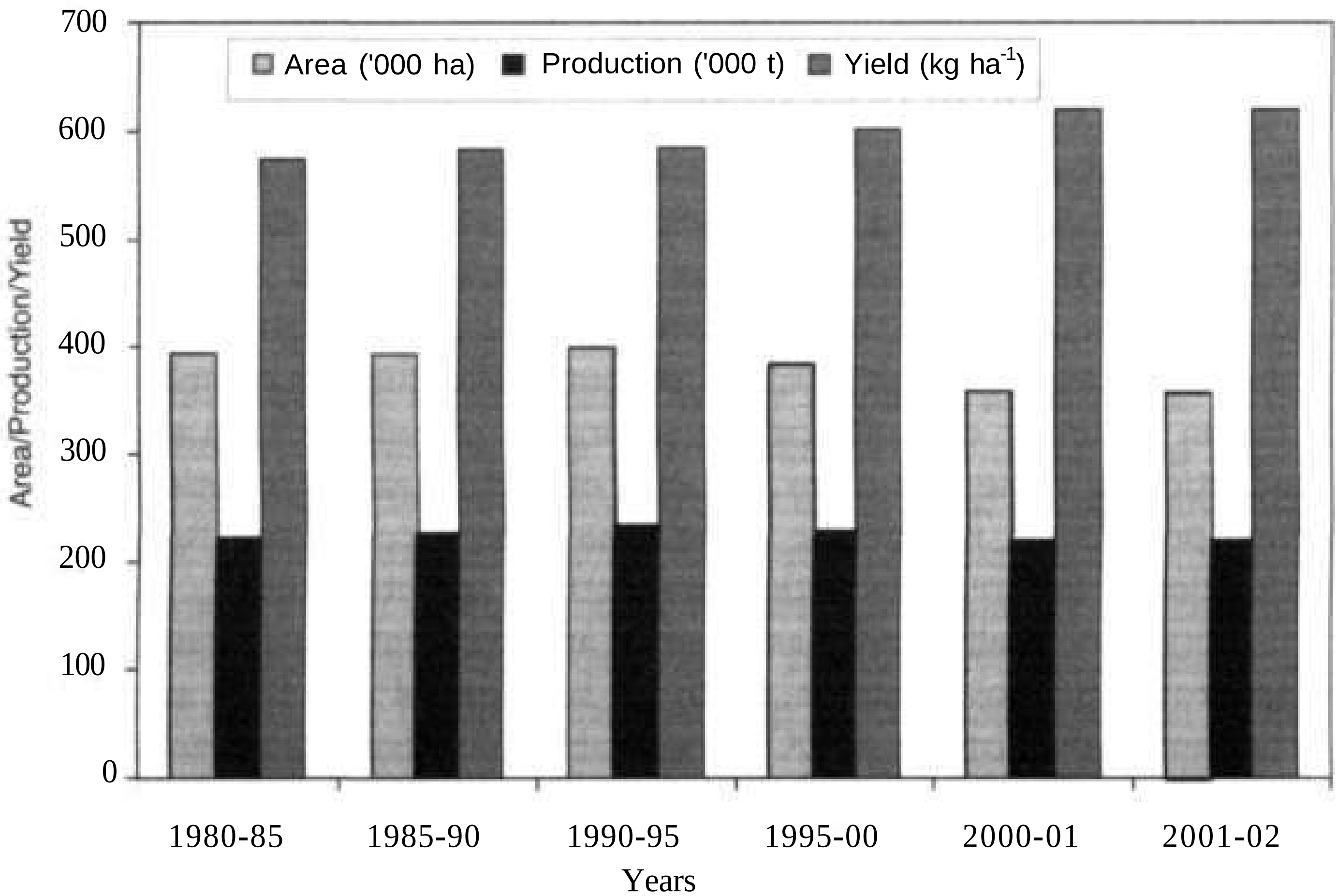

Figure 1. Trends in area, production and yield of sorghum in Pakistan.

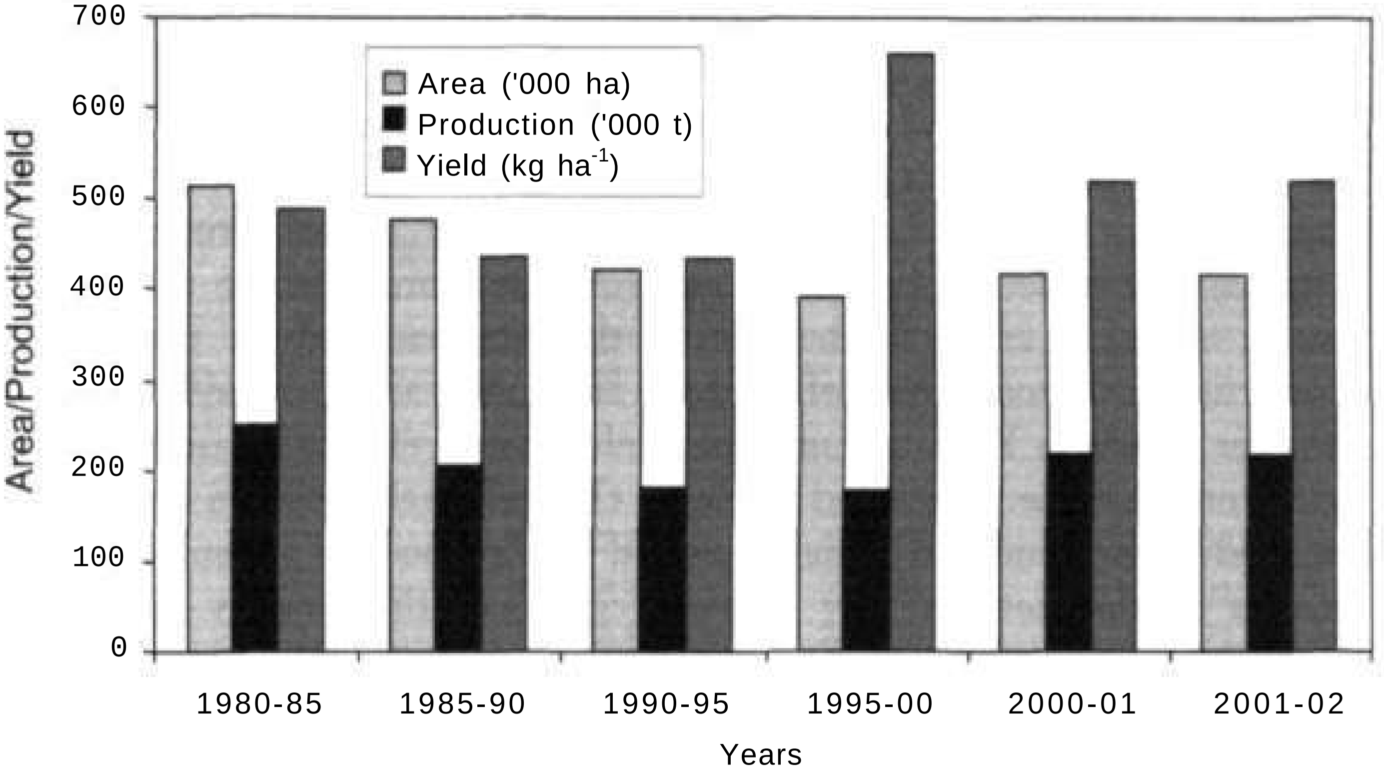

Figure 2. Trends in area, production and yield of millet in Pakistan.

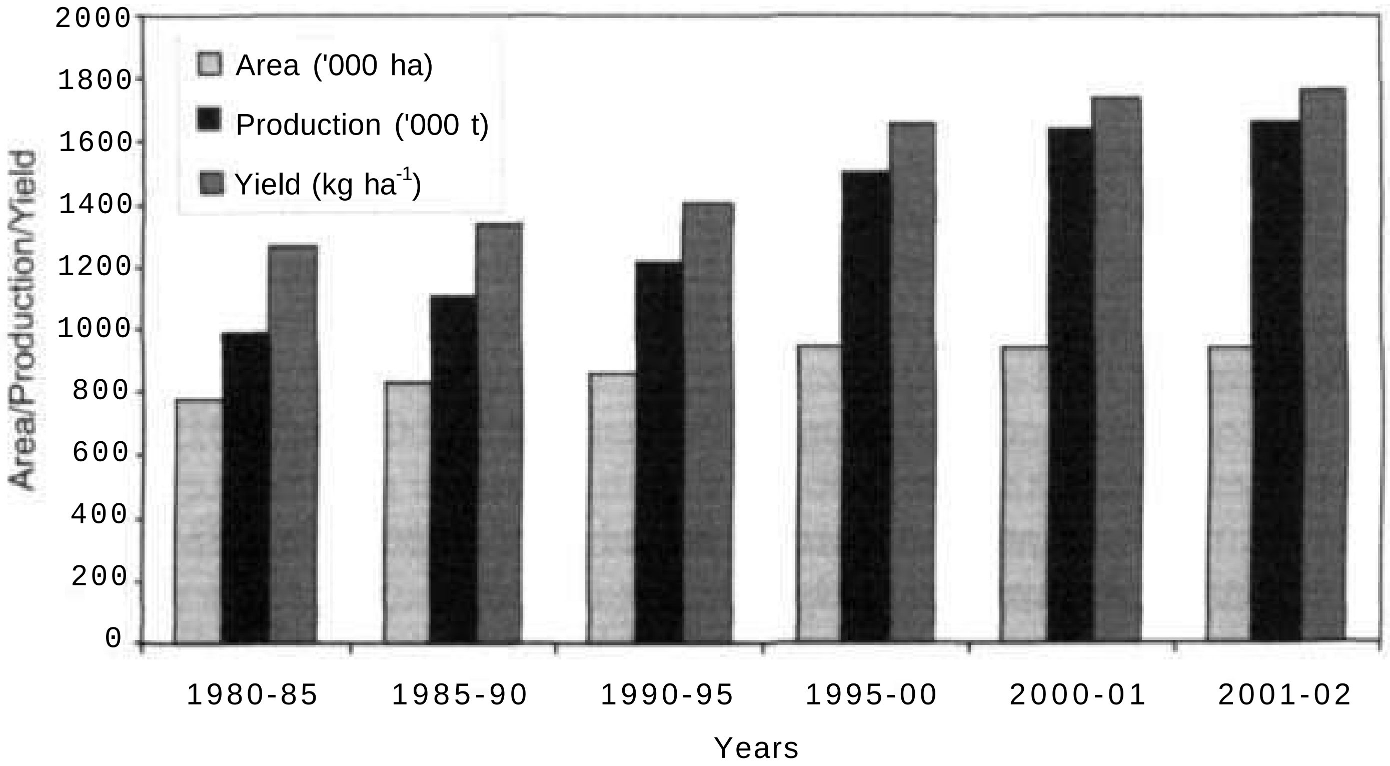

Figure 3. Trends in area, production and yield of maize in Pakistan.

Currently sorghum and millet, each contribute about 3% of the cereal area and slightly less than 1% of cereal production (Table 1).

Thus, with marginal yield improvements and slightly declining areas, the total production of sorghum and millet in Pakistan is stagnant. Due to the improvements in the competing crops especially maize, production of sorghum and millet is shifting to more marginal areas where subsistence nature of these crops further limits the improvement in production. Production and productivity of sorghum and millet are likely to improve in the near future in Pakistan, until and unless more efforts on research and extension are made. The trend has to be changed in the positive direction if the food security and nutritional levels and the livelihood of the small poorest farmers in the hot and dry agro-ecoregions of the country are to be improved.

Utilization

Cereals are mainly used as human food in Pakistan (Table 2). Cereal grains and green and dry fodder are also used in livestock feeding.

Human food

Wheat is the most important cereal in Pakistan because it is the staple food and is the largest cereal crop in terms of its production. The average wheat consumption as food was 10 million t in 1981-85 and increased to 19 million t in 1995-2000. The overall growth rate of wheat (1981-2000) in food was 4.28%. About 91% of wheat is used for food while the remaining 9% is used for feed and other uses (Table 2). Per capita consumption of wheat progressively increased from 113 kg in 1981-85 to 144 kg in 1995-2000 (Anonymous 1981-2002).

Food consumption of maize in Pakistan was 57,000 t in 1981-85 which increased to 907,000 t in 1996-2000 with an overall growth rate of 2.97%. Per capita consumption of maize increased from 6 kg in 1981-85 to 7 kg in 1996-2000 (Anonymous 1981-2002).

Food consumption of sorghum in Pakistan was 190,000 t in 1981-85 which slightly increased to 200,000 t in 1996-2000. The share of sorghum in food almost remained stagnant (86-87%) during the past two decades but has recently declined (-2.54). Consequently, per capita consumption of sorghum decreased from 2 kg in 1981-85 to 1.5 kg in 1996-2000

Table 2. Consumption ('000 t) of cereals in Pakistan.

Year	Total	Food (%)	Feed (%)	Others (%)
Wheat				
1981-85	11283	10051 (89.08)[1]	231 (2.05)	1001 (8.87)
1986-90	13582	12248(90.18)	260(1.91)	1074(7.91)
1991-95	16607	15086(90.84)	314(1.89)	1207 (7.27)
1996-2000	20739	18915(91.20)	385(1.86)	1438(6.93)
Growth rate (%) (1981-2000)	4.22	4.28	3.41	2.10
Maize				
1981-85	988	570 (57.69)	197(19.94)	220 (22.27)
1986-90	1126	662 (58.79)	226 (20.07)	238(21.14)
1991-95	1226	722 (58.89)	244(19.90)	260(21.21)
1996-2000	1565	907 (57.96)	344(21.98)	314(20.06)
Growth rate (%) (1981-2000)	2.90	2.97	3.45	2.27
Sorghum				
1981-85	220	190(86.36)	11.2(5.09)	19.2(8.73)
1986-90	229	198(86.46)	11.4(4.98)	19.4(8.47)
1991-95	235	204(86.81)	11.8(5.02)	19.2(8.17)
1996-2000	231	200 (86.58)	11.6(5.02)	19.0 (8.23)
Growth rate (%) (1981-2000)	0.47	0.48	0.31	-0.46
Millet				
1981-85	250	107(42.80)	125(50.00)	19.0(7.56)
1986-90	206	87 (42.23)	103(50.00)	15.8(7.67)
1991-95	181	76(41.99)	91 (50.28)	13.8(7.62)
1996-2000	178	74(41.57)	89 (50.00)	15.0(8.15)
Growth rate (%) (1981-2000)	-2.0	-2.2	2.11	-1.5

1. Percentage values are given in parentheses.

(Anonymous 1981-2002). The traditional use of sorghum flour for food purposes is mainly in the form of *roti* or *chapati* (unleavened flat bread). It is estimated that as in India (Murty and Subramanian 1982) about 70% of the sorghum grown in Pakistan could also be used for making *roti*.

Sorghum flour can be blended with wheat flour up to 10% without seriously affecting the baking quality of the composite flour. Such blending could help in easing the food situation in the country and help to save the wheat for export purposes. In parts of Sindh and Punjab, sorghum grains are popped and sometimes mixed with raw sugar and used as snacks (Kambal 1988).

Food use of millet in Pakistan was 107,0001 in 1981-85 and declined to 74,000 t in 1996-2000 (Table 2). The share of millet as food ranged from 42 to 44% of its total consumption during the past two decades. The per capita consumption of millet has significantly declined from 1.2 kg in 1981-85 to 0.4 kg in 1996-2000 (Anonymous 1981-2002). Sorghum and millet are both used by the rural community as part of their food. A decrease in the per capita consumption may be due to the preference of people in Pakistan to use more wheat in their diets.

Animal feed

Wheat, maize, rice, sorghum and millet are basically grown for human dietary needs but they are also used as animal feed. Before the development of commercial poultry feed industry, the grains of these crops were basically used to feed livestock and rural poultry. However, with the advancement of poultry industry, the grains of these crops are being effectively utilized as ingredients of commercial rations more precisely in the poultry feed. Maize grains arc used up to 40% in the poultry rations. However, when the maize price increases it is substituted with other cereal grains or their byproducts. Wheat is also used in poultry feeding and in commercial dairy farming system. However, wheat use in poultry feed formulations does not exceed 15% because it has adverse effects on egg laying. Sorghum is used up to 5% level in commercial poultry feed. Millets are not used in commercial poultry feeds but are used for livestock feeding. Although milled rice is not incorporated in the livestock and poultry rations, its byproducts (rice bran, rice tips, rice polish) are utilized for commercial poultry and livestock feeds.

Since the development of livestock and poultry feed industries in Pakistan in the mid-1970s, the annual use of cereal grains in feed increased at a rate of 2.53% and their byproducts at a rate of 3%. Although wheat in feed represents a smaller proportion (2%) of its total production, it is still the largest cereal grain utilized for this purpose (Table 3). Wheat grain used for livestock feed was 231,0001 in 1981-85 and increased to 385,000 t in 1996-2000 at an annual growth rate of 3.41%. The projected feed use of wheat in 2010 is 654,000 t.

Table 3. Utilization ('000 t) of cereal grains in livestock feed in Pakistan.

Year	Wheat	Maize	Millet	Sorghum	Total
1981-85	231	197	125	11	564
1986-90	260	226	103	11	600
1991-95	314	244	91	12	661
1996-2000	385	344	89	12	830
Projected 2010	654	489	89	11	1243
Growth rate (%) (1981-2000)	3.41	345	2.11	0.31	2.53

Maize is the second most important cereal in livestock feed in Pakistan. Utilization of maize in feed was 197,000 t in 1981-85 and increased to 344,000 t in 1996-2000 (Table 3). The average annual growth rate of maize in feed (3.45%) is the highest among the cereals. Its projected demand for feed is 489,000 t for 2010. Maize in livestock feed is used up to 22% of its production. Currently, in poultry feed rations, the cereal component is composed of 40% maize, 40% rice (byproducts), 18% wheat and 2% sorghum with no millet and barley *(Hordeum vulgare)* included in commercial poultry rations (M Sadiq, Sadiq Brothers Poultry, Rawalpindi, Pakistan, personal communication).

Millet is the third most important cereal in livestock feed in Pakistan. The use of millet in feed shows a constantly declining trend. In 1981-85, 125,000 t of millet was used in feed while in 1996-2000 only 89,000 t was used (Table 3). It is estimated that the use of millet in feed will not increase in future. Thus, the projected demand for millet in feed is 89,000 t for 2010. The use of millet in feed is very conventional, and for the last two decades 50% of the millet produced has been utilized for this purpose. It is a major contributor in the feeding of rural cattle and poultry but it is not used in commercial poultry rations. In Pakistan, millet is the most popular bird seed commonly fed to pet birds.

Sorghum grain has been conventionally utilized for livestock feed. However, a very small portion of the total sorghum produce (about 5% or less) goes into the feed. The average sorghum consumption in feed was 11,200 t in 1981-85 which slightly increased to 11,600 t in 1996-2000 with an average growth rate of 0.31% (Table 3). Also, the projected sorghum demand for feed for 2010 is only 10,500 t which is slightly less than its current utilization.

Among the industrial byproducts of cereals, wheat and rice brans, rice tips and polish, maize oil cake and gluten 20% and gluten 60% are used in livestock and poultry feeds (Rasool et al. 1996). The use of all these byproducts has been increasing at an average annual growth rate of 2 to 3% since early 1980s. This trend continues and with increase in industrial processing of these major cereals, the utilization of the byproducts is expected to increase. In case of rice, only the industrial byproducts and not the grain itself are used in livestock and poultry feed products. Since sorghum, millet and barley are currently not industrially processed in Pakistan, their byproducts are not likely to be utilized in the feed industry in near future.

Animal fodder

The stover of sorghum and millet, after the harvest of grains, is used as a dry fodder, particularly during winter when feeds are usually scarce. Stover represents up to 50% of the total value of the crops and its value and contribution increases in drought years. The percentage of the total area of sorghum and millet devoted to fodder production is not known. According to some estimates (PARC 1977), at least 50% of the irrigated and 25% of the rainfed sorghum area is harvested for fodder before the grains are formed. However, it is generally believed now that the area harvested for fodder is increasing rapidly, particularly near towns. In addition, both these crops are specifically grown for production of green fodder. In fact, sorghum is the most important *kharif* fodder crop in Pakistan and its fodder utilization is increasing particularly in irrigated areas near towns (Table 4).

Table 4. Area, production and yield of *kharif* fodder crops in Pakistan.

Crop	Area ('000 ha)	Share in total area (%)	Fodder production ('000 t)	Share in total fodder production (%)	Fodder yield (t ha^{-1})
Sorghum	515	35.85	7877	39.08	15.29
Millet	105	7.36	758	3.75	7.21
Guar	311	21.67	3545	17.58	11.38
Maize	48	3.34	961	4.76	19.96
Moth	1	0.10	17	0.10	12.15
Others	45	31.68	6997	34.71	15.37

Source: Coordinated Programme on Fodder Crops, National Agricultural Research Centre, Islamabad, Pakistan.

Large quantities of maize, sorghum and millet crop residues are available in Pakistan, which are of good nutritive value and can be better utilized by ensiling. However, the technology of making silage is currently not in practice. Agro-industrial byproducts are important sources of protein supply but their availability is limited and a major part is used in poultry feed industry.

Forage sorghum hybrids have yielded up to 78% higher green fodder and 75% higher dry matter than the improved open-pollinated variety (Hussain et al. 1996). Improved varieties of sorghum yield up to three-fold higher than the local variety (Rasool et al. 1996). However, these varieties and hybrids could not be extended to the farmers who still grow the conventional low-yielding local landraces and varieties.

Alternative uses

Wheat, maize, sorghum, millet and barley are used for food, feed and other purposes. The byproducts from wheat and rice are mainly used for livestock feeding and also in poultry feeding. Maize is processed in wet milling industries basically to produce starch for textile industries. The other major products are liquid glucose and cooking oil. Among other products, maize oil cakes and gluten are used in commercial poultry rations and in livestock feeding. Sorghum and millet are both utilized at the village level and thus no byproducts are produced. The contribution of cereals in livestock feeding over the last twenty years ranged from 6 to 9% while in poultry feed it ranged from 31 to 34%. Thus, cereal grains are used more in poultry feeds than in livestock feeds. The contribution of cereal grains especially maize in commercial poultry feed is expected to increase since with improving incomes and lifestyles, the poultry industry is going to flourish in future at a rate of 4.5% annually. The ruminant feed consumption in Pakistan is projected to increase annually at a rate of about 7.0% by 2010. However, the contribution of cereals in ruminant feeding is projected to decline to about 2% by 2010.

Very insignificant amounts of millet are used in bakery products in combination with other cereals. With improvements in flour processing of sorghum and millet, their non-conventional utilization in human food, pet foods and health foods may be initiated. However, currently non-conventional food utilization and industrial processing of these cereals are not feasible.

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Alternative Uses of Cereals - Methods and Feasibility: Thailand Perspective

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Abstract

Methods and feasibility on alternative uses of sorghum in Thailand are discussed. The use of sweet sorghum for ethanol production is proposed. As sorghum is one of the most efficient crops in terms of producing fermentable sugars as well as grain, it is one of the most ideal crops for the simultaneous production of energy and food. Technology for ethanol production adapted from the sugarcane industry can be utilized almost directly to produce ethanol from sweet sorghum. Comparative studies on various raw materials available in Thailand for ethanol production are analyzed. Minor uses of various types of sorghum are also discussed.

Sorghum *(Sorghum bicolor)* is an important cereal crop grown in Thailand and ranks third following rice *(Oryza sativa)* and maize *(Zea mays).* It is cultivated for its grain and primarily used for animal feeding. In 2002, total production of sorghum in Thailand was 300,000 t from an area of about 160,000 ha; the yield was about 1,875 kg ha"[1] (FAO 2002).

There are four classes of sorghum commonly grown in Thailand: grain sorghum, fodder sorghum, sweet sorghum and broomcorn. Major emphasis is on grain sorghum production. This paper focuses on the alternative uses of sorghum as a renewable resource for ethanol production and the potential of growing sweet sorghum as an alternative cash crop for Thai farmers. Other uses of various types of sorghum are also discussed.

Direct use of sorghum grain

In Thailand, sorghum grain is primarily utilized for the livestock feed industry. However, high tannin sorghum grains are not efficiently utilized by monogastric animals. Vast quantities of sorghum stover have a high potential for use as ruminant diets to maintain live weights during the dry season. However, the utilization in this form is still very low in Thailand because a large amount of rice straw is available for beef and dairy farmers.

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Sweet sorghum as a source of fermentable sugars for energy

Sweet sorghum has a long history of cultivation in Asia, Europe and America. Recently, high-sucrose sweet sorghum cultivars have been developed with potential as a sugar crop. Because of the rapid increase in crude oil prices that occurred during the 1970s, sweet sorghum has been investigated as a potential source of fermentable sugars for ethanol fuel production. This is because of the crop's high sugar content and biomass production, wide geographic and climatic adaptation, and relatively low water and fertilizer requirements (Nathan 1978). It has been grown for making sweet syrup in the United States. It is also suitable for feeding to animals as forage, silage and hay.

Despite the long history of cultivation in many countries, little attention has been paid to sorghum in Thailand because of its minor economic importance, and there has been little improvement made in this crop. Although many promising varieties of sweet sorghum have been introduced to Thailand more than 20 years ago, their utilization is still limited.

Following the energy crisis of the world, which started in 1973 when the petroleum cartel OPEC (Organization of the Petroleum Exporting Countries) in Vienna, Austria initiated a series of price increases and later mounting political instability among several OPEC members, much emphasis has been placed on alternate and renewable energy resources and energy independence. In the developing countries, one alternative to the energy crisis is the production of bioenergy from biomass. Ethanol is an appropriate alternative fuel.

Traditionally, ethanol has been produced mainly from sugarcane *(Saccharum officinarum)* molasses. Sweet sorghum provides grain from the panicles and sugar (and hence ethanol) from its stalks; the bagasse is an excellent fodder for animals. Thus it provides food, fuel and fodder. No other crop yields all these products together.

Recently, the Thai government promoted the use of gasohol (gasoline + 10% of 99.5% ethanol) and also tried to promote the use of diesohol (diesel + 10% ethanol) in the future. Daily domestic consumption of 20 million L of gasoline and 55 million L of diesel imply the need for huge quantity of ethanol. Mixing 10% of ethanol in both gasoline and diesel results in the requirement of 7.5 million L day^{-1} of ethanol.

Of the raw materials, ie, rice, cassava *(Manihot esculenta)*, sugarcane, molasses and sweet sorghum for producing ethanol in Thailand, only cassava and molasses were cost effective (Table 1). Use of cassava and molasses as raw materials for producing ethanol can generate more income than selling as cassava chips, cassava pellets and raw molasses. Production of ethanol from rice and sugarcane will decrease the value of the crops. Selling rice and sugarcane in terms of grain and sugar will generate more income than using these two crops as raw materials for producing ethanol.

It is impossible to use all exported cassava and molasses for producing ethanol because of competition with permanent markets. Many experiments on sweet sorghum production have been done at Khon Kaen University, Khon Kaen, Thailand. It is already proved that sweet sorghum is one of the suitable crops for use as an energy resource. It can grow in a wide range of geographical areas. It has a production capacity equal or superior to sugarcane. It is a short-maturing crop and at least two crops per year can be produced under rainfed conditions. It has a potential for low unit costs because it requires less water and fertilizer than sugarcane.

On-shelf technologies

Ethanol from cassava and molasses has been produced in pilot runs at the Thailand Institute of Science and Technology, Bangkok about 25 years ago. Recently, the Thai government announced the new policy on energy. The National Ethanol Committee approved eight ethanol production plants as large-scale for energy. Sweet sorghum can be used for ethanol production by adopting the technology available for sugarcane industry (Schaffert and Gourley 1982).

In Thailand, the normal harvesting period for sugarcane is from November to April while the proposed harvesting period for sweet sorghum

Table 1. Analysis of cost effectiveness of various existing raw materials for ethanol production.

Raw materials[1]	Production (million t) Domestic	Export	Export value (million US$)	Estimated ethanol production (million L)	Estimated value of ethanol[2] (million US$)	Difference[3] (million US$)
Rice	8.9	6.7	1783.8	2513	658.4	-1125.4 (-63.1)
Cassava	4.1	14.5	543.6	2610	683.8	140.2(25.8)
Sugarcane	15.9	36.6	833.3	2562	671.2	-162.1 (-19.5)
Molasses	1.4	1.0	33.3	260	68.1	34.8 (104.5)

1. One ton of rice, cassava, sugarcane and molasses yielded 375, 180, 70 and 260 L of ethanol, respectively.
2. Cost of ethanol = US$0,262 L^{-1}.
3. Percentage values are given in parentheses.

is from June to October with planting beginning at the onset of rainfall in March or April. In this case the two crops supplement each other and when used together increase the period of industrial operation, decrease the unit cost of ethanol production, and increase the total amount of ethanol that can be produced by a distillery in one year. The same equipment is used to process both sugarcane stalks and sweet sorghum stalks. Consequently, little interest is given to the superior productivity of sugarcane or sweet sorghum. However, the economic production of both sugarcane and sweet sorghum are considered important.

Sweet sorghum productivity and quality

Sweet sorghum is a relatively unknown crop in Thailand. It is considered an underutilized crop and never grown as a commercial crop. Few researchers work on this crop. At Khon Kaen University, some improved varieties of sweet sorghum introduced from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India and USA yielded 40-62 t ha^{1}.

The quality of juice from sorghum is usually slightly inferior to juice from sugarcane. Two types of sweet sorghum have been developed: (1) syrup varieties which contain invert sugars in the juice to prevent crystallization; and (2) sugar varieties which contain mostly sucrose and very little invert sugars in the juice for crystallization. Both types of sweet sorghum produce ethanol. But good types that produce ethanol need not be associated with high sucrose purity of the sugar types or the quantity and quality of syrup produced per ton of stalks of the syrup types. The total amount and extraction of total invert sugars (fermentable sugar) is important for ethanol production.

Economics of producing ethanol from sweet sorghum

The Thailand Ministry of Industry reported the production costs of ethanol in various raw materials (Table 2). Based on production cost, only cassava, sweet sorghum and molasses are the most suitable raw materials for producing ethanol. The production costs should not be higher than US$0.15 L^{-1} otherwise it cannot compete with the fossil energy.

Significance for improving livelihood and income generation

Sorghum grain is mainly used in Thailand for animal feeding. In 2002, the production of sorghum grain was 300,000 t, valued US$990 million at farm

Table 2. Estimated production costs of ethanol from various raw materials.

Raw material	Cost of raw material (US$ t^{-1})	Ethanol yield (L t^{-1})	Production cost of ethanol (US$$L^{-1}$)
Molasses	37.5	260	0.144
Sugarcane	14.6	70	0.209
Sweet sorghum	10.0	70	0.143
Cassava	25.0	180	0.139
Maize	87.5	375	0.233
Rice	200.0	375	0.533

Source: Modified from Thailand Ministry of Industry (2001).

level. Although it gave less value compared to rice and maize, the crop is drought tolerant, has very good adaptability and can grow on marginal lands. These traits will be of great benefit to the poor farmers in dry areas. However, an alternative use of sorghum grain as human food is very less in Thailand because rice is still surplus.

The energy crisis, which started in 1973, initiated the emergence of bioenergy. An integrated food, feed, biofertilizer and energy production system using sweet sorghum may be an economical and logical response for energy production. At present, sweet sorghum is not produced by the Thai farmers. After the establishment of eight approved ethanol production plants, sweet sorghum has very high potential for use as a raw material. In this case, we estimated at least 40,000 ha of planting area could produce 1.8 million t of fresh stalks which valued about US$19 million at farm level.

Minor utilization of sorghum

Sorghum panicles as ornamental flowers

According to Thailand policy on generating income for Thai farmers through the promotion 'One Tambon One Product' (Tambon comprises many villages), sorghum was included in this project. Value-addition of sorghum panicles (heads) can be done by making ornamental flowers (Aree et al. 1995). Sorghum panicles are cut at 5 days after flowering, dried at room temperature for 1-2 weeks, bleached in 50% hydrogen peroxide solution for 10 minutes and dried again for 1-2 weeks. The panicles are then dyed with different colors. Sorghum panicles as ornamental flowers can generate more money than selling grain.

Broomcorn

Broomcorn is grown almost entirely for the elongated branches to the panicle, which are used for the manufacture of brooms. The crop is grown on a small area. The price of the brooms depends on how beautiful, innovative and creative the products are. The brooms are usually exported.

Using sorghum grain as fungal medium for mushroom production

Mushroom producers in Thailand prefer to use sorghum grain as the fungal medium stock. Mushroom can grow very well on steamed sorghum grain. Sorghum plays an important role in mushroom production, since a large amount of grain is used.

Forage sorghum

Forage sorghum also offers great potential for supplementing fodder resources and a great opportunity for producing both silage and hay. However, very few researchers work on forage sorghum in Thailand. There is only one seed company which promotes forage sorghum using 'Sudax' (sorghum X sudangrass) as a commercial hybrid. This company also promotes pearl millet *(Pennisetum glaucum)* as a fodder resource. However, the utilization of forage sorghum and pearl millet is limited since they face high competition with forage grasses, cassava and maize (*Zea mays).*

Conclusion

Although sorghum production in Thailand is low compared to other cereals (rice and maize), it has very high potential to expand production. Sweet sorghum as an energy source is the most attractive for alternative uses of sorghum. If the large-scale production of ethanol for fuel from sweet sorghum becomes a reality, the future of the crop will be bright. It will produce reasonable yields of ethanol per hectare on marginal lands with minimum production costs. At present, we use surplus crops as well as divert some of the current crop production to ethanol fuel programs. Future programs will bring new marginal lands into production of sweet sorghum though the area will be very less compared to that of other industrial crops. Research on sweet sorghum breeding, cultural practice improvement and the process for ethanol production are urgently needed.

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Strategy for Commercialization of Sorghum

IR Nagaraj[1]

Abstract

The paper discusses the need for a business model for commercialization and recommends the use of 'Product centric' and 'Value chain' approaches to enhance impact of technologies. The possible derivatives of the sweet stalk sorghum are used to describe the stages in product development, the use of tools to analyze the cost-benefits and the steps for building a value chain to create alternative livelihoods for the poor in the semi-arid tropics.

There is a great opportunity for R & D centers, working in the development-oriented programs, to adopt the business model for commercialization for enhancing impact of improved technologies. Two such business concepts are discussed in this paper: (1) Product centric approach; and (2) Value chain approach .

Scientists work on solving problems related to crops, food, nutrition and poverty and roll out products or technologies that can help solve the target problem. These products include high-yielding, drought or pest resistant varieties, analytical reports and policy guidelines on problems of the poor. In many instances though these are referred to as products, in real sense they may not qualify as 'products' when commercial rules are applied.

Characteristics of a product

In the commercial parlance, a product is one that provides a tangible value and also provides a satisfying experience to the customer. In today's context of customer-driven markets both have to co-exist in a product.

For every product the customer provides a feedback. There are two types of feedback: (1) 'sales-feedback' for the product; and (2) 'profit-feedback' for the enterprise. High sale indicates that the customer likes the product. The second element of feedback, ie, profit, is a recognition for the effectiveness of the product. Higher profit *is* a result of higher satisfaction of the customer due to the high effectiveness of the product.

Now let us apply this principle to our work in development of new varieties of crops. When varieties are released, rate and extent of adoption is the

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equivalent to sales feedback. Large-scale adoption of a variety indicates the preference of the farmer to the crop. If this large-scale adoption and the effectiveness of the variety bring higher yields and profits to the farmer, then that is the feedback on improvement in livelihoods. This is equivalent to the feedback of profit for commercial products discussed earlier. Scientists producing new varieties with unique traits should ponder: Are we successful in commercializing the products we create to enhance the livelihoods of the poor?

Though there are some success stories of commercialization, there is scope for improvements. Adoption of the product centric approach and value chain approach in product development for commercialization can enhance the success rates. The ultimate objective of any product development initiative is creating competitive advantage for the product. This can be achieved in two ways; provide a higher value than the competing products (variety) for the same price. Alternatively, provide the same value of the competing products at lower costs than the competing product or variety.

Product development

A system approach to product development will be a very effective method to tackle all the dimensions of product development and its impact in the market. A product development process model is given in Figure 1. All product development processes are linked to the mission of the organization or an objective of the program. At each of the stages from planning to production ramp-up, we have to do sensitivity and trade-off analysis to help us in moving forward or to exit the product development cycle.

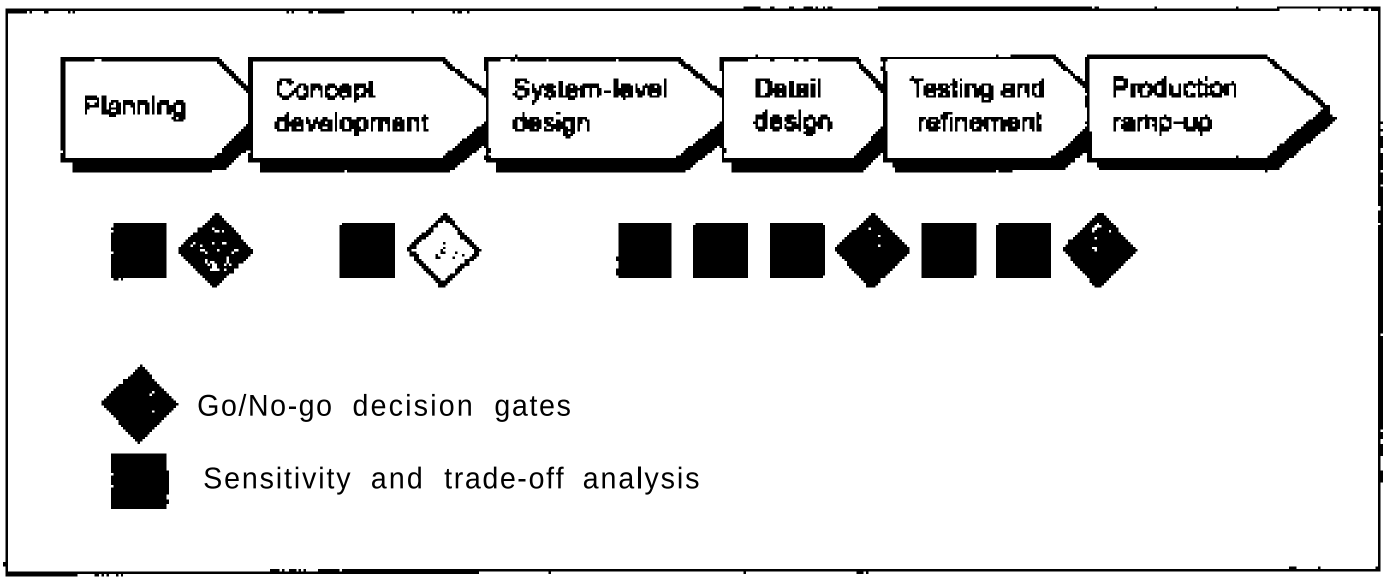

Figure 1. Schematic representation of a product development process model.

While all the components of the above process are important, 'concept development' stage will be discussed in detail, as it is very critical for the success of any product.

Who is the customer?

Traditionally, we target the farm community as our customer. It is perfect as long as the consumption of the product is at the farm level. If our objective is to create a livelihood value, then the product we provide to the farmer is only an input in the value chain, as the produce will be traded to reach the ultimate customer - the consumer.

The challenge in commercialization is to identify multiple customers along a value chain. The interesting aspect of a product is that the perceived value (trait) by the scientist need not be the realized value (higher yield) or commercial value (marketability) to the farmer. Establishing the sync between the perceived value, realized value and commercial value is the process for establishing a value chain for a product.

Case study of value chain model for sweet stalk sorghum

Figure 2 expounds the model of value chain for sweet stalk sorghum *(Sorghum bicolor).* From this model, we can appreciate that there are many players with different set of competencies and resources needed to build a value chain. Building these types of value chains for the products we produce provides greater chance of success in enhancing the livelihood of the poor. Establishing such a coalition of partners and players requires careful planning and identifying the right segment and intermediate customers.

The concept development process

Figure 3 indicates the various stages and processes required for a successful commercialization of a product. Here, we need to elaborate the economic analysis process, which will help us to determine the viability of the product. This process is also referred to as Business Case Analysis or Product Economics. The most common method used is Net Present Value (NPV). The process is explained in Figure 4.

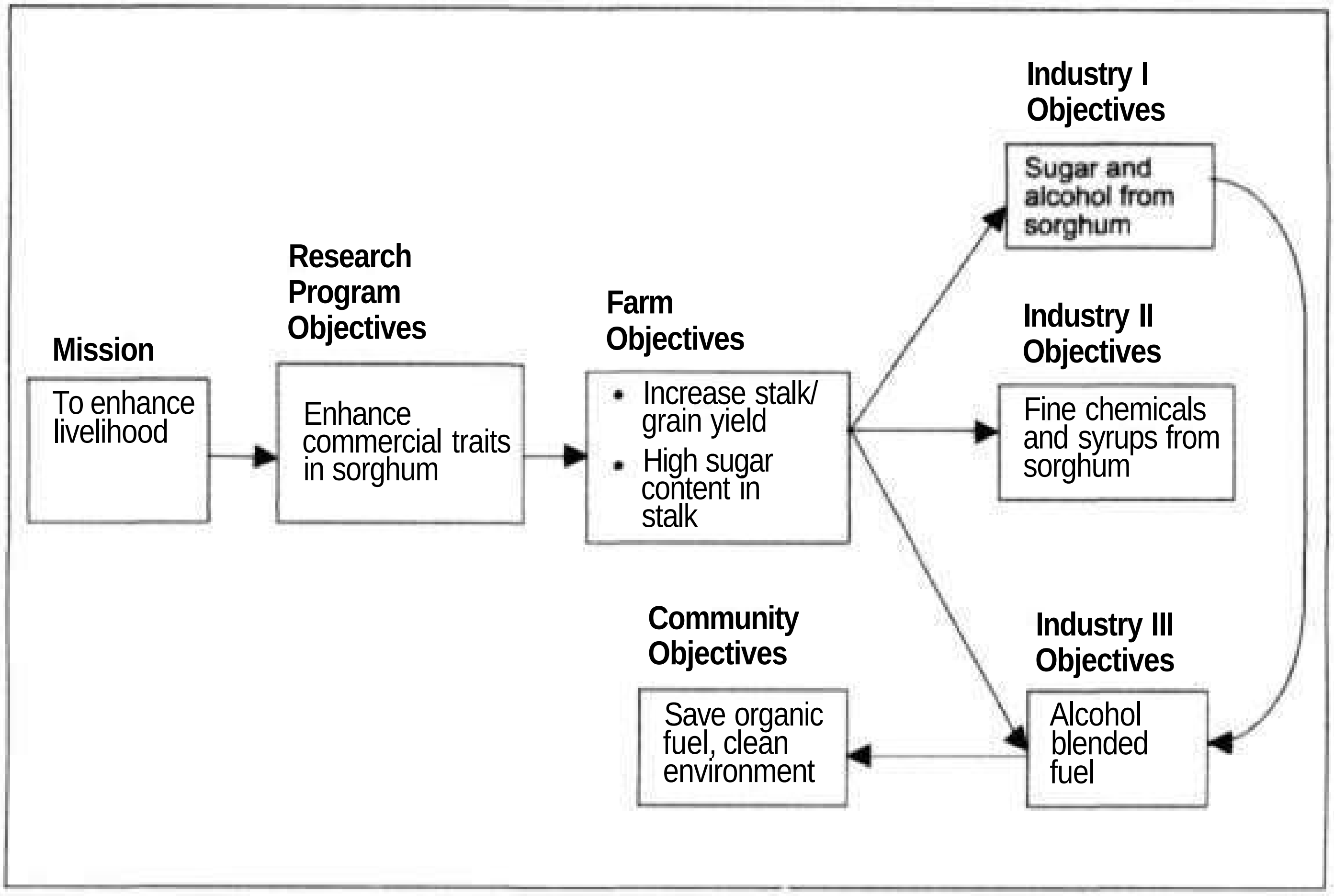

Figure 2. A model value chain for sweet stalk sorghum.

There are two distinct time span stages in a product commercialization process: (1) Development time; and (2) Payback time. During these two stages money is invested for product development and marketing. The pace of investment, though high during development stage, evens out later. When the sales revenue surpasses the investment curve, operating profit is achieved. However, net profit is achieved only when sales revenues go up and the revenues cover all operating costs resulting in cash surplus.

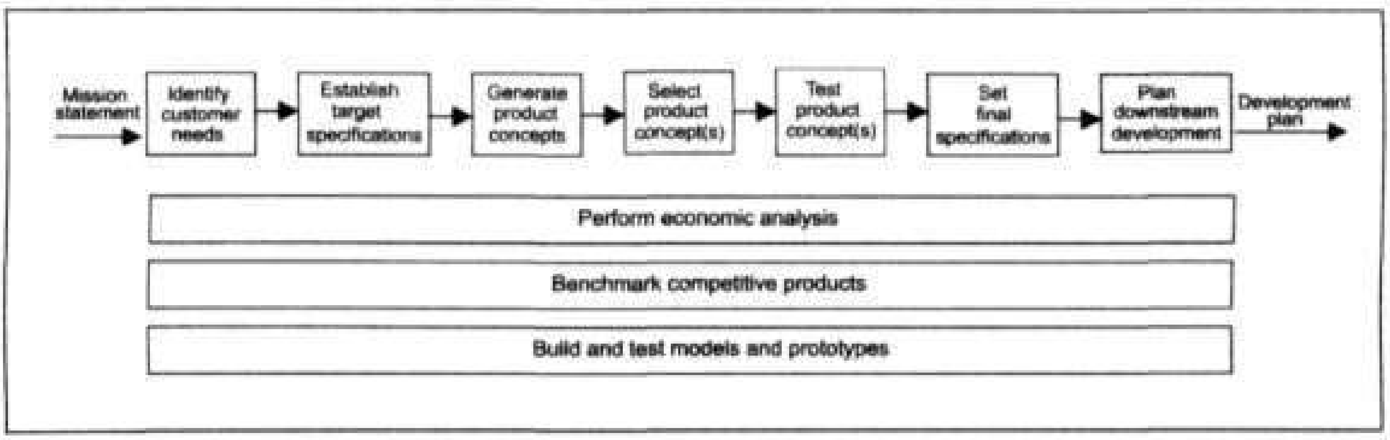

Figure 3. Schematic representation of concept development process.

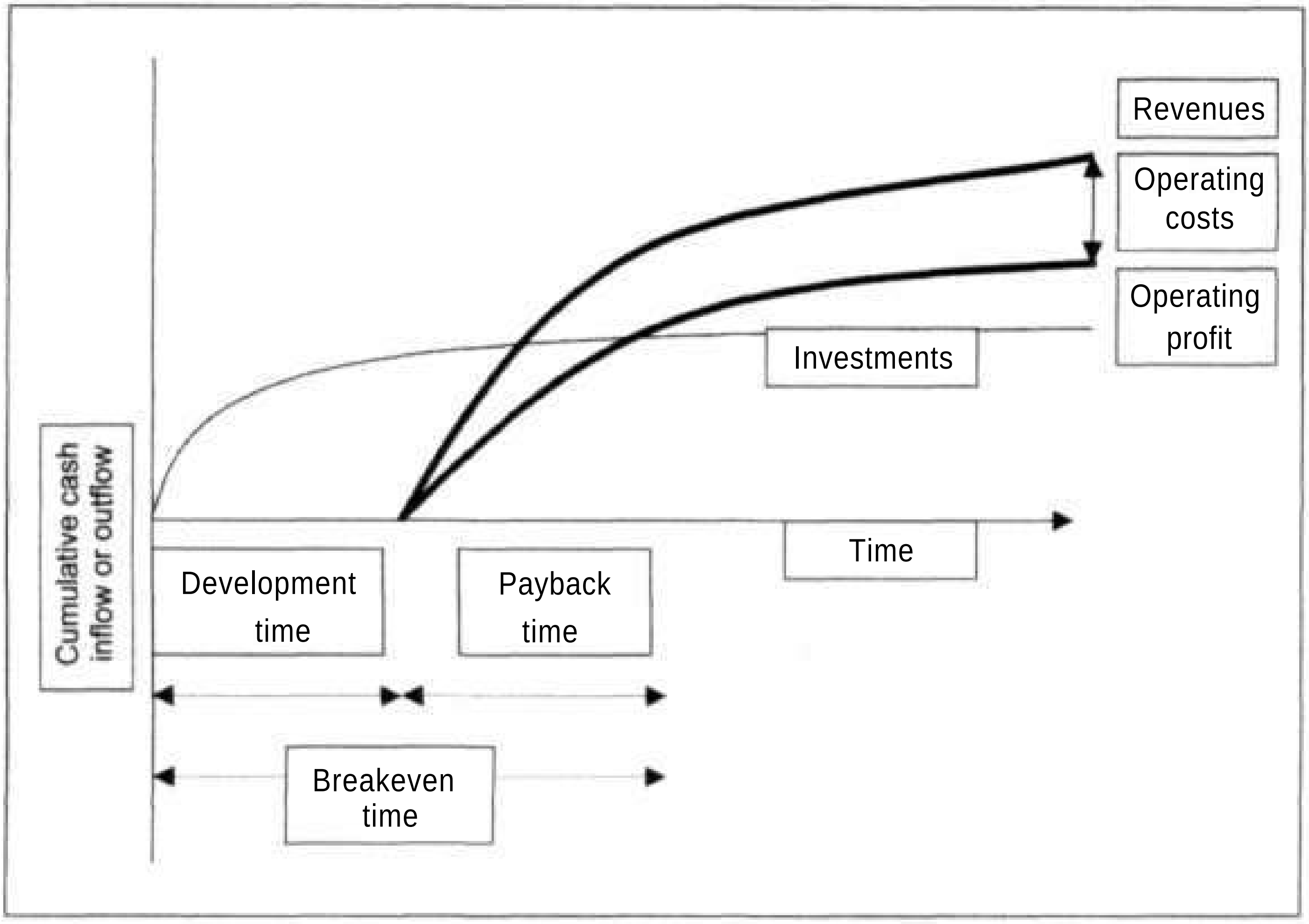

Figure 4. Product development cash flow.

The critical factor is to predict as closely as possible the current investments, the future cost and the anticipated returns of the product and its associated services. Both cost and time dimensions determine the profitability and eventual success of the product. Besides this the sensitivity and trade-off analysis will support the product development decisions. For example the social or political aspects of the economy where the product is to be deployed can be well analyzed in the sensitivity analysis.

Conclusion

Where there are constraints for financial resources, it is important for development institutions to adopt business models to plan, develop and commercialize products. The concepts and models dealt above will provide a better understanding for scientists working on international public goods to enhance the livelihoods of the poor.

The Commercialization of Sorghum and Pearl Millet in Africa: Traditional and Alternative Foods, Products and Industrial Uses in Perspective

DD Rohrbach[1] and AB Obilana[2]

Abstract

Sorghum and millets are primarily grown as subsistence food crops in Africa. Less than 5% of annual production is commercially processed by industry. The expansion of agro-processing and industrial utilization depends on the growth of per capita incomes and urbanization. However, for sorghum and pearl millet to be competitive with alternative grains, gains are also required in farm productivity and market efficiency. High marketing costs represent a particular problem in many regions of Africa where market density is low and production levels are unstable. Entrepreneurs need assistance in evaluating the trade-offs in using alternative grain inputs. They also need more information about alternative processing technologies and end uses of these crops. The varied experiences with sorghum and pearl millet commercialization that are evident in diverse regions of Africa need to be publicized. A strategic framework of public and private sector partnership is proposed as a basis for addressing these challenges.

Sorghum *(Sorghum* bicolor) and millets are major food crops in Sub-Saharan Africa. The two grains account for 56% of the area planted to cereals in this region, and 41% of cereal production. In comparison, maize (*Zea mays)* accounts for 36% of cereal grain production. Rice *(Oryza sativa)* and wheat *(Triticum aestivum)* make up most of the remaining 23%.

Postharvest processing and utilization (PPU) of sorghum and millets are major ingredients for food and feed security; and when done appropriately, become a significant strategy for cash income and diversification of livelihood of people in the semi-arid tropics (SAT) of Africa. Together with increased production and productivity, appropriate PPU responds to and enhances market demands within the different village/community-national-regional level continuum. Processing technologies and equipment for utilization of sorghum and millets for several intermediate and end products should be appropriate to the specific needs of consumers and processing industries in Africa. We have to

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acknowledge the co-existence of these postharvest technologies at the three socioeconomic levels: communal/cottage industry, the medium scale/service level, and the large industrial scale. The status of these PPU technologies varies and at present more communal/cottage-level and medium-scale industries serve the community and peri-urban needs. It is necessary for us in Africa to develop from this scenario and tilt the balance of PPU towards more of medium- to large-scale industries. This will enhance the growth of the industries and increase quantity and quality of end products as well as allow R & D responses to new innovations in the use of sorghum and millets.

In Southern Africa, the sorghum industry diversified from the originally common use in brewing opaque beer into products of meal, flour, thin porridges, energy drinks and other cereal products. However, these are product areas associated with other cereal crops like maize and wheat. A similar scenario of industrial change is now occurring in West Africa and Kenya, and beginning in other countries of East and Central Africa (Tanzania, Rwanda and Uganda). This diversification necessitated the development and use of sorghum varieties and hybrids with appropriate properties, acceptable to both processors and consumers. It also pitched sorghum in competition with the commonly used cereals, maize and wheat in the region. This development now requires sorghum as a cereal crop to be seen and used for its uniqueness in developing or modifying technologies relevant to appropriate products. Producers, consumers, processors and traders now have to interact more closely with market situations.

Throughout Africa, there is a huge resource of genetic materials and expertise in sorghum and millet utilization. The huge natural and improved genetic resources need to be identified and enhanced for uniqueness and end use properties. An attempt at this started in the Southern Africa region in the 1980s, and earlier in the West Africa region. Some progress was reported through databases generated on grain quality assessments (Obilana 1985, 1994, 1998, Okon and Uwaifo 1985, Gomez et al. 1997, Murty et al. 1997, Manful et al. 2001). Expertise in sorghum and millet processing and utilization also exist and have been reported in several publications (FIIRO 1976, Okafor and Aniche 1980, Aisien 1990, Bogunjoko 1992, Taylor 1992, 1993, Sooliman 1993, Daiber and Taylor 1995, Nicholson and Taylor 1997, Ndoye 2001).

Available literature shows that expertise in postharvest processing technology and utilization lies with indigenous knowledge, small enterprises, large-scale food and feed processors, research institutes and universities.

However, there is a major problem of information dissemination, access and retrieval for use. In Africa researchers have not been able to capitalize on the available information regarding this expertise. This is because they are scattered and buried in R&D reports with individuals in farmer groups, institutions, organizations and industries within countries and across the regions of Africa. They are not shared, resulting in little or no awareness of such expertise. The situation must change if Africa is to progress in increased production and commercialization of sorghum and millets through improved postharvest processing and utilization science and technologies. There must be linkages across the continuum of producers-processors-traders/markets-consumers for Africa to achieve these PPU objectives in a market-oriented goal and environment.

Despite their relative importance in regional food systems, very little sorghum or pearl millet *(Pennisetum glaucum)* is commercially processed. Rough estimates suggest less than 3% of Sub-Saharan Africa's sorghum production is used in the formal food and feed industries; the remaining >90% is traditionally processed into foods and beverages. Industrial utilization of pearl millet is rare.

The relative importance of these crops in Africa's traditional food systems suggests substantial opportunities should exist for their commercialization. In the first instance, commercial processing can provide urban migrants from sorghum or pearl millet production zones with a familiar food product. As incomes grow, demand will evolve toward more processed food products. In the longer term, the dominant share of sorghum and pearl millet may be consumed in Africa as animal feed.

However, many factors will influence the level and speed of this transition. Industrial processing of the crops is currently constrained by low and variable levels of production, high assembly and processing costs, and uncompetitive grain prices. Further, many commercial grain processors remain unfamiliar with the use of these grains. They then question consumer preferences for sorghum- and pearl millet-based food and feed products. These grains must compete for attention with better-known commercial inputs such as maize, wheat and rice.

This paper reviews the traditional sorghum and pearl millet products, their commercialization and industrial utilization in Africa. It starts with the status and development needs of processing and utilization technologies, and provides a brief overview of available data on the current levels of commercial utilization of these grains. It then highlights production and marketing constraints limiting the growth of industrial processing. Several strategies are proposed, including strategic, public and private group/institutional partnerships, for resolving these constraints.

Sorghum and pearl millet production

According to FAO (Food and Agriculture Organization of the United Nations) data (FAO 2003), Sub-Saharan Africa annually produces about 18 million t of sorghum and 13 million t of millet (Table 1). The published data do not distinguish between various species of millet. We estimate that approximately 87% of this is pearl millet, 10% is finger millet *(Eleusine coracana)* and the remainder comprising fonio *(Digitaria exilis)* and teff (*Eragrostis tef),* mostly (ICRISAT and FAO 1996). This compares with the production of about 27 million t of maize, the closest cereal grain substitute in both production and commercial processing systems.

Equal production areas are planted to sorghum, millet and maize. But since maize tends to be grown in higher rainfall zones, it offers higher average yields. Sorghum and millet yields tend to remain low because these crops are mostly adapted to, and grown in drier, drought-prone regions. Correspondingly, sorghum and pearl millet are better known as food security crops.

The lack of a commercial market for sorghum and pearl millet has discouraged investment in the development and adoption of new varieties and crop management practices. At least 5% of the sown area of sorghum is still planted to traditional, landrace varieties. More than 90% of pearl millet area sown in Sub-Saharan Africa is similarly sown to traditional varieties. Fertilizer use on these crops is rare and many farmers do not even use available manure. As a result, there has been virtually no growth in average grain yields of sorghum and pearl millet in Sub-Saharan Africa during the past 20 years.

Table 1. Area, yield and production of major coarse grains in Sub-Saharan Africa, 1999-2001.

Crop	Area (million ha)	Yield (t ha^{-1})	Production (million t)
Sorghum	21.8	0.8	18.1
Millets	20.0	0.7	13.1
Maize	21.0	1.3	27.2

Source: FAO (2003).

On-shelf technologies

Postharvest processing begins with threshing of the grain (removal of grain from panicle and separation from glume), winnowing and cleaning (removal of sand, stone and extraneous matter), followed by primary (dehulling) and secondary processing (milling and malting). For each of these stages, mechanical threshing and milling should be the norm. Hand or draft power threshing, usually result in the grain becoming dirty and contaminated with sand and other microbes (like mold). Because sand and microbial contaminants are difficult to eliminate, machinery can be damaged resulting in unpalatable and gritty food products, which could also have toxins due to molds. Each of these stages, except for winnowing and cleaning, have implications on genetic variation and grain quality of the varieties. These varietal differences have been documented in grain quality evaluation data generated in Southern Africa for pearl millet (Monyo 1998) and for sorghum (Obilana 1994, 1998).

Grain quality parameters related to and of importance in the processing technologies have been identified to include: grain hardness, water absorption, flour yield (milling quality), tannin content, particle size index, pericarp thickness, seed coat (testa), endosperm texture, kernel weight, size and shape, diastatic power, germinability and germination vigor (all related to malting quality) (Gomez et al. 1997). Tables 2 and 3 show the grain quality traits in different sorghum (database of over 500 samples) and pearl millet (database of over 100 samples) lines. The databases generated include data for both improved and farmer varieties.

Recently, the importance of using appropriate equipment in primary and secondary processing for the promotion of sorghum products in Senegal was documented by Ndoye (2001). As much as there are several types of cereal threshers, dehullers and mills manufactured in Europe, the issues of processing technologies and equipment have to take a new perspective for Africa. This approach focuses on the use of successful sorghum and millet processing technologies and equipment, which have been locally manufactured to address the problems faced with using imported European/ American equipment. Problems with application of such machines and technologies from the developed world include: high cost, very high material throughput, high complexity, sophisticated maintenance requirements and lack of robustness (JRN Taylor, University of Pretoria, Pretoria, South Africa, 2002, personal communication).

Table 2. Grain quality *traits* related to processing and utilization for different sorghum types from Southern Africa.

Grain trait	Range of values		
	White sorghums	Red sorghums	Brown sorghums
Testa	Absent	Absent	Present
Hardness score[1]	2.6-4.8	1.7-4.7	1.4-3.8
Flour/milling yield (%)	72.60-90.82	69.23-88.20	64.20-86.20
Water absorption (%)	3.8-11.8	4.2-13.1	5.1-14.8
100-seed mass(g)	1.57-3.88	1.44-3.32	1.25-2.95
Grain size[2]	Medium to large	Medium to large	Small to large
Floaters (%)	11-85	23-100	55-100
Flour color[3]			
Dry Agtron reading	68.2-82.5	59.5-76.8	50.7-72.1
Wet Agtron reading	48.8-63.6	32.2-55.4	24.4-48.8
Malting quality (SDU values)	14.68-73.34	15.90-72.62	28.28-74.17
Tannin content (% ce)	0	0.0-0.5	0.5-5.0
Crude protein (%)	10.9	10.9	10.9

1. Score on a 1-5 scale where 1.0—2.5 = soft, 2.6-3.4 = intermediate, 3.5-4.5 = hard, and 4.6-5.0 = very hard.
2. Grain size: Large = >4.00 mm, medium = 2.60-4.00 mm, small = <2.60 mm.
3. The higher the reading the lighter is the product color.

Source: Modified from Obilana (1998).

Table 3. Grain quality traits related to processing and utilization of some pearl millet cultivars in Southern Africa.

Grain traits	Range of values
Visual hardness score[1]	2.4-3.3
Proportion of floury endosperm	0.25-0.53
Particle size index	9.17-12.14
100-seed mass(g)	0.92-1.41
Floaters (%)	53-93
Dehulling loss (%)	4.60-11.90
Milling yield (%)	81.00-93.50
Water absorption (%)	8.50-12.80
Size fractions[2]	
Large	8.51-72.07
Medium	27.71-91.18
Small	0.15-1.79
Flower color (Agtron reading) (dry)	48.00-56.40

1. Score on 1-5 scale where 1 = very soft and 5 = very hard.
2. Large = >2.6 mm; Medium = 1.77-2.6 mm; Small = <1.7 mm.

Source. Modified from Monyo (1998).

Threshing and dehulling process

To increase and diversify sorghum and millet utilization, mechanical threshing and dehulling has become the norm. We are aware of some machines that have been developed or modified and put into use in Southern Africa. In Namibia, for example, an agricultural machine company manufactures small portable petrol-powered pearl millet threshers. The same Namibian company is trying to modify a larger tractor Power Take Off (PTO) maize thresher for pearl millet and sorghum. Modification is still continuing with replacement of the larger mesh screen in the PTO by a smaller screen of 6-mm mesh, and the thresher fan which is too powerful for the smaller grains.

Several threshing machines imported from developed countries, specific for threshing wheat, barley (*Hordeum vulgare)* and oats *(Avena sativa),* can also be modified for threshing sorghum and pearl millet. This is already happening in Zimbabwe. In Senegal, mechanical threshers made in France and specifically adapted for pearl millet are used. These modified threshers range in output of 300 kg h^{-1} (small) to 1000 kg h^{-1} (large).

Dehullers suitable for sorghum and modifiable for pearl millet are manufactured in Botswana and Zimbabwe. The dehuller is manufactured by the Rural Industries Innovation Center (RI1C), Kanye, Botswana. The throughput speed is 10 kg min^{-1} and 400-600 kg h^{-1}. A significant development with this sorghum dehuller is that it has been combined to a hammer mill by the RIIC to create a dehulling-milling package/chain to ease milling process and make it more time and cost efficient. The dehuller on its own can be used for both commercial and service operations.

For the purpose of adapting these dehullers to West Africa, it should be noted that current dehulling technology is not yet very efficient for sorghum and pearl millet. Research and development effort is still needed to develop a dehulling technology that removes the germ clean from sorghum and pearl millet grains. The theoretical and scientific reasoning behind this recommendation is that both grains (sorghum averages 2.8 g fat $100g^{-1}$) have large oil-rich germs (more so in pearl millet, 3.0 g fat $lOOg^{-1}$). For example, to produce sorghum meal of low fat content (< 1.0 g fat $100g^{-1}$), up to 40% of the grain must be decorticated by dehulling. With such amount of loss, excessive dehulling of sorghum and millets may become an uneconomical process and may not be viable. To make the dehulling process viable, the market for the byproduct, which is bran, must be put in place for animal feed production.

Milling

In general, sorghum (dehulled or undehulled) is milled using either the hammer mill or roller mill. The hammer mill, although a very simple and effective technology for breaking up whole or dehulled grain into meal, is not adequate to produce meal and flour of uniform particle size required to produce quality baked (eg, bread or biscuits) or steamed products. The hammer mill produces rough meal for *sadza* or *bogobe* (stiff porridge) and *tchwala* (thin porridge) in Southern Africa. These products are rough in texture and require larger grain milled product of 500-800 um granulation. The hammer mill fabricated at RIIC has three mesh sizes for different grades of meal.

However, finer meal and flour for same food products (stiff and thin porridges) are obtained from roller mill. The finer meal products of granulation 300-500 um are sold for higher prices in the market. When the grains are conditioned to about 16% moisture and roller milled, the quality and yield of the flour is better, finer and smoother. Dehulled grain that is roller-milled also gives close to the quality obtained with moisture-conditioned roller milling. It is this type of fine flour of 250-500 um granulation that is required for making the smooth product of *to* or *tuwo* (stiff porridge) and *ogi/akamu* (thin porridge) commonly consumed in West and Central Africa. For composite flour (with wheat) and baking flour for flat or semi-leavened breads (*kisra, injera)* and biscuits, superfine flour of <250 um granulation is required.

Milling equipment

There are several good dehulling and milling machines that have been fabricated or modified in Southern Africa (South Africa, Botswana and Zimbabwe) and East Africa (Kenya). A multi-component milling line for the production of sorghum meal was established by the Kenya Industrial Research and Development Institute (KIRDI) in 1985 and 1991 as pilot and small-scale commercial production plant, respectively. Its viability and present status needs investigation. At the time of establishment, it functioned as a semi-detached four-machinery system linked with intensive labor operations. It was inefficient. The Millrite grinding mill from Zimbabwe is mobile (wheels can be attached or detached) and portable with fine sieves, and can be mounted on pickup vehicle making it possible to move around the village or market centers. Thus it can be used for both service and commercial mill operations. The sorghum dehuller-hammermill combined machine from RIIC is unique and can be set up in a line system for dehulling and milling in one process. It could be a better and more practical machine for testing and adaptation for small- and medium-scale millers in the rest of Africa. Also it can be fabricated at RIIC to buyers'/users' specifications, and 85% of its parts are available in Botswana or West Africa. The Maximill equipment can be obtained with full parts from South Africa. One outstanding development in the processing equipment research is the small-scale, double roller mill from Namibia. It produces sorghum grits and meal of high quality. There is need for R&D to adapt it to produce meal from millet, and fine meal and flour from both sorghum and millet. One of the latest innovations in processing equipment fabrication is the development of a fonio dehuller in Senegal. The dehuller seems to be very effective and can be adapted for dehulling other smaller millet grains like finger millet.

Malting

Sorghum and millets have been traditionally used for brewing cloudy and opaque beers in Southern, Eastern and Central Africa. The grains are used both in the form of malt and unmalted adjunct. In Southern and Central Africa, traditional beer brewing has long been a large-scale commercial enterprise (Taylor 1992, 1993). More recently in Nigeria, technologies have been developed to commercially brew clear lager beer and dark stout with sorghum malt and sorghum grain as adjunct (FIIRO 1976, Okafor and Aniche 1980, Obilana 1985, Okon and Uwaifo 1985, Aisien 1990, Bogunjoko 1992, Murty et al. 1997). These latter technologies of utilization including production of non-alcoholic sorghum malt beverages by the breweries, and food beverages by agro-food industries in Nigeria and South Africa, have great potential throughout SAT for widespread commercialization and income diversification.

In recent times, much effort is being made to improve the quantity and quality of cereal proteins by using processing techniques such as malting and fermentation. Enhancing these efforts would positively respond to the increasing need for raising the overall nutritional status and health of consumers of sorghum and millets, especially in the SAT. Malting, which simply involves the limited germination of cereals in moist air under controlled conditions, is a technique that can positively affect the physico-chemical composition of cereals by improving their nutritional value. Two methods have been used in the commercial malting process in Southern Africa, namely, floor malting (large-space open air germination and drying of steeped grains) and pneumatic malting. Steeping (in conical steel vats or rectangular containers) is common to both methods, but germination and drying are different. In any of these malting processes (more so in the floor malting) it is very difficult to remove or reduce the heavy contamination with molds, which are serious problems faced with malting and known to produce mycotoxins in malts. The technology of malting process has been perfected in South Africa and used on a large commercial scale. These malting processes resulting in opaque beers have been described in detail by Daiber and Taylor (1995). In efforts to enhance use of malted sorghum and millet by processors for food, drink and health of consumers, collaborative research is required to develop and implement simple technologies to produce grain of good microbial quality and to prevent mold growth during malting.

Traditional sorghum and millet products and their commercialization

To increase and diversify sorghum and millet utilization, it is no good copying existing products made from other cereals, eg, pasta. Generally, these products, if made from sorghum and millets, become inferior and unfavorable to compete with those made from cereals with the desirable functional characteristics. It therefore follows that such substitute products will reflect badly on sorghum and millets. The emphasis should therefore be on exploiting the potentially useful intrinsic qualities of sorghum and millets, and hence develop and produce unique and alternative value-added products. Production of substitute products using sorghum and millets, for which these cereals have no desirable traits, has been one of the reasons for limited commercial successes in using them for composite bread and baked or extruded products.

One other concern is the general expectation that sorghum and millets should be cheaper than other cereals for them to be commercially utilized in different end products. It is not correct to think that millet and sorghum will be a cheap filler for other cereals. Millet and sorghum will and should always be at least expensive as other cereal grains. The cost of production will always be similar, and attempts to sell at lower prices than other cereals will be disadvantageous and further impoverish the resource-poor farmers of the SAT. It will also render their production uneconomical and not viable. Research into their productivity to encourage prices and enhance use as raw materials in industry is increasing and should be highly prioritized across Africa.

Primary foods: meal, flour, baked and steamed products

As stated earlier, food uses must be appropriate to the particular characteristics of millet and sorghum. In Southern and Central Africa, very little sorghum and millets flour and meal is used in stiff porridges (except in Botswana as *bogobe* and in Namibia as *mhunga* meal). This is contrary to the situation in West Africa where stiff and thin porridges of sorghum and millets (with couscous) are staple foods. In Kenya, however, a unique situation exists where thin porridges (*uji* mixes) of sorghum, pearl millet and finger millet are very common and commercially available in supermarkets, in well-packaged forms on the shelf. Sometimes, these are also fortified with soybean *{Glycine max),* or composited with wheat or maize flour. We believe that more intensive research into the improvement of processing and development of already existing stiff *(to/tuwo)* and thin (*kamu, ogi)* porridge flours, with better packaging into ready-made products on the shelf, will enhance commercialization of such food products in West Africa.

Neither sorghum nor millet grains possess gluten. Thus they cannot substitute directly for wheat in bread and other baked goods. However, with good milling technologies (and appropriate handling of the amylose and amylopectin in the grains) to produce suitable flour, meal and grits, a wide range of excellent textured baked and steamed food products can be produced, for example, couscous, steamed and deep-fried dumplings, flat breads such as *chapati* and tortilla, and even semi-leavened breads such as *injera* and *kisra.* Networking throughout Africa will bring these products and the technologies to produce them to the attention of people in different parts of the continent who had not been familiar with them. An example is the interchange between Namibia and Senegal. In Namibia, pearl millet porridge is a staple, and the concept of using pearl millet to make couscous as is done in Senegal has elicited great interest.

Levels of industrial utilization: processing of secondary foods and products

Estimates of the quantities of grain being industrially processed are difficult to obtain. A partial summary of available estimates for sorghum and pearl millet is outlined in Table 4. This includes estimates for Botswana, Kenya, Mali, Nigeria, Rwanda, South Africa, Tanzania, Uganda and Zimbabwe.

Table 4. Examples of commercial utilization of sorghum and pearl millet in Sub-Saharan Africa annually.

Country	Sorghum	Pearl millet
South Africa (2001/02)	113,000 t malt ; 66,000 t meal; 11,300 t grits; 16,200 t animal feed	No significant commercial utilization
Nigeria		
(1992 estimates)	120,000 t brewing (malt and adjunct); 17,000 t malt/malt extracts for food and beverages; 25,000 t animal feed	No significant commercial utilization; but about 1,000,000 t informally exported to five sorrounding countries annually in cross border trading
(19S5 estimates)	200,000 t brewing; 25,000 t food industry	
(2005 projections)	1,500,000 t both brewing and food industries	
Botswana (1999 estimates)	60,000 t meal; 4,000 t malt	No significant commercial utilization
Zimbabwe (2000 estimates)	17,500 t brewing (mostly malt); 1,800 t animal feed; 150 t meal	75 t animal feed; 30 t brewing
Tanzania (2002 estimates)	1000 t brewing (mostly adjunct); 80 t meal; 800 t school feeding program; 5 t animal feed	No significant utilization
Kenya (2003 estimates)	100 t meal-based food products	15 t food products; 50 t finger millet for breakfast porridge mixes
Niger (2000 estimates)	50 t biscuit flour <51 for couscous	No significant utilization
Rwanda (1998 estimates)	2000 t brewing (mainly adjunct)	No significant production; finger millet informally used
Uganda (2002 estimates)	<50 t brewing (mainly adjunct)	No significant production; 100 t finger millet for composite flour beverage/food products

Source: Bogunjoko (1992), Rohrbach et al. (1993), Rohrbach (2000), Rohrbach et al. (2000), Rohrbach and Kiriwaggulu (2001), SAGIS (2003); and ICRISAT data files.

In general, the level of industrial processing appears more closely related to per capita income levels than to the quantities of grain produced. Nigeria, Sudan, Ethiopia, Burkina Faso and Tanzania are the largest producers of sorghum in Sub-Saharan Africa, accounting for about 75% of the region's production. However, South Africa is the largest commercial processor of this grain. It has one of the highest per capita income levels in Sub-Saharan Africa, and one of the strongest agro-industrial bases. It also has one of the highest levels of urbanization.

South Africa annually produces 200,000-300,000 t of sorghum, from which up to 206,500 t can be commercially processed (Table 4). An additional 50,000 to 60,000 t of grain was exported. Virtually all of this grain was obtained from less than 1000 large-scale commercial farmers.

About 90% of South Africa's commercially processed sorghum is used for food products. The majority of this is allocated to the production of opaque beer malt. This includes grain malted for sale as beer powder as well as grain malted and used directly by the industrial breweries. Approximately 65,000 t is milled and sold as sorghum meal. The remaining 10% of industrial utilization is accounted for by the animal feed industry. Pearl millet is grown commercially in South Africa as a forage grass and virtually none of the grain is commercially processed.

The second largest commercial processor for which data are available is Nigeria. This country annually produces about 7.5 million t of sorghum and 5.8 million t of millet. Estimates derived from a survey conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in 1992 suggest about 150,000 t of sorghum is commercially processed - about 2% of annual production. Most of this is used as a source of starch in the brewing of lager beer, or as a source of malt in the production of non-alcoholic malt drinks. A residual of about 17,000 t and 25,000 t are estimated to be used in the agro-food and animal feed industries, respectively. Later estimates from the breweries and food industries in 1995 and projections for 2005 show increases in use of sorghum as malt and adjunct to be about 200,000 t brewing (malt and adjunct), 25,000 t food beverages and 1 million t brewing and food beverages. However, 90% of sorghum production, and virtually all pearl millet production, is still consumed without commercial processing.

Botswana is the third largest commercial processor of sorghum. An estimated 60,000 t of sorghum is commercially processed by the milling industry into sorghum meal, despite the fact that this country only produces about 11,000 t of grain annually. The combination of rising incomes and rapid urbanization has led to a sharp increase in the demand for commercially processed meal. In addition, the government has periodically purchased a sorghum-based weaning food for use in drought relief programs. An estimated 4,000 t of sorghum is used as malt for the commercial production of opaque beer. This is entirely imported as processed malt. Virtually no sorghum is used in animal feeds. Small amounts of pearl millet are produced in Botswana, but not commercially processed.

Zimbabwe annually produces about 100,000 t of sorghum and 45,000 t of pearl millet. About 20% of the sorghum is commercially processed, mostly for use as malt in the opaque beer industry. The animal feed industry will use sorghum if this is available at prices substantially lower than the price of maize. However, average levels of utilization remain small. Several millers have expressed interest in the commercial production of sorghum meal. But investments here have recently been constrained by grain price and movement controls. Small quantities of pearl millet are also used for beer malt and animal feed.

Tanzania annually produces about 750,000 t of sorghum, but commercially processes less than 2,000 t on an annual basis. Approximately one-half of this is used for the production of opaque beer, though entirely as a source of starch. The single, commercial opaque beer brewer in the country imports its malt requirements from South Africa. Approximately 100 t of grain are processed each year for sale as sorghum meal. In 2002, 800 t of sorghum grain was processed, for the first time, for school feeding programs. Tanzania produces about 175,000 t of pearl millet, but virtually none of this is industrially processed.

Kenya produces about 130,000 t of sorghum annually but industrially processes only about 100 t yr^{-1} into meal-based products such as breakfast foods. Less than 15 t of the country's 30,000 t pearl millet is industrially processed.

Niger annually produces about 500,000 t of sorghum. But here also, commercial processing remains extremely limited. One baker has recently experimented with the use of about 50 t of sorghum in the production of sweet biscuits. A small amount of grain is processed and commercially sold as couscous. Virtually none of the country's 1.5 million t pearl millet is industrially processed.

Both Rwanda and Uganda also commercially process sorghum, but in very small quantities. In Rwanda, from the brewery's 1998 estimates, about 2000 t of sorghum is used as adjunct for lager beer brewing. Uganda's use of sorghum commercially is only just beginning and is still less than 50 t adjunct, annually.

Major industrial products and potential for increased commercialization

The industrial processing of sorghum and pearl millet in Africa has largely developed as a commercial investment in the supply of traditional food and beverage products.

Beers and malt drinks

The most common commercial use of sorghum, south of the Sahara, is in the production of opaque beer (sorghum beer), clear lager beer and malt products. Opaque sorghum beer is a traditional drink in much of Eastern and Southern Africa. This is commonly brewed by farm households seeking to supplement their income or by small-scale traders associated with peri-urban markets. As incomes have increased, sorghum beer production has been commercialized. This provides urban consumers a more convenient and consistent product. In some countries, particularly in Southern Africa, powdered beer malt is sold to households seeking to produce their own beer. In Nigeria, where clear lager beer and stout are pioneered using sorghum malt or adjunct, non-alcoholic malt drinks offer a related beverage to pregnant women, lactating mothers, convalescents, invalids and the Moslem populations. These malt drinks are now also being sold in Eastern Africa.

Preferences for sorghum-based beer allow some brewers to offer a premium price for sorghum used for malting. However, there are limits to this advantage. Shortages of clean sorghum have led opaque brewers in Zambia and Tanzania to produce 100% maize beer using industrial enzymes as malt. Brewers unwilling to invest in malting may use sorghum simply as a starch source adding a traditional flavor and color to their beer. The quantity of sorghum used, compared with alternative sources of starch such as maize, depends on the relative grain prices.

Sorghum use as malt or starch source (adjunct) in the production of lager beer and stout is increasing in West Africa, though remains relatively rare in Eastern and Southern Africa. Breweries in Nigeria started using sorghum as malt (with 100% replacement of barley malt) as far back as 1987, and as adjunct later when the price dropped below that of maize and also when imported enzymes were being used in the brewing process. However, brewers in most Eastern and Southern African countries have been reluctant to pursue such experimentation, except in Rwanda and Uganda where sorghum is now being used mainly as adjunct in clear lager beer production.

Milling

The main traditional use of sorghum and pearl millet is as a thin or thickened porridge. However, industrial processing of sorghum and pearl millet meal has been relatively limited. Maize is the most common industrially milled grain in Sub-Saharan Africa, and wheat processing is rapidly growing as pure or composite flours for baking.

The dominance of maize milling, particularly in Eastern and Southern Africa, can be attributed, in part, to the relatively higher productivity of maize grown in the region's higher rainfall zones. However, commercial investments in maize production and processing have also been reinforced by historical market supports favoring this crop. These include price supports and public stockholding arrangements. In regions of West Africa where sorghum and pearl millet are dominant, industrial grain milling systems are simply less developed.

One of the main constraints to industrial milling of sorghum and pearl millet is the contamination of grain with sand and stones. This results from the common practice of threshing the grain on the ground, and then sweeping the threshed product into grain bags destined for the market. The cleanliness of sorghum grain supplied to the milling industries in South Africa and Botswana is assured because this grain is all mechanically harvested and threshed. Experimentation with the use of small-scale threshers, however, failed in Zimbabwe because millers could still not assure that all grain bags delivered to the factory gate were clean. This has led to more successful experimentation with mechanical grain cleaning systems involving screens, aspiration systems and destoners. But the cost of this equipment remains prohibitive without throughput of at least 5,000 to 10,000 t yr^{-1}.

Nonetheless, once grain supply constraints are resolved, the experiences of South Africa and Botswana show that sorghum meal can be sold at prices competitive with maize meal on the retail market. Similar industries can be expected to develop in other parts of the continent as incomes grow and countries become more urbanized. The prospects for commercial production of pearl millet meal are less certain because of the higher cost and less consistent supply of this crop.

Livestock feed

More than 95% of the sorghum produced in higher income, industrialized countries, and the majority of millet are used for animal feed (ICRISAT and

FAO 1996). In contrast, the levels of sorghum and millet use for feed in Sub-Saharan Africa remain extremely limited. The justifications for this limited utilization merit further investigation.

Part of the problem is that animal feed manufacturers lack consistent access to low priced grain. Cheap grain may be widely available after a particularly favorable rainy season. But this grain becomes, prohibitively expensive following drought. Since drought is most common in sorghum **and** pearl millet growing regions, price fluctuations are common. Such variability of grain supply also demands flexibility in feed formulations, a practice easier for large experienced feed manufacturers than smaller, newer operations.

Nonetheless, grain price competitiveness may be less of a problem than common uncertainty about the feed value of sorghum and pearl millet. Informal ICRISAT interviews with animal feed manufacturers in Botswana, Nigeria, Tanzania and Zimbabwe reveal common misconceptions about tannins. We have heard arguments that 'the tannins in sorghum killed my chickens' or that 'all sorghum has tannin'. Related questions arise about the risks of mycotoxins. Some argue that the digestibility of sorghum is 25-30% lower than that of maize. Others complain about low protein levels or the lack of amino acids. Data about feed values from university laboratories and research trials are discounted. Manufacturers argue that they need proof of the value of these grains from other feed manufacturers in Africa.

In addition, feed manufacturers complain that sorghum, in particular, does not mill well. Whereas maize can be cracked in a hammer mill, softer sorghum grains mill to powder; this is said to further reduce feed efficiency.

We know, however, that there are varieties and types of sorghum that have very hard grains with high milling yields, especially the white-grained sorghums and some red-grained varieties, both of which have no tannins (Table 2). Since the feedmillers' and farmers' beliefs are erroneous, more research data and information need to be generated in collaboration with the feed manufacturers and made widely available to the users.

Information on the use of sorghum and millets for livestock feed in ruminants, monogastrics and poultry is scanty but available in disaggregated forms. We believe, however, that animal scientists and commercial farmers have precise data about the feed value of different types of sorghum grain (white, red or brown), whole plant (forage, silage or crop residue), and milling/malting byproducts (bran/brewers waste/spent grain) for different feeding applications. Such know-how and precision information need to be effectively shared among R & D specialists and other processors/farmers in Africa to be able to move up from the plateau of little restricted use to larger scale and wider use of sorghums in livestock feed to achieve crop diversification of raw materials and commercialization goals. The level of expert know-how about feed value of various millets is presumably good but less precise and less known.

A two-pronged effort is required to increase sorghum use as livestock feed. Firstly, farmers and feedstock manufacturers must be made aware of and trained in the use of 'alkali-bleach test', a simple test for distinguishing between tannin (brown) and condensed tannin-free (white and red) sorghum grain. Secondly, animal scientists must collaborate and run feeding trials using sorghum and millets with farmers and feedstock manufacturers to show them the true feed value of millet and sorghum types in various applications.

One such example is the cattle feed program considered by cattle producers in Zimbabwe during the mid-1990s when there was deficit of the popularly used maize crop (in food and feed). The cattle feed program, developed by the Cattle Producers Association (CPA), Zimbabwe has a ratio of 50% maize: 50% sorghum (Diet A). The cattle equivalence (feed value) obtained in the use of this feed ration compared to whole maize (Diet B) is shown in Table 5. The feed program ration (Diet A) gave higher daily gains of steers (8.6%) and equal feed conversion ratio compared with whole maize ration (Diet B). According to the CPA, the farmer using this tested cattle feed in Diet A, need only put the sorghum through a hammer mill, without using the screen (this will ensure that the grain is just crushed and not milled into a meal) and out into the feed. The CPA has observed that both red and white sorghums are suitable for ruminant stockfeed (cattle and sheep) but white is better suited for monogastric (pigs and poultry) requirements. This is 'feed for thought' for the rest of Africa in the development and promotion of sorghum and millet in livestock (animals and poultry) feed use.

Table 5. Cattle equivalence resulting from feeding trials using two diets in Zimbabwe[1].

Components/Observations	Diet A	Diet B
Maize (%)	32.23	63.9
Sorghum (red) (%)	32.23	0
No. of steers in trial	20	21
Initial liveweight (kg)	276	281
84-day daily gain (kg day^{1})	1.65	1.52
Feed conversion ratio (kg kg^{1})	7.25	7.22

1. Diet A contains 50% maize and 50% sorghum; Diet B contains 100% maize.

Source: Anonymous (1998).

Food products

Conventional food products like stiff and thin porridges of various types from different processes are already available in Africa. Indigenous knowledge and industrial technologies in its rudimentary stages are also available. This expertise, as earlier stated, is highly disaggregated and compartmentalized in large-scale and small-scale industries and enterprises, farmer groups, and research organizations, private or public, and also cuts across countries and regions. Complicating this problem is the lack of awareness of expertise that exists with others. Very close collaboration and linkages will need to be forged among all stakeholders for developing, testing, improving existing ones and promoting end-use food products from sorghum and millets. Information flow and technology exchange process should be improved and strengthened. There will be a need for continued intense training of food scientists and technologists in Africa. Effective networking among regional networks and related organizations, public and private, is imperative.

The Namibian Ministry of Higher Education with assistance of FAO is implementing a very indigenous project for the development and promotion of new pearl millet products. The Council for Scientific and Industrial Research in South Africa are producing sample quantities of a range of concept products, such as instant porridges and snack foods. These will be consumer evaluated in Namibia to determine the preferred concept products. At the same time a pearl millet food product manufacturing training facility is being constructed in northern Namibia. Food technologists at the facility will train entrepreneurs to manufacture these products. This project should serve as a model for other millet and sorghum producing countries to follow.

Novel food products and traits

There are novel food products which could be vehicles for improving nutrition and health of consumers and diversify income sources of producers and processors. They could also be sufficiently attractive for resource mobilization. Some of these novel foods are already being looked into in South Africa, like Power Flow otherwise known as Amylase Rich Flour. This flour is used to thin weaning porridges to make them more palatable and increase their nutrient density. Others include: Maltabela (a malted sorghum baby porridge), Instant Mageu/Maheu (white or red sorghum non-alcoholic drink which can be flavored, Morvite (pre-cooked sorghum and maize for instant drink) and Kings Brew Beer Powder (red sorghum malt-alcoholic). These are convenience foods and drinks well presented in good packages and commercially available. A new product is the Popsorghum which is very simple to produce and serves as a nutritive convenience food that can be well-packaged.

The intrinsic uniqueness of sorghum and millets, added to the fact that they originate from Africa and are genetically diversified, make the two crops a haven of novel traits. Most of these traits are still not tapped. Intense research-for-development using both agronomic and biotechnological/ molecular tools would be required for basic informative science and applied research to be undertaken to unravel the goodness of these traits, and improve their quantities and quality. Some of these novel traits related to foods and health include:

- yellow endosperm (occurring mostly in the indigenous 'Kaura' sorghums of Nigeria; and some farmer varieties of pearl millet in Nigeria, Togo, Burkina Faso and Mali) for pro-vitamin A (beta-carotene) levels
- glossy seedling leaves for high amylopectin in grain
- stay-green for terminal drought stress (for productivity increase under drought) and forage/crop residue quality (for animal feed)
- polyphenols (mostly tannins, and other phenolic compounds like anthocyanin and anthocyanidins) for antioxidants and improved health with nutrition
- germ oil containing lipids with 0.01% cholesterol and 0.54% sitosterol (both sterols), and 68% triacylglycerols (neutral lipids)
- sweet stem in sorghums for sugar and molasses [replacing sugarcane *(Saccharum officinarum)* in drought/semi-arid areas], and ethanol production
- malting quality for development and promotion of malt foods, malt drinks and beverages, glucose and malt confectioneries, and brewing products like lager beer
- micronutrients like calcium, zinc and iron in the grain for enhanced plant, animal and human nutrition and health
- use of hydrophobic proteins of sorghum in biofilms for fruit and vegetable protection in export trade

Uncompetitive grain prices

The combination of problems of grain availability, cleaning and processing, along with uncertainty regarding consumer demand, place sorghum and pearl millet at a distinct disadvantage relative to alternative grain inputs in Sub-Saharan Africa's agro-industrial sector. These relationships are highlighted in recent data collected on industry prices for alternative grains in Zimbabwe (Table 6). Prices for sorghum and pearl millet are generally heavily discounted compared with those for maize - the closest grain substitute. Uncertainty about these inputs also leads to large variation in the factory gate prices offered within the same industry.

The opaque beer industry in Southern Africa tends to offer intake prices for sorghum and pearl millet that are marginally lower than those for maize. If the industry is particularly short of sorghum, these prices may rise marginally above those for maize. Again, this is because sorghum is viewed as a necessary ingredient for opaque beer production. Yet if sorghum costs rise too high, the industry will shift to using imported enzymes instead of sorghum malt.

Sorghum and pearl millet tend to be most heavily discounted in the animal feeds industry. These prices range around 70 to 80% of the prices offered for maize. Two of the three millers processing sorghum in Zimbabwe similarly indicated they would purchase sorghum or pearl millet if the price dropped less than 75% the price of maize. The miller

Table 6. Coarse grain buying prices (Z$ t^{-1}) offered by industry at the factory gate in Zimbabwe, June 2001.

Industry	Buyer/company	Maize	Sorghum	Pearl millet
Brewing	Chibuku	7500	7000	No purchases
	Ingwebu	7500	6500	7000
Milling	Jati Millers	8500	5557	No purchases
	Blue Ribbons	8000	No purchases	No purchases
	National Foods	8200	8000	7000
Animal feed	Feeds & Feeds	7500	5500	5000
	National Foods	8200	8000	7000
	Agrifoods	8400	6900	8000
	Premier Milling	8300	6000	6500
Grain trading	Grain Marketing Board	7500	5500	5000

Source: ICRISAT surveys.

offering the highest price was the company most experienced with these grains.

These discounts are reflected in the government set prices offered by the national Grain Marketing Board. While government prices are supposed to establish a floor under the market, these strongly influence the prices offered by the private sector.

Such prices place sorghum and pearl millet producers at a large disadvantage. Not only do they receive a lower payment at the factory gate, but in addition, marketing costs for sorghum and pearl millet are commonly higher than those for maize. In many countries these grains are being drawn from outlying semi-arid regions and thus face higher transport costs. But in addition, farmgate prices are influenced by low trade volumes which lead to higher marketing costs per unit of grain sold.

The severity of this relationship is apparent in a recent assessment of marketing margins in Tanzania (Table 7). Here it may take a trader a week or more to collect enough grain to fill a 15 t truckload. Each bag must be checked for contamination and grain quality. Local village taxes must be paid. Ultimately, the farmer earns only 60% of the cost of grain delivered to the nearest business center. And the farmer earns only 42% of the factory gate price for grain delivered to an agro-processor in Dar es Salaam.

Table 7. Example of grain trading margins in central Tanzania, 2002.

Description	Unit	Trading margin (Z$ per unit)
Grain	Bucket (16 kg)	900 (52.94)[1]
Grain bag	1 bag	300 (3.00)
Village stay	1 week	2000 (0.33)
Village storage	Room	8000(1.33)
Guard	2 per week	2500 (0.42)
Tax levy	Bag	300 (3.00)
Labor for filling bags	Week	1500(0.25)
Loading	Bag	150(1.50)
Truck hire to Dodoma	Bag	2150(21.50)
Unloading	Bag	150(1.50)
Grain cost	Bag	8577 (85.77)

1. Margin in Z$ kg^{-1} is given in parentheses.

Source: ICRISAT surveys, 2002.

In these circumstances, farmers complain that they do not earn enough to justify expanding production. But given such high marketing costs, grain processors can barely afford to pay more. The prices on offer are capped by the prevailing prices for maize grown in higher potential regions of the country where trading volumes are higher, and market infrastructure is more developed.

Grades and standards

The present commercialization trends are not too encouraging, except for the industrial uses in South Africa, Nigeria, Botswana and Zimbabwe, which also need a lot of up-scaling. As a beginning, there is need for strong documentation of data and information on alternative uses and processing technologies of the crops. A critical analysis of these would help identify further gaps, assess the needs and rationalize the way forward.

Grain end-use quality

As emphasized earlier, in order to diversify and increase millet and sorghum utilization, it is essential that grain with known and suitable end-use quality characteristics is always available for processing. Obviously, since grain crops availability in individual countries fluctuate between a surplus and deficit situation, there must be greatly increased regional trade in millet and sorghum. This demands internationally accepted standards for millet and sorghum grain end-use quality and appropriate methods for determining 'in trade' whether batches of grain meet these standards. ICRISAT has made a large contribution to this area through the publication in 1997 on methods for evaluation of sorghum and pearl millet quality (Gomez et al. 1997). A project sponsored by the United States Agency for International Development (USAID) in 2001 was undertaken in Southern Africa and entitled 'Development of Simple, Common Grain Quality Standards for Sorghum to Facilitate Grain Trade in Southern Africa'. This resulted in five standards for sorghum grain and simple methods to measure them. These were:

- Detection of tannin sorghum by the alkali-bleach test
- Determination of defects in sorghum grain, including weevil damage
- Classification of sorghum grain according to color (white, red and brown)

- Estimation of sorghum grain hardness (very soft, intermediate and very hard)
- Determination of germinative energy of sorghum

The methods have been included in the draft sorghum standards for Botswana and have been submitted to the International Association for Cereal Science and Technology for approval as draft international standards methods (JRN Taylor, University of Pretoria, Pretoria, South Africa personal communication and consultancy report). Obviously, these activities only represent initial steps in what has to be an ongoing process to develop and implement comprehensive trading standards for sorghum and millet grain, as these exist for other grains. However, in the short-term it is proposed that the developed methods and standards should be applied to ICRISAT and sorghum breeding programs in Africa and that similar methods and standards be developed and applied for millets. The baseline data on cultivar end-use quality developed will help ensure the constant availability of grain of suitable quality for utilization and lead to an ongoing improvement in grain end-use quality.

Food products quality

It is suggested that an Africa-wide database of traditional, new, alternative and improved millet and sorghum food products and full details of the processing technologies used to produce them be created. The availability of such data will encourage entrepreneurs and institutions in countries to test millet and sorghum food products that are novel to them. The example of the interest in pearl millet couscous in Namibia has been mentioned.

Packaging

In Southern Africa, sorghum and millet foods and beverages are packed in diverse (plastic bags, jute sacks, food cardboard boxes and bottles) and convenient containers of different shapes, strength, color, sizes and with logos of manufacturers. Packing is done mostly by full or partial mechanization. In West Africa, only plastic and jute bags are used mostly, and packing is also mostly manual. For effective and wider commercialization in West Africa, we need to start using convenient and attractive packaging of the food products (as is presently being done for beverages from the breweries).

Public and private partnerships

The successful commercial processing of sorghum in countries like South Africa and Botswana suggests potential for the development of these markets. However, available evidence from neighboring countries also suggests the need to resolve a number of inter-linked constraints to industrial processing. Improvements in production productivity are essential for sorghum or pearl millet to become more competitive with grain inputs like maize. Larger quantities of grain must be consistently sold by farmers in order to both reduce per unit marketing costs, and assure industry of a reliable input. Grain destined for food processing must be cleaned. Industrial processors need to be educated about the processing characteristics of these inputs, and the food or feed value. Entrepreneurs must be willing to take risks in developing new markets.

The pursuit of this combined set of solutions requires new partnerships between public and private agencies willing to combine investments in the development of these markets. These are best defined in the context of specific investment strategies targeting the expansion of particular agro-industrial outputs.

Institutional alliances

The importance of technology exchange in increasing and diversifying millet and sorghum utilization cannot be overemphasized. As stated in the introduction, there is a huge resource in Africa of millet and sorghum expertise; the problem is how to create the necessary synergies to fully exploit this resource. The idea of a database of traditional and developed millet and sorghum food products and the full details of the processing technologies used to produce them has already been mentioned.

One most effective way for technology exchange to take place would be for organizations involved in the promotion of millet and sorghum such as ICRISAT, the USAID supported INTSORMIL, regional and sub-regional forums like CORAF (West and Central African Council for Agricultural Research in Eastern and Central Africa) and CILSS; advanced research institutes like CIRAD (Centre de coopération internacionale en recherche agrnomique pour le développement) (all in West Africa region) to obtain and provide funding for technical and information exchange visits for millet and sorghum scientists, technologists and teachers between institutes in the various millet and sorghum producing countries in Africa. Such activities will best be regional or cross-regional in nature involving the three regional forums, CORAF, ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa) and SACCAR (Southern African Center for Coordination of Agricultural Research), through their respective networks.

The training of food/feed scientists, nutritionists and technologists, and fostering their networking with public and private sector organizations or industries can be set to enhance postharvest processing and utilization in Africa. A concrete mass of food/feed processing and marketing scientists and nutritionists, including engineers/equipment fabricators and information technology specialists is still a requirement in Africa, for promotion of commercialization of underutilized and under researched, though nutritional, cereal crops.

Premium market

One option is to pursue a few premium or niche markets wherein sorghum or pearl millet grains have unique values; for example, the production of malt for malt beverages and drinks, opaque beer, for weaning foods or glucose manufacture. In these circumstances, traders and processors may be willing to pay a premium price for high quality grain specially suited to their manufacturing process. This premium price may at least partly offset the higher costs of finding, assembling and cleaning these grains, or organizing the grain market. The premium market could encourage farmers to invest in new technologies promoting the expansion of their production.

In order to support this option, crop breeders need to develop varieties with traits specifically suited to the target niche market. Breeders and seed producers need to be sure these varieties are multiplied and distributed to farmers capable of producing for the commercial market niche. Farmers and industry may also benefit from public support for grain stockholding necessary to assure a consistent production and supply of high quality grain. However, the justifications for such public investments may be reduced by the limited number of beneficiaries. Private investors should be encouraged to participate.

Low cost market

Alternatively, the development of sorghum and pearl millet markets may be pursued by targeting deliveries of low cost grain - for example, for animal feed. This market probably has the highest potential for growth in Africa as incomes rise and the demand for livestock products correspondingly increases. The logical primary target would be the expansion of the poultry feed industry.

In the initial stages of market development, sorghum and pearl millet may only be used when available at substantial (20-40%) price discounts relative to maize. This, at least, could help establish a floor price under grain prices when rains are favorable. However, over time, as the animal feed industry gains greater familiarity with these grains, such discounts should decline and eventually fade away.

Public support for this strategy could involve the collection of grain stocks following favorable harvests, and sale of these stocks later in the year. Public investment could also encourage industry experimentation with the processing and feed use of these grains. On-farm trials are now a common component of publicly funded agricultural research. Factory trials could similarly be a component of research programs encouraging the growth of commercial grain processing. Industry should be encouraged to articulate what research and trial programs are needed.

Again, however, the problem with this strategy is its limited scope. Farmers may benefit from higher grain prices following favorable rainfall seasons. However, it is unlikely that this will be enough to encourage investments in better varieties and crop management necessary to develop a more commercially competitive agro-industrial enterprise. The scenario could change with appropriate policy interventions in relevant countries.

Economies of scale

A third market development option would encompass efforts to promote the use of sorghum or pearl millet as a common, industrially processed, food product - for example sorghum meal or sorghum breakfast porridge. If grain demand is assured in most seasons, farmers may be more willing to invest in better varieties or crop management practices. Larger, and more consistent trade volumes can lead to reductions in per unit marketing costs with consequent gains in farmgate prices, and a possible reduction in the costs of grain at the factory gate. The average search and assembly costs for grain will decline. More consistent demand may also encourage traders to hold larger inventories, reducing seasonal price fluctuations, and assuring commercial processors of a consistent flow of grain throughout the year.

Governments can do many things to facilitate such private investments necessary to develop these markets. A starting point is to examine where governments are already facilitating the production and trade of alternative commodities such as maize or rice. In many countries, strategic grain stocks are still held and subsidized by governments. In Tanzania, for example, the national Strategy Grain Reserve is made up entirely of maize. The replacement of 10% of this maize reserve with sorghum could triple commercial market flows overnight. Currently, government-supported school feeding programs only use maize, even if these are operating in sorghum and pearl millet growing regions. The conversion of these programs to 50% sorghum or pearl millet could lead to a doubling of commercial demand for grain from the central part of the country.

In Botswana, grain import controls designed to protect domestic producers led to a rapid decline in sorghum consumption during the 1980s. The removal of import controls, and the promotion of small grants to entrepreneurs interested in establishing small-scale sorghum mills, stimulated a ten-fold increase in commercial sorghum milling in the mid-late 1990s.

In Zimbabwe, a new experimental program is encouraging commercial milling of sorghum for food relief programs targeting urban consumers. The miller involved recognizes the potential market for sorghum meal, but wants more proof of the potential size of this market before he expands his own investments in sorghum milling. The aid program may be adequate to provide this proof.

In sum, we commonly accept the need to subsidize farmers with public investments in the development of production technologies. Yet the incentive to apply these technologies commonly depends on the demand for the grain product in the commercial market. Similar investments in the development of product markets, or in linking technology flow with efforts to facilitate market development, can offer substantially larger impacts on farmer, processor and consumer welfare in the long run. Historically, these public investments have favored crops such as maize and rice in Africa. Stronger investments in market facilitation may benefit larger numbers of poorer farmers if directed toward commodities such as sorghum and pearl millet.

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Sorghum and Pearl Millet for Poultry Feed

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Abstract

This paper reviews the chemical composition, nutritive value and utilization of sorghum and pearl millet. Sorghum is almost comparable to maize but pearl millet has better protein value. The energy source of these ingredients is lower than that of maize. However, these can be used as energy ingredients for poultry, replacing maize partly or completely in poultry diets. Hence alternative energy ingredients like sorghum and pearl millet can share the increased demand of maize. Further, there is a need to study the nutritive value and utilization of sorghum and pearl millet cultivars developed in recent years.

Sorghum (*Sorghum bicolor)* and pearl millet *(Pennisetum glaucum)* have food value for human consumption particularly by rural people. The quality of the grain depends on the season, varieties and agronomic practices. Use of sorghum in poultry feed is discouraged mainly due to the presence of tannins and grain molds. The chemical composition and nutritive value of the grain varies and is dependent on many factors. Recently, many cultivars with improved yield and grain quality have been developed. Poultry feeds contain cereal grains to the extent of 40-60% and these ingredients contribute energy. Among the cereals, yellow maize *[Lea mays)* and wheat *[Triticum aestwum)* are commonly used depending on their availability. Maize-soybean *(Glycine max)* ingredients are extensively used to meet the complete nutrient requirement of poultry diets. Alternatively, sorghum and pearl millet are also used in poultry feeds on the basis of least cost formulation.

Grain structure

A brief review has been attempted on the use of sorghum and pearl millet in poultry feed. Genetic and environmental factors play significant roles in determining the grain composition. An extensive review was made on sorghum and pearl millet (FAO 1995). Sorghum and pearl millet grains show considerable diversity in color, shape, size and certain anatomical

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components (Table 1). Grain structure is similar in sorghum and pearl millet. The principal components are pericarp, endosperm and germ. Pericarp is the outermost layer comprising of sub-layers, namely epicarp, mesocarp and endocarp. The pericarp consists of the epidermis, which is often pigmented and hypodermis, which possesses three layers of thickness. Mesocarp thickness is associated with mold resistance and it varies widely among the genotypes. Grains with thick mesocarp are preferred for dehulling by hand-pounding. The seed sub-coat or testa lies just below the endocarp and its color and pigments are variable and genetically controlled. Brown sorghums have dark seed sub-coat. If the cultivars contain tannin, most of it is in the testa.

Endosperm is the major storage tissue comprising the aleurone layer and peripheral corneous and floury zones. Aleurone cells are rich in B-complex vitamins, minerals and oil and contain hydrolyzing enzymes. The protein bodies in the endosperm of sorghum and pearl millet are spherical. In sorghum, the number of protein bodies decreases with the rise in starch content from peripheral zone to the central core where the floury endosperm is located. In pearl millet the protein bodies are more numerous in the floury zone than in the corneous zone. Novellie and Liebenberg (1976) have reported the presence of several enzymes such as protease, 3-glucosidases, 3-galactosidase and phosphatase in the protein bodies of sorghum. The germ comprises the scutellum and is rich in lipids, protein, enzymes and minerals. The ratio of endosperm to germ is larger in sorghum than in pearl millet (Table 1).

Table 1. Structural features of sorghum and pearl millet grains.

Parameter	Sorghum	Pearl millet
Grain color	White, yellow, red, brown	Gray, white, yellow, brown, purple
Grain type	Caryopsis	Caryopsis
Grain shape	Spherical	Globular, hexagonal, globose
1000-seed mass(g)	25-30	2.5-14
Seed coat or testa	Single layer, sometimes pigmented (brown sorghum is dark colored)	Single layer, sometimes pigmented
Starch granules	20-30 urn diameter	10-12 um diameter
Protein matrix size	0.3-3 urn	0.6-0.7 urn
Endosperm:germ ratio	8.4:1	4.5:1

Source: FAO (1995).

Chemical composition

Chemical composition and nutritive value of maize, sorghum and pearl millet reported in Nutritional Research Council (1994) and reviewed by Rama Subba Reddy (1998) and Rama Subba Reddy and Nageswara Rao (2000) are presented in Tables 2 to 4.

Protein

Sorghum and pearl millet contain high protein levels compared to maize (Tables 2 and 3). Grain proteins are broadly classified into four fractions according to their solubility characteristics. These are albumin (water soluble), globulin (salt soluble), prolamin (alcohol soluble) and glutelin (alkali

Table 2. Chemical composition and nutritive value of different cereals used as feed.

Parameter	Sorghum	Pearl millet	Maize
Dry matter (%)	87	89	89
Metabolizable energy (kcal kg^{-1})	3288	2675	3350
Crude protein (%)	8.8	14	8.5
Fat (%)	2.9	4.3	3.8
Crude fiber (%)	2.3	3.0	2.2
Linoleic acid (%)	1.13	0.84	2.20
Calcium (%)	0.04	0.05	0.02
Total phosphorus (%)	0.30	0.32	0.28
Non-phytin phosphorus (%)	0.09	0.12	0.08

Source: Nutritional Research Council (1994).

Table 3. Chemical composition of sorghum and pearl millet on dry matter basis.

Parameter	Sorghum	Pearl millet	Maize
Dry matter (%)	88.4-99.2	88-89.3	88.4-89.6
Crude protein (%)	10.0-14.1	7.1-14.4	8.8-10.4
Crude fiber (%)	1.5-5.9	2.3-3.0	2.3-2.8
Fat (%)	1.8-5.7	4.3-5.1	1.8-3.8
Total ash (%)	1.77-3.60	2.6-6.2	1.8-3.2
Nitrogen-free extract (%)	65.3-84.2		64-90
Calcium (%)	0.01-0.36	0.03-0.31	0.02-0.07
Phosphorus (%)	0.13-0.69	0.11-0.77	0.11-0.45
Available carbohydrates (%)	56-63	60.8	-

Source: Rama Subba Reddy (1998), Rama Subba Reddy and Nageswara Rao (2000).

Table 4. Chemical composition and nutritive value of sorghum cultivars and maize on dry matter basis.

Parameter	Sorghum cultivars				Maize
	CSV 15	CSH 16	PSV 16	S 35	
Dry matter (%)	93	92	93	92	92
Crude protein (%)	9.40	10.32	10.80	11.90	9.3
Fat (%)	3.01	2.85	2.40	3.73	3.8
Crude fiber (%)	3.20	2.48	2.81	4.02	2.20
Ash (%)	1.13	1.30	1.37	1.53	1.30
Nitrogen-free extract (%)	83.26	83.05	82.62	79.22	83.4
Metabolizable energy (kcal kg^{-1})	3422	3196	3402	3238	3700

Source: Laxmi Tulasi (2003).

and acid extractable). Solubility fractionation studies indicated higher levels of albumin plus globulin in pearl millet varieties than in sorghum, while amounts of the cross-linked prolamin, β-prolamin, were higher in sorghum than in pearl millet (Table 5).

Studies on amino acid composition of the protein fractions of sorghum grain (Ahuja et al. 1970) showed that the albumin and globulin fractions contained high amounts *of* lysine and tryptophan and in general were well balanced in their essential amino acid composition. On the other hand, the prolamin fraction was extremely poor in lysine, arginine, histidine and tryptophan and contained high amounts of proline, glutamic acid and leucine. Present in the form of protein bodies, prolamin was found to be the predominant protein fraction directly associated with the protein content of

Table 5. Distribution of protein fractions (% of total protein) in sorghum and pearl millet grains.

Fraction	Sorghum		Pearl millet	
	Range	Mean	Range	Mean
Albumin + globulin	17.1-17.8	17.4	22.6-26.6	25.0
Prolamin	5.2-8.4	6.4	22.8-31.7	28.4
Cross-linked prolamin	18.2-19.5	18.8	1.8-3.4	2.7
Glutelin-like	3.4-4.4	4.0	4.7-7.2	5.5
Glutelin	33.7-38.3	35.7	16.4-19.2	18.4
Residue	10.4-10.7	10.6	3.3-5.1	3.9

Source: FAO (1995).

the grain. Glutelin, the second major protein fraction, is a structural component that represents the protein matrix in the peripheral and inner endosperm of the sorghum kernel.

Sorghum contained high tryptophan, while pearl millet contained higher levels of essential amino acids as compared to maize (Table 6). Amino acid composition varied with cultivars. The cultivar S 35 has high essential amino acid content. The amino acid digestibility in sorghum is slightly less as compared to maize (Table 6).

Carbohydrates

Sorghum and pearl millet slightly differ in characteristics of starches (Table 7) and composition of souble sugars (Table 8). In many sorghums, starch digestibility is low and starch content more variable (Wagner 1982).

Fat

Crude fat content of sorghum is 3%, which is lower than that of maize and pearl millet. The germ and aleurone layers are the main contributors to the lipid fraction. The germ itself provides about 80% of the total fat. Average fatty acid composition of sorghum and maize is given in Table 9.

Table 6. Amino acid composition (% of protein) of sorghum (SG) and maize and their digestibility coefficients.

Amino acid	SG	Pearl millet	Maize	SG cultivars				Digestibility coefficient (%)	
				S 35	PSV 16	CSV 15	CSH 16	SG	Maize
Methionine	0.17	0.25	0.18	0.17	0.17	0.15	0.16	88	91
Cystine	0.16	0.24	0.19	0.19	0.16	0.17	0.18	80	88
Lysine	0.24	0.45	0.27	0.22	0.20	0.20	0.20	78	82
Threonine	0.31	0.48	0.32	0.33	0.30	0.27	0.29	80	84
Tryptophan	0.10	0.08	0.07	0.12	0.11	0.09	0.10	85	80
Arginine	0.37	0.74	0.44	0.40	0.36	0.33	0.34	78	90
Isoleucine	0.34	0.37	0.31	0.40	0.36	0.31	0.35	88	89
Leucine	0.99	1.14	1.07	1.31	1.19	0.79	1.16	93	93
Valine	0.44	0.49	0.42	0.51	0.47	0.46	0.45	86	88
Histidine	0.20	0.39	0.26	-	-	-	-	86	91
Crude protein (%)	10.5	15.7	9.0	10.5	9.52	8.27	9.08	-	-

Source: Nutritional Research Council (1994), Degussa Feed Additives (2001).

Table 7. Characteristics of starch of sorghum and pearl millet.

Grain	Amylose (%)	Gelatinization temperature (℃) Initial	Final	Water binding capacity (%)	Swelling at 90℃ (%)	Solubility at 90℃ (%)	Viscosity (amylogragh - Brabend) At 93 to 95℃	After holding at 95℃	Cooled to 35 or 50℃
Sorghum	24.0	68.5	75.0	105	22	22	600	400	580
Pearl millet	21.1	61.1	68.7	87.5	13.1	9.16	460	396	568

Source: FAO (1995).

Table 8. Composition (%) of soluble sugars in sorghum and pearl millet grains.

Grain	Number of cultivars	Total sugar	Sucrose	Glucose + fructose	Raffinose	Stachyose
Sorghum	10	2.25	1.68	0.25	0.23	0.10
Pearl millet	9	2.56	1.64	0.11	0.71	0.09

Source: FAO (1995).

Table 9. Average fatty acid composition of sorghum and maize.

Grain	Dry matter	Ether extract	Selected fatty acid (% of feed ingredient) $C_{12:0}$	$C_{14:0}$	$C_{16:0}$	$C_{16:1}$	$C_{18:0}$	$C_{18:1}$	$C_{18:2}$	$C_{18:3}$
Sorghum	89	2.8			0.56	0.15	0.03	0.89	1.13	0.06
Maize	89	3.8			0.62	-	0.10	1.17	1.82	0.09

Source: Nutritional Research Council (1994).

Fiber

The fiber content of sorghum is higher than maize but is quite variable (Table 4). Karim and Rooney (1972) reported that the pentosan content of sorghum varied from 2.51 to 5.57%. Pentosans occur in cell walls of cereal grains and are a heterogeneous mixture of polysaccharides; many of which contain proteins. Earp et al. (1983) identified the mixed linked β-glucans in sorghum pericarp, aleurone and endosperm. These are water soluble and form viscous, sticky solutions. This property may be important in malting of sorghum but it is a disadvantage in the alimentary tract of birds. Cholesterol lowering property is seen in glucans isolated from sorghum.

The fiber content of pearl millet is higher than sorghum and maize (Table 2). Pentosans of pearl millet represent arabinose, xylose and galactose, follwed by rhamnose and fucose (Bailey et al. 1979). Pearl millet contains 0.66% water soluble non-starch polysaccharides and 3.88% water insoluble non-starch polysaccharides.

Minerals

Mineral composition of sorghum is compared with pearl millet and maize (Table 10). In sorghum grain, minerals are unevenly distributed and are more concentrated in the germ and seed coat.

Vitamins

Choline, niacin, pantothenic acid and riboflavin are high in sorghum and pearl millet as compared to maize (Table 11). Sorghum contained higher biotin than maize. Pearl millet contained almost double the quantity of thiamine compared to maize.

Nutritional inhibitors and toxic factors

Antinutritional factors can be classified broadly as those naturally present in the grains and those occurring due to contamination which may be of fungal

Table 10. Mineral composition of sorghum, pearl millet and maize.

Mineral	Sorghum	Pearl millet	Maize
Calcium (%)	0.04	0.05	0.02
Phosphorus (%)	0.30	0.32	0.28
Non-phytin phosphorus (%)	0.09	0.12	0.08
Sodium (%)	0.01	0.04	0.02
Sulfur (%)	0.06	0.13	0.08
Potassium (%)	0.35	0.43	0.30
Chloride (%)	0.09	0.14	0.04
Iron (ppm)	45	25	45
Magnesium (ppm)	0.15	0.16	0.12
Manganese (ppm)	15	31	7
Copper (ppm)	10	22	3
Selenium (ppm)	0.2	-	0.03
Zinc (ppm)	15	13	18

Source: Nutritional Research Council (1994).

Table 11. Vitamin composition (ppm) of sorghum, pearl millet and maize.			
Vitamin	Sorghum	Pearl millet	Maize
Biotin	0.26	–	0.06
Choline	668	793	620
Folacin	0.2	–	0.4
Niacin	41	53	24
Pantothenic acid	12.4	7.8	4.0
Pyridoxine	5.2	-	7.0
Riboflavin	1.3	1.6	1.0
Thiamine	3.0	6.7	3.5
Vitamin E	7	-	22

Source: Nutritional Research Council (1994).

origin or may be related to soil and other environmental influences. These factors modify the nutritional value of grains and some of them have serious nutritional and health consequences. The antinutrients and toxic substances associated with sorghum and pearl millet are discussed below.

Phytate

Phytic acid is the main phosphorus store in mature grain. It readily forms complexes with minerals and proteins. Most phytate-metal complexes are insoluble and make several minerals unavailable in animals and birds. Bran and aleurone layers of the grain are a major source of phytate and total phosphorus in sorghum. The phytate content of sorghum and millet are almost similar to that of maize and it is not a serious problem in diets for chicken.

Polyphenols

Widely distributed polyphenols in plants are not directly involved in any metabolic process and are therefore considered secondary metabolites. Phenolic compounds in sorghum can be classified as phenolic acids, flavonoids and condensed polymeric phenols known as tannins. Phenolic acids, free or bound as esters, are concentrated in the outer layers of the grain. They inhibit growth of microorganisms and probably impart resistance against grain mold. Flavonoids in sorghum, derivatives of the monomeric polyphenol flavon-4-ol are called anthocyanidins. The two flavonoids in sorghum are luteoforol and apiforol. Jambunathan et al. (1986) observed that resistance to grain molds rather than to birds (Subramanian et al. 1983) was associated with flavon-4-ol content of the grain.

Tannins are polymers resulting from condensation of flavon-3-ols. During grain development, flavonoid monomers are synthesized and then condensed to form oligomeric proanthocyanidins of four to six units. Tannins, while conferring the agronomic advantage of bird resistance, adversely affect the grain's nutritional quality (Butler et al. 1984). Tannins are generally located on the outer seed coat of sorghum grain. There is no clear relationship between seed coat color and tannin content. High tannin sorghums are usually darker in color, but some dark colored sorghums are low in tannins.

A quick test was developed to cut the seed and observe presence of pigmented tannin in the testa. A bleach test for presence or absence of pigmented testa gives a fair indication of tannin in grains. About 20 g sorghum is mixed with 5 g potassium hydroxide and 75 ml of household bleach. The mixture is shaken until potassium hydroxide dissolves and then it is set aside for 20 minutes. Grains are stained and rinsed with water and placed on a paper towel. Potassium hydroxide removes the outer pericarp and so the testa is exposed. High tannin grains appear dark brown or black while low tannin grains are bleached white or yellow (Leeson and Summers 2001). Tannins in grain can be estimated by spectrophotometric method (Burns 1971, Porter et al. 1986). The adverse effects of tannins are reduced digestibility and growth retardation in chicken when protein in diet is marginal.

Different methods have been tried to inactivate or detoxify the tannins in bird resistant sorghums to improve their nutritional quality. Some of these methods are moisturizing with alkali, dilute aqueous ammonia, Mugadi soda solution, formaldehyde and polyethylene glycol (FAO 1995).

Digestive enzyme inhibitors

Inhibitors of amylases and proteases have been identified in sorghum and some millets (Pattabhiraman 1985). The nutritional significance of the enzyme inhibitors present in sorghum and millets is not clearly understood and hence further research is needed.

Goitrogens

Goitrogens were identified in pearl millet (Osman and Fatah 1981). Feeding trials in rats showed that goitrogen inhibited deiodination of thyroxine (T_4) to triiodothyronine (T_3). Iodine supplementation did not alleviate the goitrogenic effect of pearl millet. Yellow colored pearl millet was less goitrogenic than brown or gray millet.

Mycotoxins

Like other cereals, sorghum and pearl millet are susceptible to fungal growth and mycotoxin production under certain environmental conditions. Storage fungi, mostly species of *Aspergillus* and *Penicillium* are found on food grain stored with moisture content greater than 13% (Sauer 1988). Moldy sorghum panicles were reported to be contaminated with aflatoxins B and G (Tripathi 1973). Infestation of pearl millet by parasitic fungi, *Claviceps fusiformis,* caused an outbreak of ergotism. *Fusarium* spp on sorghum released T_2 toxin.

Sorghum utilization in poultry diets

The information available on the growth of chicks fed on sorghum to replace maize part by part or isocalorically have been reviewed by Rama Subba Reddy and Nageswara Rao (2000). Data indicated that sorghum can be included up to 60% in broiler diets replacing maize without affecting the performance. The broilers tolerated up to 0.26% tannins in their diet. The addition of tallow at 6% improved feed conversion ratio (FCR) at highest dietary tannin content (0.65%) (Pour-Reza and Edriss 1997). Reduction in body weight and FCR due to high tannin content intake can only partially be improved by the addition of animal fat. Improved FCR resulted from reduction in the rate of passage of digesta (Pour-Reza and Edriss 1997). In broiler chicks, Sharma et al. (1979) observed superiority of pearl millet over maize, wheat and sorghum.

Effect of feeding sorghum to broilers on meat quality was studied by Cherian et al. (2002). Sorghum feeding may improve the color stability of meat by its antioxidant effect. Tannin and related phenol compounds are as effective as vitaminE as an antioxidant.

Supplementation of sorghum grain diets with methionine (0.15%) and choline (0.2% of 25% purity) resulted in significant improvement in weight gain and FCR. Polyvinylpyrrolidone (1%) completely attenuated the tannic acid effect in broilers. Layer birds on sorghum diets at 50 and 100%

replacement of maize have resulted in similar performance as compared to maize (Rama Subba Reddy and Nageswara Rao 2000).

Pearl millet utilization in poultry diets

Inclusion of pearl millet at high rate (47.1%) promoted best efficiency of protein digestion. Pearl millet replaced total maize in broiler diet without affecting the broiler performance. Singh and Barsaul (1976) have observed improvement in the FCR when pearl millet replaced maize in broiler diets. When pearl millet replaced maize part per part or isocalorically and isoproteinically, the performance of chicks was either comparable or better than those fed with maize (Ayyaluswami et al. 1967, Singh and Barsaul 1976, Sharma et al. 1979, Asha Rajani et al. 1986, Nagra et al. 1987, Satyanarayana Reddy et al. 1989, Purushothaman and Thirumalai 1995, Rama Rao et al. 1997). As such, maximum level used in the experiments (21.5 to 60%) could be taken as the maximum level of inclusion of pearl millet in diet. Pearl millet was included at 27.8% in unground form or ground form or at 27.8% unground form plus 27.8% ground form. The performance was similar whether pearl millet was in ground form or unground form. In two studies on layers, pearl millet was included at 32% part per part for maize and at 60%) part per part or isocalorically and isoproteinically at the expense of maize. In all the cases, the performance of layers with pearl millet feed was comparable to those on maize diet, but for yolk color (Ramachandra Reddy and Reddy 1970, Srilatha Rani 1995).

Digestibility of dry matter, ether extract, crude fiber, nitrogen-free extract and balance of calcium and phosphorus remained unaffected at 3 and 9 weeks of age (Singh and Barsaul 1976). Energy and protein deposition in broilers when fed on pearl millet was observed to be better than when fed on maize diet (Sharma et al. 1979). Satyanarayana Reddy et al. (1991) observed no effect of pearl millet diet on abdominal fat and ready to cook yield in broilers while Rama Rao et al. (1997) reported higher abdominal fat when broilers fed on pearl millet diet than on maize diet. Source of energy in the diet did not influence egg production, indicating that pearl millet can be used as an alternative to yellow maize without affecting egg production in broiler breeder diet. Kumar et al. (1991) and Purushothaman and Thirumalai (1995) did not find differences in egg production due to feeding of pearl millet.

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Potential of Sorghum for Feed Industry in Thailand and Indonesia

B Boonsue[1]

Abstract

Maize has been a traditional feed grain in Thailand and Indonesia for many decades. Recently, there was a big shortage of maize supplies due to increasing demands from the rapidly growing poultry industry. Consequently, large quantities of maize grain have to be imported annually to balance the deficits in both countries. The chance to increase maize production seems limited due to continuous environmental stresses resulting in unfavorable conditions for profitable maize cultivation at subsistence levels. As sorghum is drought tolerant, it may be a good alternative feed grain in these areas. The essential need is to develop a sound breeding program to breed more adaptable varieties and hybrids with better yield and quality.

Feed consumption in Southeast Asia has steadily increased during the last four decades. Since 1960, the total maize (*Zea mays*) feed consumption in the region increased 16-fold from less than 1 million t in 1960 to about 16 million t in 2002. Thailand and Indonesia consume about half of this quantity. The poultry industry has been rapidly growing in these countries.

Thailand, with 62 million people, is the major poultry producer for exports. It exports about one-third of its total annual production while Indonesia's poultry production is mainly for domestic consumption having a population of 225 million (Fig.1).

Maize, a traditional cereal in the region, is the only major grain source for the feed industry in both countries. Most maize farmers are still farming at subsistence levels. Although Thailand has long been known as a maize exporter, now it is crucial for Thailand to import maize to meet the increasing demand of domestic feed consumption (Fig.2). A similar situation is taking place in Indonesia where more than 1 million t maize is imported annually to meet the requirement of the growing demand of feed industry (Fig.3).

It is anticipated that sorghum (*Sorghum bicolor*) with its unique ability to better withstand environmental stresses such as drought should be seriously studied to be an additional alternative feed grain for this wet tropical region.

1. Charoen Pokphand Group, 313 Silom Road, Bangrak, Bangkok, 10500, Thailand.

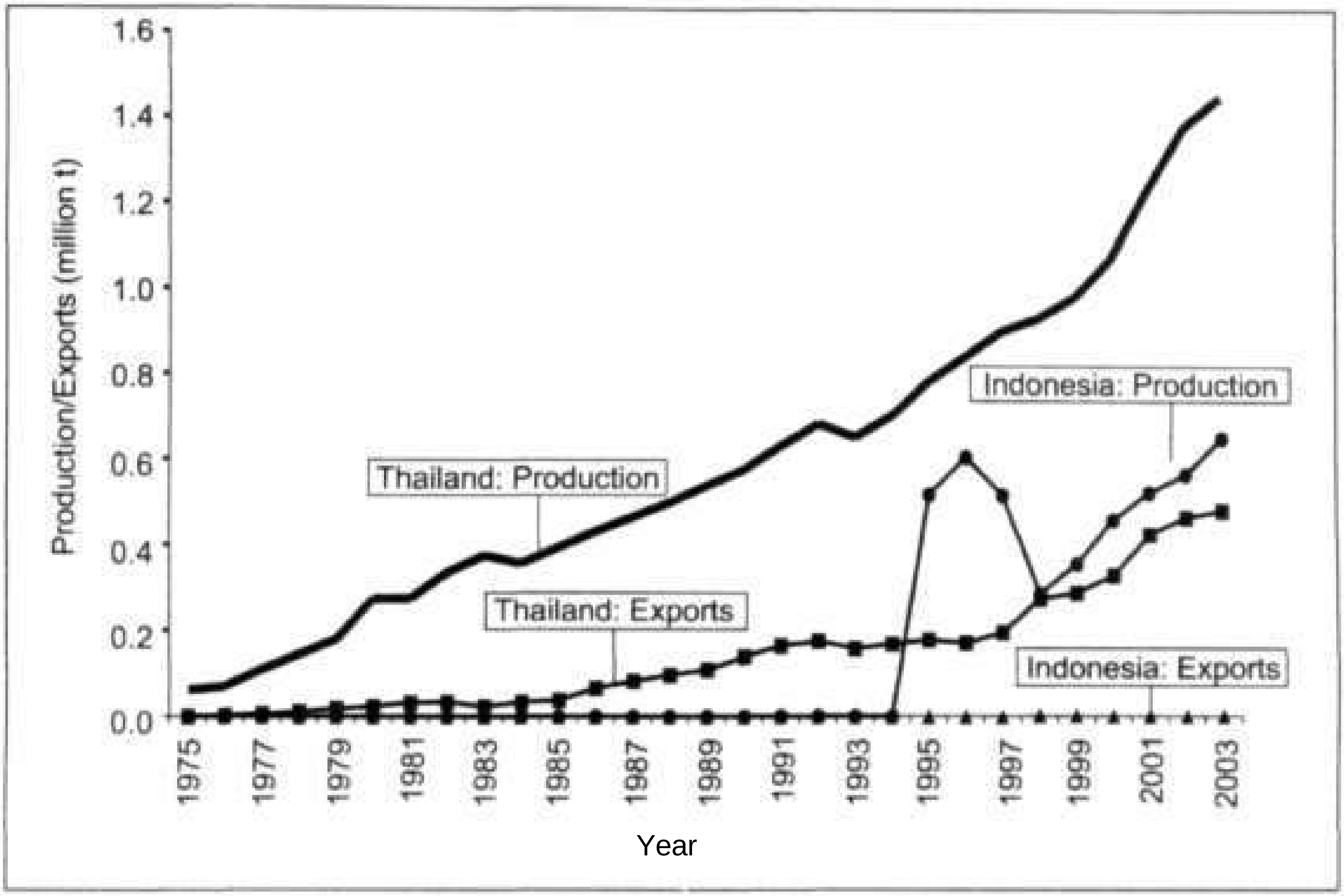

Figure 1. Poultry production and exports in Thailand and Indonesia. (Source: USDA 2003.)

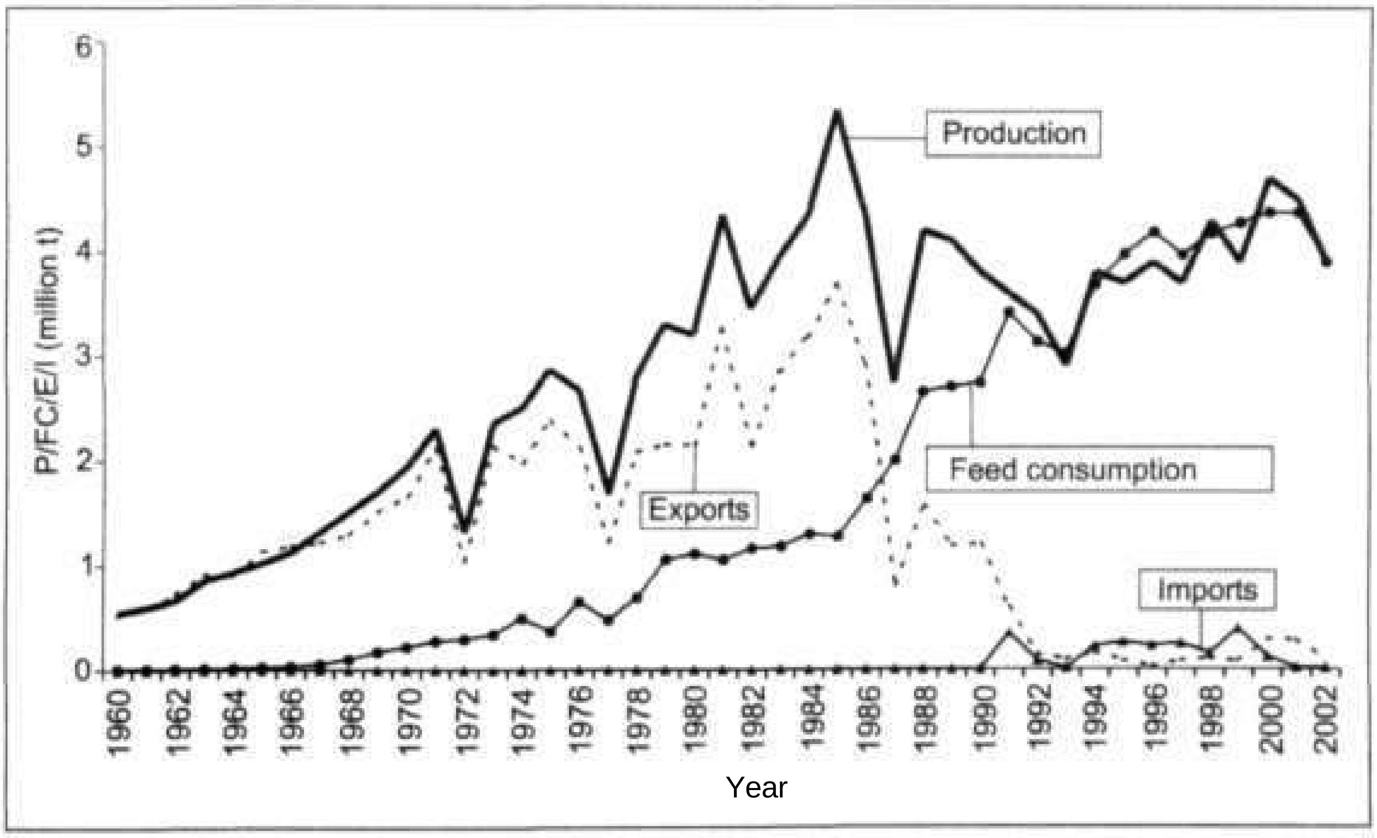

Figure 2. Production (P), feed consumption (FC), exports (E) and imports (I) of maize in Thailand, 1960 to 2002. (Source: USDA 2003.)

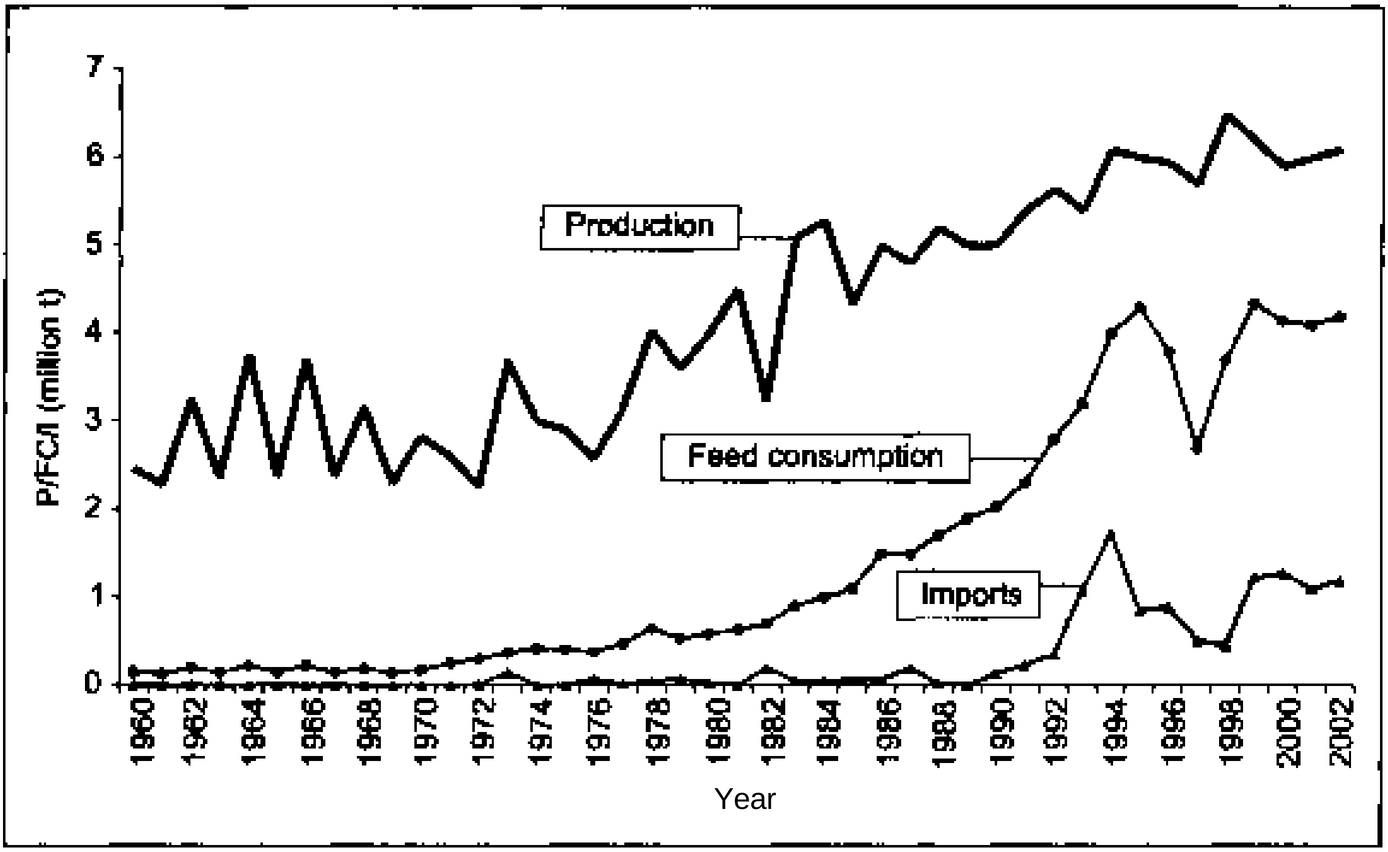

Figure 3. Production (P), feed consumption (FC) and imports (I) of maize in Indonesia, 1960 to 2002. (Source: USDA 2003.)

The marginal lands that are not suited for maize may be potential areas for sorghum production.

Feed grain improvement in Thailand

In 1966 the National Corn and Sorghum Research Program was organized as a cooperative effort involving Kasetsart University, the Ministry of Agriculture and Cooperatives, and the Rockefeller Foundation. This program provided Thai farmers with improved maize and sorghum varieties and cultivation practices, resulting in 5-fold increase in maize production within two decades. Maize was then (until 1985) produced mainly for exports (about 60-70% of annual production).

However, in the last two decades maize areas steadily declined from maximum 2.3 million ha to the current 1.1 million ha. But its rather consistent annual production of about 4 million t was maintained by higher yields of many superior hybrids released from private seed companies (Fig. 4). In the meantime, the booming feed industry absorbed most of the production until some imports starting from 1991 till date balanced the deficits (Fig.2).

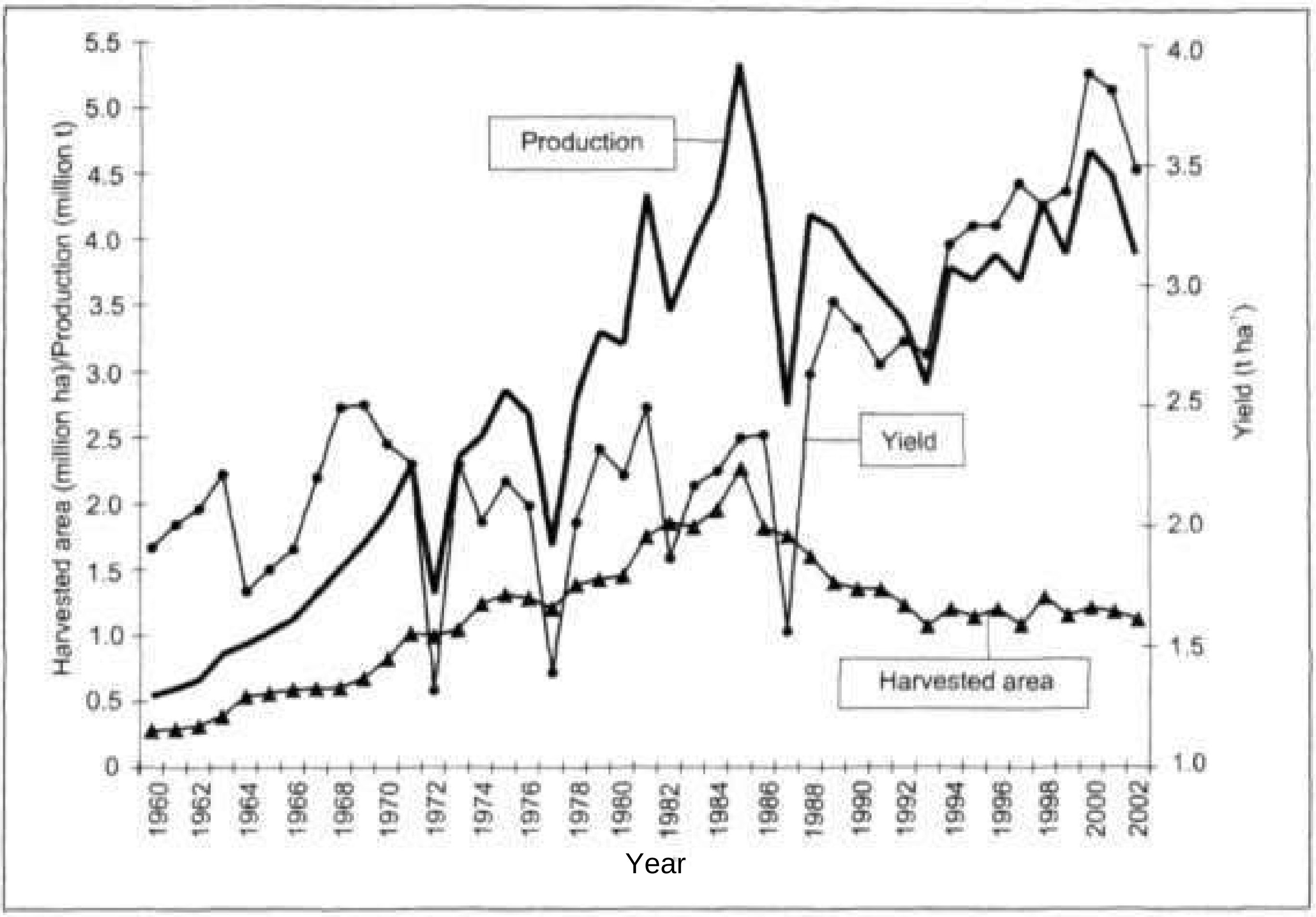

Figure 4. Harvested area, production and yield of maize in Thailand, 1960 to 2002. (Source: USDA 2003.)

The challenge is how to utilize the 1 million ha old maize areas for feed grain production again. Most of these areas were natural rain forests where farmers, after deforestation, had exploited virgin soil fertility and good rainfall for maize cultivation with profitable yields in the past several decades. Consequently these lands became depleted in soil fertility and moisture and were unsuitable for growing more profitable maize crop. If suitable sorghum varieties with satisfactory economic returns to farmers could be developed for these marginal lands, at least 1-2 million t of feed grain could be produced to substitute for current maize imports.

On the contrary, the nation-wide sorghum production, meanwhile, was not significantly increased as compared to maize. Sorghum area was maximum in 1985/86 and reached only 280,000 ha; later, it drastically dropped down to the present level of 90,000 ha (Fig.5}.

The highest annual production of about 400,000 t also reduced to around 150,000 t despite the average yield increase from 1.25 to 1.75 t ha^{-1}. The yield improvement was attributable to improved varieties from public institutions and commercial hybrids from private seed companies.

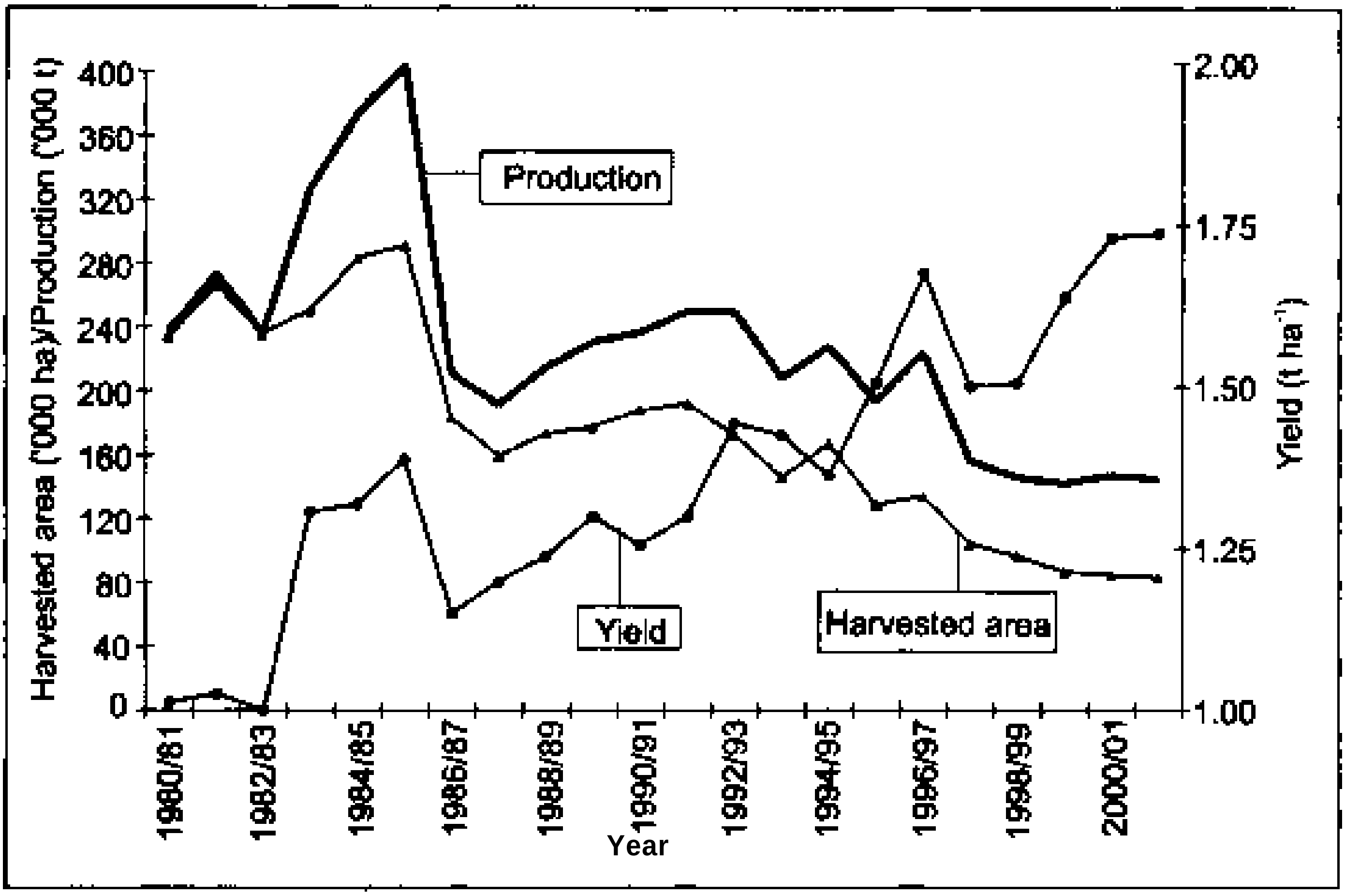

Figure 5. Harvested area, production and yield of sorghum in Thailand, 1968 to 2002. (Source: Ministry of Agriculture and Cooperatives 1960-2002.)

The following are some main facts attributable to the above sorghum phenomena:

- Most sorghums are planted as second crop after maize on uplands and depend only on residual moisture after maize harvest. The rest are grown as main crops in areas where seasonal rains are more irregular and risky for maize.
- The average yields of sorghum under above situations are consistently lower (about 50%) than those of maize under good condition and are not good choices when farmers have other alternatives.
- Farmers normally use less improved production inputs (ie, fertilizers and cultural practices) than used for maize to reduce the cost of sorghum production and make more profits.
- Price of sorghum grain is normally lower (about 10%) than that of maize.
- Farmers have more difficulties in handling sorghum crop production (ie, bird damage, drying and storage facilities). These problems often result in poor grain quality and field losses.

Feed grain development in Indonesia

Maize has long been a traditional food and feed crop in Indonesia. Since 1960 farmers had depended on unimproved local varieties with an average yield of about 1 t ha^{-1}. After the government's promotion on foreign investment for maize seed industry in 1981, not only high-yielding varieties and hybrids were commercially developed but also high quality seeds were made available to farmers on industrial scale (Boonsue 1988).

Consequently, maize production doubled in three decades from 3 million t in 1975 to more than 6 million t in 2002, while planting area remained almost the same at about 3 million ha (Fig.6). Obviously, the production increase was due mainly to the improved yields of new varieties and hybrids from both public and private seed enterprises.

Four distinct maize production systems in Indonesia are described by Mink (1984). The most common practice (55%) is monoculture of maize after maize for two or three crops per year by using short-season varieties. The second (24%) is a single maize crop per year, normally intercropped with upland rice *(Oryza sativa)* or cassava *(Manihot esculenta)* for the *tegal* (upland) areas. In

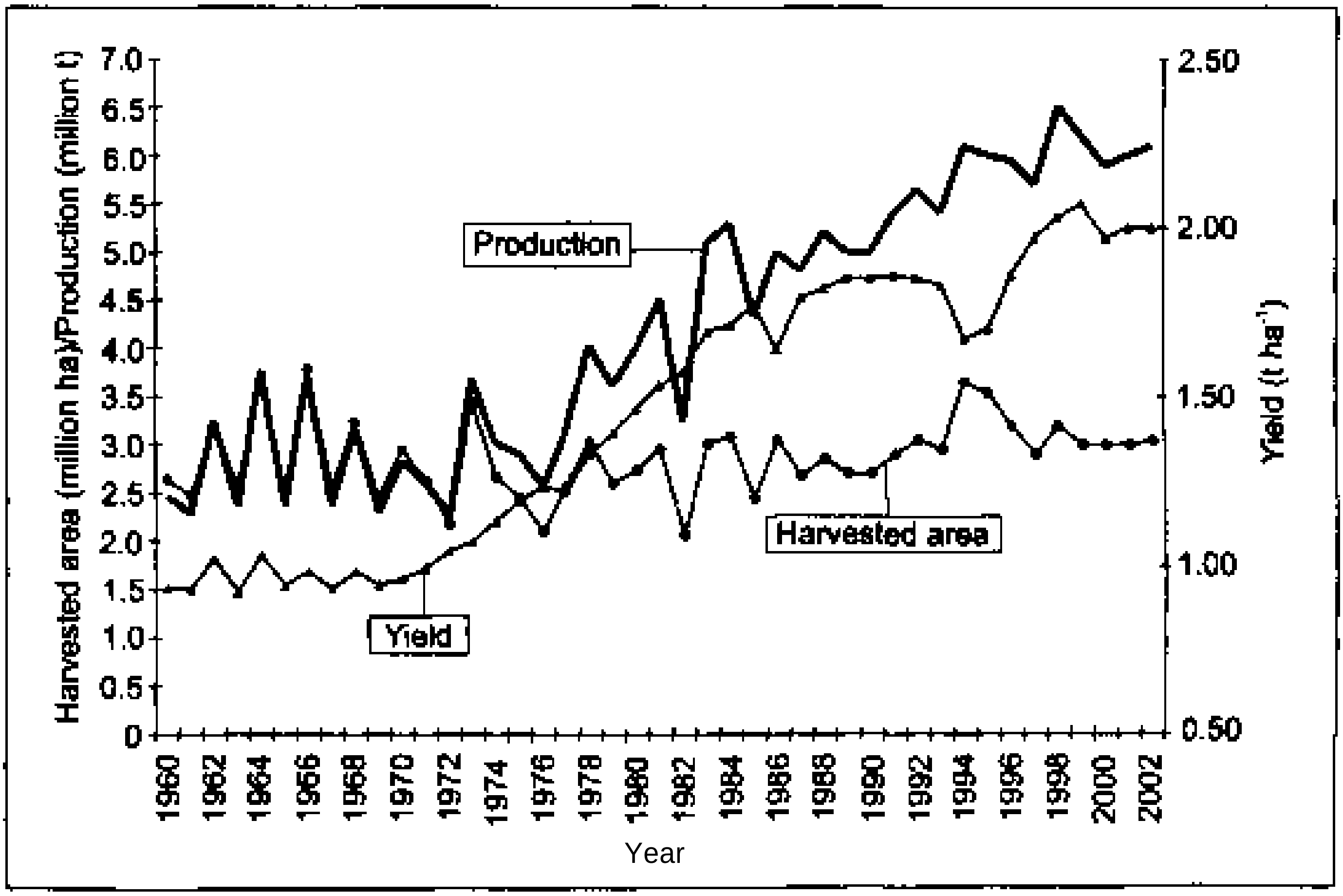

Figure 6. Production, harvested area and yield of maize in Indonesia, 1960 to 2002. (Source: USDA 2003.)

the third system (10%), early maize varieties, mostly intercropped with soybean (*Glycine max)* and mung bean *(Vigna radiata),* are planted either before or after rice for the rainfed *sawah* (lowland) areas. The fourth system (about 11%) is the most intensive production practice where medium to late varieties are cultivated under irrigated *sawah,* in one or two seasons after the main rice crop. The average yield is about twice the national average, due mainly to use of improved seed and cultural practices. Obviously most Indonesian maize production systems still depend on rainfed situations.

It is noted that maize is also used as human food in rural areas especially where rice is inadequate. Therefore, Indonesia has to depend on some imports to meet balance of the rising demand of feed consumption. In the last decade annual maize imports were close to 1 million t to meet the feed demand that rapidly increased from 1 million t in 1984 to more than 1 million t in 2002 (Fig.3).

Potential for more feed grain from sorghum

About 20 million ha of cultivated land is used for food crops in Indonesia, of which 5 million ha (25%) is irrigated and 15 million ha (75%) is rainfed (Table1). A conservative estimate of 10% (1.5 million ha) of the 15 million ha non-irrigated land being marginal for maize is quite plausible. If sorghum could be grown successfully on these risky areas, there would be at least 2-3 million t of additional feed grain for Indonesia. This amount could be used to substitute the current imported maize also.

Table 1. Cultivated land ('000) for food crops in Indonesia during 1999.

	Wetland					Dryland	
	Irrigated			Non-irrigated			
Island	Technical	Semi-technical	Non-technical	Rainfed	Valley	Garden/Dry field	Shifting cultivation
Java	1551	392	662	763	3	2862	231
Sumatra	296	282	499	585	274	3351	1646
Bali dan Nusa Tenggara	130	240	132	93	1	828	370
Kalimantan	25	30	185	348	334	933	808
Sulawesi	238	122	247	275	3	1162	577
Indonesia	2240	1067	1726	2064	614	9137	3631

Source. Central Bureau of Statistics (2002).

But how can such sorghum varieties or hybrids be developed, which could give competitive yields and incomes to farmers and fit in a sustainable production system as well? The chances of achieving these goals are quite high as given below:

- Our existing cultivated lands have been continuously threatened by environmental stresses, especially water shortages. We are looking for more drought tolerant crops to make these lands more productive.
- Commercially, sorghum is rather new in Indonesia and still not yet well known in feed industry.
- Sorghum, known as a highly drought tolerant crop among cereals under cultivation, has much more unexploited genetic diversity for improvement of various traits related to its adaptability to drought environments and other biotic hazards.
- About 75% of cultivated lands for food crops in Indonesia (15 million ha) are non-irrigated. There will be a big opportunity for sorghum research and development to make use of this crop to better fit in these crop lands.

Thus, there is plenty of room for sorghum improvement and its utilization as alternative feed grain in Southeast Asia, especially Thailand and Indonesia. The future challenge is its genetic improvement (for varieties and hybrids) to commercially fit in the existing areas defined as less-favorable environments (for maize) and traditional cropping systems of this wet tropical region.

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Potential for Sorghum Development in Indonesia

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Abstract

Sorghum area in Indonesia has been constantly decreasing since 1989 because the price of sorghum is lower than that of maize, no government program focuses on intensive cultivation of the crop and the grain is susceptible to storage insects. However, sorghum is a potential crop in drylands where maize frequently suffers from drought. Sorghum grain may be a substitute for maize in feed. Indonesia imports more than 1 million t of maize each year. There are large areas where the rainfall is less than 100 mm per month over a period of nine months. These areas are suitable for cultivation of sorghum. Sorghum grain can be used as food and the stover as feed. Sweet sorghum can be used as grain and also for production of sugar.

Sorghum *[Sorghum bicolor)* is a minor crop in Indonesia. It is cultivated in the provinces of Central Java, Yogyakarta, East Java, South Sulawesi, West and East Nusa Tenggara. The harvested area of sorghum was about 63,400 ha with a production of 42,220 t in 1982; the area decreased continuously until 1987 and increased slightly in 1988 and 1989 (Table1). A similar trend was also noticed in East Java (Table 2), wherein the sorghum area reduced from 5538 ha in 1989 to 1843 ha in 2000. Since sorghum is normally grown by farmers in drought-prone marginal lands without fertilizer, the grain yields are low. In drylands, sorghum is intercropped with upland rice or other crops. Sorghum is grown after rice *(Oryza sativa)* or maize *(Zea mays)* in lowlands (rice-rice-sorghum, rice-maize-sorghum and rice-sorghum) (Rusmarkam and Subandi 1996). In West Timor, some farmers sow sorghum with maize and foxtail millet *(Setaria italica).* According to the Agricultural Extension, Wonosari and Demak, Central Java, reduction in sorghum area is attributed to the following reasons:

- The government program is more concentrated in increasing rice and maize production.
- The decrease in price of sorghum as compared to maize after 1980s is high.
- Farmers have difficulties in sorghum processing.
- Sorghum grain is susceptible to storage insects.

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Table 1. Area, production and yield of sorghum in Indonesia.

Year	Area (ha)	Production (t)	Yield (t ha^{-1})
1980	38,900	42,900	1.10
1981	60,500	53,600	0.88
1982	63,400	42,220	0.66
1983	37,400	36,130	0.97
1984	23,900	28,810	1.20
1985	32,000	33,160	**1.04**
1986	19,500	26,100	**1.34**
1987	12,150	18,900	**1.56**
1988	22,008	34,900	**1.58**
1989	25,700	37,900	**1.47**

Source: BPS (1984,1989).

Table 2. Area, production and yield of sorghum in East Java.

Year	Area (ha)	Production (t)	Yield (t ha^{-1})
1988	4,849	10,202	2.10
1989	5,538	**11,949**	2.16
1990	5,052	**10,684**	2.11
1991	4,399	**9,473**	2.15
1992	6,405	**16,117**	2.52
1993	3,683	**8,428**	2.29
1994	3,368	**7,896**	2.34
1995	3,859	**8,875**	2.30
1996	3,609	**8,478**	2.35
1997	2,819	**6,979**	2.48
1998	2,239	**5,382**	2.40
1999	1,751	**4,257**	2.43
2000	1,843	**4,505**	2.44

Source: Agricultural Extension, East Java, 2001.

- The availability of an alternative and more profitable crop is common [eg, mung bean *(Vigna radiata)* - the price of seed is high and the crop matures within 2 months].
- Farmers' perception that rice and maize planted after sorghum need more fertilizers and the soil becomes compact.

Since mung bean is more profitable than sorghum and maize in Demak, farmers have recently changed the cropping pattern from rice-rice-sorghum to rice-rice-mung bean. Consequently, sorghum cultivation is negligible in this area contrary to the area of more than 10,000 ha planted in 1982.

Export of sorghum from Indonesia was lower than import (Table 3). Indonesia imports sorghum mainly from Australia for food industry.

Potential of sorghum for animal feed and fodder

Indonesia imports more than 1 million t of maize each year mainly for feed (Table 4). The demand for maize feed has consistently increased. During the dry season, there is shortage of animal fodder. Hence the price of maize stover is expensive. Consequently, fanners in some areas sell their cattle at low price due to severe shortage of fodder. Some farmers grow sorghum for forage mixed with maize and rice. Due to large number of animals in Indonesia (Table 5), feed and forage requirement is high.

Sorghum can be grown for feed to reduce maize import and develop animal husbandry. Sorghum and millet require less water than maize for their growth and development. The sorghum variety Badik produced 1.8 t ha^{-1}nder drought stress (Singgih and Marzuki 1996). Ismail and Ispandi (1996) reported

Table 3. Export, import and value of sorghum in Indonesia.

	Export		Import	
Year	Quantity (t)	Value (US$ '000)	Quantity (t)	Value (US$'000)
1987	-	-	27,136	3,059
1988	-	-	3,901	520
1989	455	48	-	-
1990	-	-	22,500	1,430
1991	-	-	-	-
1992	316	43	-	-
1993	318	25	430	64
1994	-	-	29,684	3,199
1995	540	79	6	32
1996	-	-	28,963	5,797
1997	-	-	-	-
1998	7	14	10	71
1999	-	-	-	-
2000	-	-	52	72
2001	-	-	70	76

Source: FAO (2003).

Table 4. Production, import and value of maize in Indonesia.

Year	Production (t)	Import (t)	Import value (US$ '000)
1997	8,770,851	1,098,354	171,675
1998	10,169,488	313,463	47,838
1999	9,204,036	618,060	80,320
2000	9,677,000	1,264,575	157,949
2001	9,165,317	1,035,797	125,512

Source: FAO (2003).

Table 5. Number of cattle and other animals in Indonesia during 1997-2001.

Animal	1997	1998	1999	2000	2001
Cattle (head)	11,938,856	11,633,876	11,275,703	11,641,876	11,191,376
Buffaloes (head)	3,064,532	2,829,291	2,503,788	2,405,277	2,287,212
Sheep (head)	7,697,690	7,144,003	7,225,690	7,426,992	7,294,000
Goats (head)	14,162,547	13,560,449	12,701,373	12,585,260	12,456,202
Pigs (head)	8,232,839	7,797,558	7,041,820	5,356,834	5,896,834
Chickens (1000)	972,832	645,518	622,531	859,497	853,832
Ducks (1000)	30,320	25,950	27,552	28,076	29,905
Horses (head)	582,284	566,485	484,285	517,333	430,000

Source: FAO (2003).

grain yield of 1.1 t ha^{-1} in local variety and 1.3 t ha^{-1} in UPCA SI (improved variety) in Lamongan, and 2.81 ha^{-1} in local variety and 3.91 ha^{-1} in UPCA SI in Bojonegoro, East Java when sorghum was grown without irrigation and fertilizer application after rice utilizing the residual soil moisture.

In Indonesia the percentage of agricultural land belonging to Oldeman D3-E3 agroclimatic zone is large (Table 6). In these areas, crops that follow rice are maize or legumes, but the grain yield of both maize and/or legumes are very low because of terminal drought. Under this condition, sorghum has the potential to yield higher than maize. In low rainfall areas like Sulawesi, Maluku, West and East Nusa Tenggara, sorghum is mixed with other crops and in this island animal husbandry is being practiced. Sorghum is suitable for these areas either as food or feed and stover for silage. Some areas of Java, which are classified under D3 and E3 climatic zones, are suitable for sorghum cultivation (Oldeman 1975). However, the price of sorghum grain will determine its competitiveness with maize. In some areas farmers utilize groundwater to cultivate maize and this increases the production cost. It may be profitable to cultivate sorghum as the price of sorghum grain is similar to that of maize.

Table 6. The percentage of agricultural areas in different climate zones of Indonesia having potential for sorghum and pearl millet cultivation.

Climate zone	Wet months[1]	Dry months[2]	Percentage of agricultural area (%)						
			Java	Sumatra	Kalimantan	Sulawesi	Maluku	Bali[3] (NTT and NTB)	Papua
C3	5-6	5-6	14	0	0	4	10	3	2
D1	3-4	<2	0	10	3	10	2	0	3
D2	3-4	2-4	5	2	1	8	5	0	14
D3	3-4	5-6	20	0	0	4	5	40	0
D4	3-4	>6	0	0	0	0	0	30	4
E1	<3	<2	0	-	5	12	5	0	0
E2	<3	2-4	0	2	1	11	5	0	0
E3	<3	5-6	9	0	0	4	5-10	5	0
E4	<3	>6	0	0	0	0	0	0	0

1. Rainfall >200 mm.
2. Rainfall < 100 mm.
3. NTT = East Nusa Tenggara; NTB = West Nusa Tenggara.

Source. Oldeman (1975), Oldeman and Syarifuddin (1977), Oldeman et al. (1979,1980).

Sweet sorghum

Sweet sorghum is comparable to sugarcane (*Saccharum officinarum)* for sugar content. Research has been conducted on identification of sorghum lines with high sugar content. In demonstration plots, the variety Rio produced 1.8 t grain ha^{-1}, 21.6 t stalk ha^{-1} and 2.2 t sugar (total sugar as invert) ha^{-1} in East Nusa Tenggara and 1.5 t grain ha^{-1}, 20.01 stalk ha"[1] and 2.5 t sugar ha^{-1} in West Nusa Tenggara (Directorate General Estate Crops 1996). Three varieties of sorghum had high brix content when harvested at 100 days after planting as shown in Table 7 (Sastrowijono 1996). Sweet sorghum juice is also used as a raw material for monosodium glutamate industry.

Table 7. Stalk yield, juice, brix and juice value of three varieties of sorghum harvested 100 days after planting.

Variety	Stalk yield (t ha^{-1})	Juice factor (%)	Brix (%)	Juice value (%)	TSAI[1] (%)
Rio	24.59	48	16.72	11.02	12.46
Roma	20.73	41	15.92	12.18	10.49
Ramada	20.02	43	15.27	11.14	9.74

1. TSAI = Total sugar as invert.
Source. Sastrowijono (1996).

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Forage Potential of Sorghum and Pearl Millet

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Abstract

Sorghum *and* Pennisetum *are two of the gifted genera of the tropical regions that provide food, feed, stover (dry straw) and fuel to millions of poor farmer families and their livestocks. Single-cut sorghum and multi-cut pearl millet varieties are also cultivated for green fodder (forage). In addition, the interspecific sorghum* x *sudangrass annual multi-cut hybrids are grown for green fodder. The interspecific pearl millet* x *napiergrass hybrids are perennial and yield green fodder throughout the year.*

Pearl millet uses less water per unit of forage production, tolerates both lower and higher soil pH and higher aluminium concentration, and is rich in minerals as compared to sorghum. However, sorghum has a wider range of adaptability and is more widely grown. Geographical preferences, limited market demand, variable prices, and lack of private industry and institutional research support have led to limited pearl millet forage research and cultivar adoption.

Forage quality is paramount to palatability or acceptability and animal intake. Plant morphology, anatomical components, digestibility, protein, mineral, cellulose and lignin contents, and anti-nutritional factors like hydrocyanic acid in sorghum and oxalic acid in pearl millet determine animal performance - milk and meat production.

Development of multi-cut annual forage sorghum and pearl millet hybrids rather than varieties could have a catalytic effect on forage yield and quality. Diversification of sorghum seed parents (white-grained rather than the currently used red-grained male steriles) and development of sudangrass pollinators with high sugar content and foliar disease resistance offer good opportunities for the exploitation of full potential of the interspecific hybrids. Crop scientists, chemical technologists, and animal health and nutrition experts have a role to play in good quality forage research and cultivar development. Inter-institutional partnerships could forge strong interlinks for strengthening sorghum and pearl millet forage research and development.

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3. ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
4. Proagro Seed Company Pvt Limited, 8-1-39, Tolichowki, Hyderabad 500 008, Andhra Pradesh, India.
5. Prabhat Agri Biotech (P) Limited, Panjagutta, Hyderabad 500 082, Andhra Pradesh, India.

Sorghum and *Pennisetum* are two of the gifted grass genera of the tropics. Each genus includes an important species used for food, feed, forage, fuel and as building material in many parts of the world, while the remaining, lesser known species in these genera are important forage producers. Sorghum (*Sorghum bicolor)* and pearl millet [*Pennisetum glaucum*) are usually grown for grain in areas where environmental conditions, especially rainfall, temperature and soil fertility are too harsh to grow maize (*Zea mays*) (Hanna and Cardona 2001). The dry fodder or stover is also used to feed animals.

Forage sorghums, by definition, include annual cultivars of sorghum and sorghum-sudangrass (S. *bicolor* x *S. sudanense)* hybrids. *Sorghum sudanense* is also grown for annual forage.

Forage *Pennisetum,* by convention, includes the annual pearl millet and the perennial napier-bajra *(P glaucum* X *P. purpureum)* hybrids. As an indispensable grain crop of the arid and semi-arid tropics, pearl millet provides both grain and stover. Dinanath grass (*P. pedicellatum)* is also cultivated for forage.

Adaptation

Both sorghum and pearl millet make efficient use of soil moisture by remaining semi-dormant during stress and responding rapidly to available moisture (Hanna and Cardona 2001). Drought tolerance capacity measured in terms of water-use efficiency of forage pearl millet (280 kg water kg^{-1} dry matter) is better than forage sorghum (310 kg water kg^{-1} dry matter) (Chapman and Carter 1976, de Lima 1998). Pearl millet produces more green and dry fodder yield than sorghum (Table 1) under limited moisture regimes (Singh et al. 1989).

Table 1. Response of different forage crops to irrigation regimes[1].

	Green fodder yield (t ha^{-1})			Dry fodder yield (t ha^{-1})		
Crop	0.25[2]	0.50	0.75	0.25	0.50	0.75
Sorghum	25.7	28.5	28.5	8.1	9.1	10.1
Pearl millet	33.4	32.7	34.7	9.5	10.8	11.4
Maize	38.6	41.7	42.5	8.4	9.2	10.6
Teosinte	37.1	40.0	39.2	7.5	8.0	9.0
Cowpea	19.4	23.3	22.6	4.1	4.9	4.7
Cluster bean	17.9	20.5	17.7	6.3	6.6	6.4

1. Mean response during summer, 1982 and 1983.
2. IW/CPE (irrigation water/cumulative pan evaporation) ratio.

Source: Singh et al. (1989).

Both sorghum and pearl millet make efficient use of soil fertility by producing higher biomass, and thus take advantage of the growing conditions. Pearl millet roots tolerate lower soil pH and higher Al^{+3} concentration than those of sorghum (Ahlrichs et al. 1991). However, pearl millet does not tolerate waterlogged soils. Sorghum has a wider range of adaptability than pearl millet (Hanna and Cardona 2001). Forage sorghum is recommended for both calcareous and saline soils, while forage pearl millet grows well in calcareous soils (ICAR 1989).

Fodder production

Traditional areas for stover production

Sorghum is the third most important grain crop in India, next only to rice (*Oryza sativa)* and wheat (*Triticum aestivum).* Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh and Rajasthan are the principal sorghum-growing states of India (Table 2). They account for 88.5% of total sorghum area (10.75 million ha), producing an estimated 88.7% of stover (22.52 million t).

Pearl millet is the fourth most important grain crop in India. It is used as a dual-purpose annual crop mainly in the drier areas of the arid and semi-arid tropics. Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana are the principal pearl millet-growing states in the rainy season (Table 2). They account for 90.7% of total pearl millet area in the country (9.43 million t ha), producing on an average an estimated 90% of 14.76 million t of stover.

Non-traditional areas for forage production

Statistics on sorghum forage area or forage production are not available. But private seed industry produced 36,600 t of sorghum-sudangrass hybrid seed during 2002-03 for supply in packages of 1, 3 and 5 kg. Estimated at 20 kg ha"^{1}, 36,600 t should cover an area of 1.8 million ha which should yield about 90 million t of green fodder or forage. Almost all grain sorghum cultivating states grow forage sorghum varieties, and/or sorghum-sudangrass hybrids during rainy season as well as hot dry (summer) season. Forage sorghums are principally cultivated in Punjab, Haryana, Delhi, western and central Uttar Pradesh and adjoining areas of Madhya Pradesh. Other forage sorghums include sudangrass for which area estimates are not available.

Table 2. Area and production of sorghum and pearl millet grain and stover in India, 1995-2000.

State	Area (million ha)	Grain (million t)	Stover[1] (million t)
Sorghum			
Maharashtra	5.33	4.82	12.05
Karnataka	1.95	1.67	4.17
Madhya Pradesh	0.85	0.73	1.82
Andhra Pradesh	0.81	0.57	1.42
Rajasthan	0.57	0.21	0.52
Tamil Nadu	0.40	0.38	0.95
Uttar Pradesh	0.39	0.34	0.85
Gujarat	0.28	0.25	0.62
India	10.75	9.01	22.52
Pearl millet			
Rajasthan	4.35	1.78	3.92
Maharashtra	1.75	1.29	2.84
Gujarat	1.05	1.21	2.67
Uttar Pradesh	0.83	1.07	2.35
Haryana	0.57	0.57	1.25
Karnataka	0.38	0.24	0.53
Tamil Nadu	0.21	0.27	0.59
Madhya Pradesh	0.14	0.13	0.29
Andhra Pradesh	0.12	0.10	0.22
Other states	0.03	0.03	0.07
India	9.43	6.71	14.76

1. Estimated from harvest index.
Source: NRCS (2001), Bhatnagar (2003).

Pearl millet is cultivated for forage, but no estimates of either the forage pearl millet area or production are available. While forage hybrids are not produced, no statistics of seed production of forage varieties are available. Considerable scope, therefore, exists for the development of high-yielding and high quality forage hybrids and varieties of pearl millet. Only a few states grow forage pearl millet in summer season: Gujarat, Uttar Pradesh, Uttaranchal, Madhya Pradesh, Haryana and Rajasthan.

Interspecific hybrids of *napier-bajra,* a perennial forage crop, are planted throughout the country for which no statistics are available. Other forages like *P purpureum* and *P pedicellatum* are also grown, but area statistics are not available.

Silage production

Although sorghum (Kalton 1988) and pearl millet (de Andrade and de Andrade 1982) are excellent for producing silage, particularly in regions with dry spells during the rainy season, pearl millet can produce higher silage yields with higher protein than sorghum (Table 3).

Forage quality

Some of the constituents that affect palatability or acceptability and animal performance include protein and lignin content, lignin type and chemistry, mineral content, plant morphology, anti-nutritional components such as hydrocyanic acid (HCN), anatomical components and forage digestibility (Hanna 1993). Preliminary studies indicate that pearl millet forage is more succulent and has higher crude protein (CP) than sorghum or maize with other chemical constituents being comparable (Table 4). The CP in pearl millet stover is less than in sorghum but more than in wheat and rice straw (Table 5). The dry matter and cell wall digestibility of pearl millet stover is also less than that of sorghum. Pearl millet does not contain HCN but contains oxalic acid, an anti-nutritional component that can have adverse effect on milk production and milk fat in cows (Hanna and Gupta 1999).

Lignin concentrations in brown-midrib (bmr) mutants are consistently lower than their normal counterparts in both sorghum (by 21.8%) and pearl millet (by 20%) (Cherney et al. 1988). The in vitro digestibility of *bmr* sorghum (642 g kg^{-1} dry matter) and pearl millet (726 g kg^{-1} dry matter) are higher than the normal genotypes of sorghum (568 g kg^{-1} dry matter) and pearl millet (659 g kg"^{1} dry matter). Most digestible and partially digestible tissues in both sorghum leaves and pearl millet stems are degraded by fiber-digesting

Table 3. Silage production and quality of sorghum, pearl millet and maize.

				Silage quality	
Crop	Silage yield (t ha^{-1})	Dry matter yield (t ha^{-1})	Dry matter (%)	Crude protein (%)	IVDMD[1] (%)
Sorghum	19.2	5.76	30	7.0	58.0
Pearl millet	31.0	8.68	28	12.0	53.4
Maize	27.0	8.10	30	7.8	60.0

1. IVDMD = In vitro dry matter digestibility.
Source: Kichel et al. (1999).

Table 4. Chemical composition (% of dry matter) of pearl millet, sorghum and maize forages.

Constituent	Pearl millet	Sorghum	Maize
Crude protein	8.2	5.9	6.7
Dry matter	19.5	31.6	28.8
Neutral detergent fiber	67.9	70.7	66.4
Acid detergent fiber	38.3	44.4	38.5
- Lignin	7.8	7.6	6.8
- Cellulose	27.7	34.6	28.6
- Silica	2.8	2.2	3.1
Hemicellulose	29.6	26.3	27.9
Cell content	32.1	29.3	33.6

Source: Singh etal. (1977).

Table 5. Chemical composition and in vitro nutrient digestibility (% of dry matter) of pearl millet and sorghum stover compared to other cereals.

Constituent	Pearl millet	Sorghum	Rice	Wheat
Crude protein	3.2	4.3	2.1	2.6
Neutral detergent fiber	79.5	79.5	74.7	76.2
Acid detergent fiber	55.6	54.2	53.6	51.8
- Lignin	12.8	9.0	8.2	9.7
- Cellulose	39.4	41.0	37.0	36.3
- Silica	3.4	4.2	8.4	5.8
Hemicellulose	23.9	25.5	21.1	24.4
Cell content	20.5	20.3	25.3	23.8
In vitro dry matter digestibility	48.9	53.3	51.4	51.9
In vitro cell wall digestibility	35.7	41.2	31.2	36.9

Source: Singh et al. (1977).

bacteria to a greater extent in *bmr* mutants than in normal genotypes. Geneticists are now attempting to incorporate the *bmr* trait into a range of backgrounds in sorghum and pearl millet (Cherney et al. 1991).

Genetic variability

Success in crop improvement depends largely on the extent of desirable genetic variability available for selection. Therefore, collection, evaluation, documentation, utilization and conservation of genetic resources assume considerable significance.

Sorghum

The National Bureau of Plant Genetic Resources (NBPGR) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India evaluated 1500 accessions from global collection for forage yield and its components under different agroclimatic conditions in India. The results indicated a wide range of variability for forage yield and its component traits (Table 6) besides a few quality traits like stalk juiciness and midrib color, suggesting ample scope for genetic enhancement of forage potential of sorghum.

Sorghum improvement at ICRISAT has developed a diversified set of hybrid parents, and grain and dual-purpose varieties. A population improvement program has developed sorghum lines with brown-midrib (*bmr),* high stem sugar, and grain yield that tiller under stress conditions, such as drought and stem borer infestation (Reddy et al. 1994). Mass selection for *bmr* gene, tillering, and high grain and biomass yield has produced pure lines which have four to five tillers. These lines were evaluated along with male-sterile lines, restorers and varieties at Patancheru (Table 7). Results indicate that high-tillering varieties combined high forage yield with high stem sugar and good ratoonability

Table 6. Estimates of some quantitative traits of 1500 selected world collections of sorghum during rainy season 1986 in three locations in India.

Character	Range[1]	Mean±SE Delhi	Mean±SE Jhansi	Mean±SE Akola
Plant height (cm)	38.0-373	144.8 + 1.14	206.5 ± 1.54	133.0 ± 1.23
Stem thickness (cm)	1.2-11.60	4.84 ± 0.038	4.34 ± 0.036	-
Number of leaves (on main stem)	4.0-25.90	11.23 ± 0.072	13.65 ± 0.086	9.51± 0.067
Length of 5th leaf (cm)	14.0-118.50	51.10 + 0.301	67.05 ± 0.452	55.022 ± 0.395
Width of 5th leaf (cm)	1.4-11.00	5.41 ± 0.04	5.79 ± 0.039	6.12 ± 0.052
Basal tillering	-	-	1.025 ± 0.007	-
Culm branching	-	-	0.733 ± 0.029	-
No. of nodes on main stem	3.00-19.30	9.30 ± 0.069	-	-
Days to 50% flowering	41.0-191.00	91.40 ± 0.57	102.79 ± 0.87	100.83 ± 0.50
Total leaf area (cm^2) on main stem	-	-	-	2517.13 ± 51.82
Forage yield ($kg\ m^{-2}$)	0.40-9.88	-	1.79 ± 0.025	-

1. Across three locations.
Source: Mathur et al. (1991).

Table 7. Performance of the selected sorghum breeding lines for grain yield, fodder yield and quality attributes at ICRISAT, Patancheru, India during rainy season 2002.

Breeding material	Stem sugar[1] (%)	Fresh fodder yield (t ha^{-1})	Grain yield (t ha^{-1})	Ratooning ability (%)	Best lines for stem sugar
Hybrid seed parents	14-18	17-35	0.8-3.3	36-81	ICSB 472 (17.9%), ICSB 401 (16.3%), ICSB 405 (16.1%), ICSB 731 (15.9%)
Varietal/restorer lines	13-20	26-46	0.6-4.5	15-77	GD 65003 (20%), Entry #64 DTN (19.7%), GD 65080 (19%), ICSV 96143 (18.1%)
Dual-purpose varieties	14-20	28-40	0.1-2.8	19-79	S 35 (19.6%), GD 65179 (18.5%), FM 345 (17.5%), GD 65122 (17.3%)
High-tillering varieties	13-21	23-52	0.3-1.9	34-95	FM 48 (20.7%), GD 65174-1 (18.3%), GD 65239 (18.1%), FM 665 (18%)

1. As % on fresh stalk basis = 0.1516 x 0.8746 brix degrees.

Pearl millet

ICRISAT has assembled more than 21,000 accessions of pearl millet consisting of landraces and breeders' products. Evaluations by NBPGR and ICRISAT covering large number of accessions from many countries revealed considerable variability for various fodder components such as plant height (49 - 443.3 cm), number of tillers $plant^{-1}$ (1-9.3), stem thickness (6-31.2 mm), number of leaves (4.3-37), leaf length (19.3-130 cm) and leaf width (1.1-8.6 cm) (Table 8). Gupta (1969) observed considerable variability for desirable fodder quality components such as protein, phosphorus (P), calcium (Ca) and anti-nutritional factors like oxalic acid in a sample of world collections of pearl millet.

Cultivar options

Forage hybrids and varieties of sorghum (Table 9) and pearl millet (Table 10) are popular with the farmers. Until 2000, 53 varieties and hybrids of forage sorghum comprising 40 single-cut and 13 multi-cut types were released in India (Table 11). They include 37 single-cut and 6 multi-cut forage sorghum varieties, 3 single-cut forage sorghum hybrids, 5 sorghum-sudangrass hybrids,

Table 8. Variability for forage components in a sample of world collection of pearl millet, at NBPGR, Issapur, New Delhi, India.

	1987[1]		1988[2]	
Trait	Range	Mean ± SE	Range	Mean ± SE
Days to 50% flowering	34.0-119.0	76±0.41	34.0-136	75±0.38
Plant height (cm)	49.0-367.0	215 ± 0.92	95.6 - 43.3	273.5±0.98
Number of tillers plant[1]	1.0-9.3	2.3±0.02	1.0-9.0	2.1±0.03
Number of productive tillers	1.0-6.0	1.7±0.01	1.0-8.6	1.6±0.02
Stem thickness (mm)	6.0-30.8	19.2±0.07	9.5-31.2	15.3±0.01
Number of nodes	-	-	5.3-37.0	13.5±0.07
Internode length (cm)	3.5-26.3	15.4±0.07	4.0 - 39.0	19.5±0.09
Number of leaves	5.7-22.3	12.6±0.05	4.3-37.0	13.8±0.07
Leaf length (cm)	22.3-130.0	68.9±0.33	19.3-126.3	75.2±0.35
Leaf width (cm)	1.7-8.5	3.6±0.02	1.1-8.6	4.3±0.02
Ear exsertion (cm)	0.0-16.3	2.1 ± 0.06	0.0-43.0	3.1±0.11
Spike length (cm)	8.8-85.3	27.5±0.23	10.0-78.3	24.2 ± 0.18
Spike thickness (mm)	5.7-47.8	20.6±0.10	10.8-47.7	20.2±0.01
1000-seed mass (g)	2.5-19.3	8.6±0.06	-	-

1. Based on 1938 accessions from world collections.
2. Based on 2458 accessions from world collections.

Source: Mathur et al. (1993a, 1993b).

1 multi-cut sudangrass variety and 1 multi-cut sudangrass hybrid. Compared to forage sorghum, only 10 pearl millet cultivars including 1 multi-cut variety and 3 hybrids have been recommended for forage cultivation. Eleven napier-*bajra* hybrids are available for perennial forage cultivation. While there is a great demand for sorghum-sudangrass forage hybrids, the non-availability and need for multi-cut sorghum hybrids has been long recognized. Efforts are also required to develop multi-cut forage pearl millet cultivars (both varieties and hybrids). During rainy season, a successful harvest fills granaries, and provides stover, while failed harvests assure forage at least.

Varieties

Both sorghum and pearl millet are grown during rainy season (June to September), while only sorghum is cultivated during postrainy season (October to March). A choice of landraces and improved cultivars are available for rainy season, but only a single variety of sorghum (Maldandi) dominates during postrainy season. Forage sorghum and pearl millet are grown

Table 9. Product and cultivar preferences of sorghum in India[1].

State	Season	Product			Cultivar	
		Grain	Stover	Forage	Grain	Forage
Maharashtra	Rainy	P	P	S	H>V	V
	Postrainy	P	P	-	V	_
	Summer	-	-	P	H	H+V
Karnataka	Rainy	P	P	S	H>V	V
	Postrainy	P	P	-	V	-
	Summer	-	-	P	H	H+V
Madhya Pradesh	Rainy	P	P	P	H>V	V
	Summer	-	-	P	-	H+V
Andhra Pradesh	Rainy	P	P	-	H>V	-
	Postrainy	P	S	-	V	-
	Summer	-	-	s	-	H+V
Rajasthan	Rainy	P	P	p	H	V
	Summer	-	-	p	-	H
Tamil Nadu	Rainy	P	P	-	H	-
	Postrainy	P	s	-	V	-
	Summer	-	_	s	-	H
Uttar Pradesh	Rainy	S	p	p	H	H+V
	Summer	-	-	p	-	H+V
Gujarat	Rainy	P	p	p	H	V
	Summer	-	-	p	-	H
Punjab	Rainy	-	-	p	-	H>V
	Summer	-	-	p	-	H>V
Haryana	Rainy	-	-	p	-	H>V
	Summer	-	-	p	-	H>V

1. P = Primary importance; S = Secondary importance; H = Hybrid; V = Variety.

during summer season (March to June). High density cultivation of landraces offers a single-cut, and staggered plantings ensure continuous supply of fodder during the off-season. On the other hand, improved varieties are amenable for multi-cut and management practices. Again, many sorghum varieties are available for forage, but the choice is limited for pearl millet - a single variety of pearl millet (Rajko) dominates the multi-cut forage scenario.

Intra-specific hybrids

Covering 54.8% of cultivated sorghum and 53.3% of pearl millet, high-yielding grain hybrids and varieties provide grain and stover during rainy

Table 10. Product requirement and cultivar types of pearl millet in India[1].

		Product			Cultivar	
State	Season	Grain	Stover	Forage	Grain	Forage
Rajasthan	Rainy	P	P	-	H<V	-
	Summer	P	-	P	H	V
Maharashtra	Rainy	P	S	-	H>V	-
	Summer	P	-	-	H	-
Gujarat	Rainy	P	s	-	H	-
	Summer	P	s	P	H	V
Uttar Pradesh	Rainy	P	p	-	H>V	V
	Summer	-	-	P	-	V
Haryana	Rainy	P	p	-	H>V	V
	Summer	-	-	P	-	V
Karnataka	Rainy	P	s	-	H	-
Madhya Pradesh	Rainy	P	p	-	H>V	V
	Summer	-	-	P	-	V
Tamil Nadu	Rainy	P	p	-	H	-
Andhra Pradesh	Rainy	P	p	-	H>V	-

1. P = Primary importance; S = Secondary importance; H = Hybrid; V = Variety.

season. Dual-purpose hybrids of sorghum (Madhya Pradesh and Uttar Pradesh) and pearl millet (Rajasthan, Uttar Pradesh and Tamil Nadu) are preferred in some states of India. During summer, parts of Gujarat grow dual-purpose pearl millet hybrids, while parts of Maharashtra and Rajasthan go for grain hybrids.

Multi-cut forage hybrids of sorghum are grown during summer, but not pearl millet multi-cut hybrids. There are indications of the possibility of producing topcross forage hybrids that are comparable in forage yield to sorghum-sudangrass hybrids.

Interspecific hybrids

Unlike sorghum, sorghum-sudangrass hybrids tiller profusely, produce succulent stems, have high leaf to stem ratio, re-grow quickly, withstand multi-cuts, and are low in HCN and tannins. Single and three-way interspecific hybrids have been developed in both public and private sectors. However, three-way cross hybrids are predominantly cultivated because private seed industry produces and supplies the hybrid seed. Red-grained

Table 11. Released varieties and hybrids of forage sorghum and pearl millet in India, 1973-2000.

Crop/Type	Single-cut	Multi-cut
Forage sorghum		
Varieties	JS 263, JS 291, JC 6, JC 69, J Set 3, JJ 4, Pusa Chari 1, Pusa Chari 6, Pant Chari 3, Pant Chari 4, Pant Chari 5, HC 6, HC 136, HC 171, HC 260, HC 308, SL 44, CSV 13, CSV 14R, SPV 669,SSV 74, K7, CO 8, Jumbo, Speed Feed, UP Chari 1, UP Chari 2, GFS 3, GFS 4, GJ 37, GJ 40, RSLG 262, Improved Ramkel, Parbhani Sweta, Rajasthan Chari 1, Rajasthan Chari *2,* Rajasthan Chari 3	MP Chari, Pusa Chari 9, Pusa Chari 23, Ruchira, CO 27, DFJ 1
Hybrids	COH 4, PCH 106, CSH 13	-
Sorghum-sudangrass		
Hybrids		Proagro 988, MFSH 3, GFSH 1, Hara Sona, Safed Moti Hybrid
Sudangrass		
Varieties	-	SSG 59-3
Hybrids	-	Punjab Sudax Hybrid Chari 1
Pearl millet		
Varieties	Giant Bajra, PCB 15, PCB 141, Raj *Bajra* Chari 2, AFB 2, CO 8	DFB-1
Hybrids	FMH 3, GHB 15, GHB 235	-
Napier x *bajra* hybrid		
Hybrid		NB 21, NB 37, CO 1, CO 2, CO 3, PBN 83, PBN 233, Pusa Giant, Yashwant, Annapurna, Swetika

three-way sorghum-sudangrass hybrids are cultivated, though there is no difference between white- and red-grained sorghum forage hybrids.

Round-the-year supply of green fodder paved the way for developing perennial napier-bajra hybrids in India. The napier-bajra hybrids combine quick re-growth, non-hairiness, narrow long leaves, thin stems, high leaf-stem ratio, high forage quality, low oxalic acid and high forage yield. Above all, *napier-bajra* hybrids can be grown on a wide variety of soil types, and in mixed, relay and intercropping systems.

Genetic enhancement of forage yield and quality

Forage yield improvement

Breeding becomes simpler when the relevant component characters are identified, inheritance patterns understood and effective breeding method(s) are chosen. Khairwal and Singh (1999) reviewed inheritance, heritability, correlations, and general and specific combining ability effects of several economic traits in pearl millet. Tiller number and stem girth were positively related with plant height, indicating that indirect selection could be effective in increasing forage yield. Dry fodder yield is positively correlated with grain yield, indicating that simultaneous selection could be effective. Resistance to rust, a foliar disease, is negatively correlated with green and dry fodder yield which augurs well for improving forage quality. Several forage-related characters like plant height, tiller number, internode number, biomass and growth index are under additive and non-additive genetic control. Also several forage-related traits like quick regeneration, tillering, plant height, thin stems and non-hairy leaves appear to be under Mendelian inheritance. Genetic improvement of forage yield and quality should, therefore, be possible through conventional inbred line development, testing for combining ability, identifying fertility-sterility reaction, developing male-steriles, and breeding varieties and hybrids.

Forage quality improvement

Quantitative traits

The primary objectives of forage quality improvement are to increase feed intake and digestibility, and reduce anti-nutritional attributes (Smith et al. 1997). In vitro dry matter digestibility (IVDMD) is under genetic control and is correlated with CP, neutral detergent fiber (NDF), acid detergent fiber (ADF) and water-soluble carbohydrates (WSC). Recurrent and divergent selections have been extensively used to improve IVDMD through decreasing cell wall concentration [measured by NDF, more recently by in vitro fiber digestibility (IVFD)], reducing lignin concentration (measured by ADF), increasing ready energy (measured by WSC) and/or increasing CP. A great deal of forage quality research is being done in other crops which could be adapted to design forage sorghum and pearl millet quality research relevant to the semi-arid tropics.

Divergent selection for IVDMD has been reported to result in 1.0 to 4.7% gains per year in several species including grasses and legumes (Casler 2000), suggesting that rapid genetic progress for IVDMD is possible. Divergent selection for IVDMD did not result in correlated response for in vitro digestibility of fiber in smooth bromegrass (*Bromus* sp) (Casler 1987) or in vitro digestibility of cell wall polysaccharides in alfalfa (*Medicago sativa;* lucerne) (Jung et al. 1994). Divergent selection for CP increased IVDMD in timothy (*Phleum pratense;* herd grass) (Suprenant et al. 1990). Divergent selection for Kalson lignin (KL) with high or low EthFA (etherified ferulic acid) revealed that both reduce IVFD, but are independent of each other (Casler and Jung 1999).

Recurrent selection for dry matter disappearance in *Cynodon dactylon* through in situ nylon-bag dry matter digestibility (NBDMD) revealed an average genetic gain of 2 g kg^{-1} yr^{-1} between 1963 and 1993 (Hill et al. 1993). Recurrent selection for combining low ADF and high CP in alfalfa decreased ADF and NDF, and increased CP, IVDMD and IVFD (Vaughn et al. 1990).

Selection for WSC in perennial rye grass (*Secale cereale)* revealed greater genetic variation for WSC than for IVDMD, and large non-additive component and positive correlation with IVDMD than for forage yield (Humphreys 1989a, 1989b).

Selection for increased CP led to correlated response for increased digestibility (Suprenant et al. 1990). Genetic progress for increased CP has been documented in several species (Casler 2000). Traditional breeding methods may be useful in improving protein quality; improving degradable proteins is easier and less expensive than non-degradable proteins.

Qualitative traits

While several forage yield and quality traits are under polygenic control and quantitatively inherited, few genes with large and direct effects (oligogenes) could be effectively used to improve forage quality, albeit indirectly. Such material could be exploited through pure line, pedigree and backcross breeding or through population improvement.

Dwarfing genes. Dwarfing genes have been isolated in sorghum and pearl millet. Dwarfing genes are recessive. They shorten the internode length and increase the leaf:stem ratio. Burton and Fortson (1966) isolated d_1 and d_2 dwarfs, while Appa Rao et al. (1986) identified d_3 and d_4 dwarfs in pearl millet. Burton (1983) incorporated d_2 dwarfing gene into forage seed and pollen parents leading to the development of dwarf forage hybrids. This resulted in 11% increase in leafiness and 17-21% increase in IVDMD, but 30% decrease in forage yield (Burton et al. 1969). While forage pearl millets are used for grazing, and hay and silage production in USA and elsewhere, they are chaffed and fed to animals in India. Reducing plant stature would, therefore, adversely affect forage yields and commercialization of forage pearl millets in India. Therefore, attempts should be directed at developing semi-dwarf and normal height forage varieties and hybrids with better forage digestibility for wider acceptability.

Trichomeless gene. Genes that affect leaf surface and epidermal features may also affect forage quality. Trichomeless gene in pearl millet increases palatability, but reduces digestibility of intact leaves (Burton et al. 1977). Bloomless gene in sorghum, on the other hand, increases digestibility of intact leaves (Cummins and Dobson 1972). Trichomeless is controlled by a recessive gene. But bloomless is controlled by two non-allelic recessive genes and sparse-bloom by three non-allelic recessive genes, segregating independently (Peterson et al. 1982). It should, therefore, be possible to transfer trichomeless and bloomless genes into elite lines through backcross breeding.

Stay-green genes. Whether grown for grain and stover (dual-purpose) or for forage, the incorporation of stay-green character is a boon for improving the quality of fodder. Stay-green character is governed by a recessive gene, which slows down senescence. Stay-green gene has a pleiotropic effect arresting the decline in protein content of the aging leaves (Humphreys 1994). Stay-green sorghum lines have been developed at ICRISAT through pedigree breeding.

Glossy genes. Appa Rao et al. (1987) identified three different non-allelic genes in pearl millet governing the glossiness of leaves. Seedling marker 'glossy' was found to be associated with shoot fly resistance and drought tolerance in sorghum.

Sweet stalks. The value of forage sorghum or pearl millet depends on the sugars left in the stover or accumulated in green forage. This is particularly true of pearl millet stover which has low feeding value and is considered inferior to that of sorghum and several other cereals. Considerable variation was observed for juiciness and sweetness of the stalks of sorghum and pearl millet in germplasm collections from Tamil Nadu (Appa Rao et al. 1982) and Rajasthan in India. Several Cameroon landraces of pearl millet also have sweet stalks. Brix varies from 3 to 16% (Harinarayana 1987). Pearl millet accessions from Tamil Nadu are late and tall, but could be used to improve stored energy of stover or green fodder. Sweetness is controlled by a single recessive gene in sorghum (Bangarwa et al. 1987).

Brown midrib genes. Lignins interfere with digestibility. Low lignin mutants offer an opportunity to increase the overall digestion of plant fiber which comprises 30-80% dry matter (Cherney et al. 1991). Low lignin mutants are characterized by brown midrib. There are four *bmr* loci in maize, one *bmr* locus in pearl millet and several *bmr* loci in sorghum and sudangrass (Cherney et al. 1991). Brown midrib loci have been reported to improve IVDMD by reducing lignin in sorghum stems by 51% and in leaves by 25% (Porter et al. 1978) and NDF concentration by 13% (Fritz et al. 1981). All *bmr* genes are recessive. Selection should, therefore, be done in selfed progenies of backcrosses where *bmr* genotype is the donor. At ICRISAT, several sorghum lines with high biomass were selected for *bmr* trait (Table 12).

WW Hanna, University of Georgia, Tifton, Georgia, USA (personal communication) has also developed several pearl millet forage seed and pollen parents incorporating the *bmr* gene. Low lignin lines with *bmr* gene have also been isolated at ICRISAT

Forage quality improvement through anti-nutritional attributes

Sorghum contains tannins, phenolics and HCN that affect forage quality adversely. Tannins in moderate quantities bind with the proteins and prevent bloating in animals, but when in excess, they lower CP and IVDMD. Tannins are negatively correlated with CP, IVDMD and ADF. Plants with tan plant color, which is controlled by a recessive gene, have low tannin (8%), while purple plants have 10 to 18% tannins (Gourley and Lusk 1978). Phenolics

Table 12. Characteristics of sorghum lines selected for dark midrib color at ICRISAT, Patancheru, India during rainy season 2002.

Cultivar	No. of entries	Midrib color[1]	Brix (%)	Days to 50% flowering	Plant height (m)	Agronomic desirability[2] (score)	Fresh fodder yield (t ha^{-1})	Grain yield (tha^{-1})	Head length (cm)
B-lines (white grain)									
ICSB 293	23	1.5	13.8	75	2.0	1.5	20.8	4.0	29.8
ICSB 301	31	1.0	14.3	77	1.7	2.5	15.2	3.2	30.5
ICSB 418	41	1.5	17.3	74	1.4	2.0	19.0	2.5	21.7
ICSB 472	46	1.5	20.3	81	2.1	1.5	27.4	2.5	14.4
ICSB 474	47	1.0	17.5	75	2.6	3.0	15.3	1.6	18.2
ICSB 507	54	1.5	15.5	80	1.7	2.5	24.5	2.0	23.8
ICSB 664	66	1.5	22.9	78	1.4	2.5	26.9	1.7	18.6
ICSB 702	71	1.5	13.8	75	1.8	2.0	23.7	3.4	28.0
ICSB 731	73	1.5	18.0	78	2.4	1.5	34.6	3.3	24.3
ICSB 765	80	1.5	17.0	69	1.4	2.5	15.1	2.3	21.0
B-lines (red grain)									
IS 10475B	47	1.5	13.8	62	1.1	3.0	9.8	2.9	29.8
Varieties (red grain)									
ICSV 96114	34	1.5	17.3	69	1.6	2.5	17.6	3.1	25.3
GD 65025	81	1.5	22.0	83	2.3	2.5	34.4	0.6	19.8

1. Score at harvest on a 1 to 5 scale where 1 = more brown and 5 = more white.
2. Score on a 1 to 5 scale where 1 = best and 5 = poor.

interfere with the digestion of structural carbohydrates and NDF (Reed et al. 1988). When absorbed into blood, HCN causes cellular asphyxiation and eventual death (Hoveland and Monson 1980). HCN is under genetic control of a major dominant gene, reinforced by multiple genes with additive effects (Duncan 1996). Pearl millet contains lignins that affect palatability and oxalic acid which affects digestibility.

Management factors

Improvement of forage productivity and quality is as much amenable to management as to genetics and breeding. Some of these management factors relate to cultural practices while others relate to applied nutrients. Effects of various management factors on sorghum crop residue have been summarized in a recent review (Reddy et al. 2003).

Cultural practices

Besides plant population and harvesting time, sowing time and irrigation have been found to have the greatest effects on fodder yield and quality. For instance, significant reduction in green fodder, dry matter content and CP yield was observed with delay in planting from 25 October to 25 November at Urulikanchan, India (Khandale and Relwani 1991). The effects of irrigation during summer on forage yields have been reported to be variable, depending on the genotype, soil type and potential evapotranspiration. Irrigation (7 cm) at different IW/CPE (irrigation water/cumulative pan evaporation) ratios of 0.25, 0.50 and 0.75 revealed that maize yielded the highest green fodder while pearl millet yielded the highest dry fodder when compared to sorghum, teosinte (*Euchlaena mexicana),* cowpea (*Vigna unguiculata)* and cluster bean (*Cyamopsis tetragonoloba)* at all irrigation regimes (Singh et al. 1989). But Singh and Singh (1986) reported that sorghum outyielded maize and pearl millet at IW/CPE ratios of 1.0, 0.6, 0.3 and 0.15.

It has also been observed that transplanted pearl millet produces more stover yield than direct-seeded crop, irrespective of the seedling age (Upadhyay et al. 2001). The response increased with increased nitrogen (N) (0 to 80 kg ha^{-1}) application (Singh 1985), but P had no effect (Upadhyay et al. 2001). Jayanna et al. (1986) observed that increased seed rate (20 to 40 kg ha^{1}) had no effect on tillering forage sorghum, but the green fodder yield increased with increasing seed rate in non- or low-tillering forage sorghums. Green fodder yield of pearl millet increased up to a seed rate of 12 kg ha^{-1}, after which it declined with increase in seed rate (Sharma et al. 1996). Pearl millet stover yield and plant height increased with increasing plant density (Singh 1985). Highest green fodder and dry matter yields were obtained when harvested at either 60 or 75 days after sowing (DAS) than at 45 DAS. However, opposite trend was observed with crude fiber (%) being lowest when harvested at 45 DAS (Ram and Singh 2001a, 2001b). Compared to single-cut, multi-cut pearl millet produced high forage yield coupled with good quality forage (Chauhan et al. 1990), though the magnitude varied from genotype to genotype (Table 13).

Table 13. Nutrient production (t ha[1]) of pearl millet as influenced by cutting.

	Single-cut				Multi-cut			
Component[1]	Comp 5	Comp 1	PHB 10	Mean	Comp 5	Comp 1	PHB 10	Mean
Green fodder	61.2	62.2	40.5	54.6	74.1	73.6	56.4	68.0
Dry fodder	9.7	10.1	7.4	9.1	15.5	14.7	11.8	14.0
DDM	5.7	5.5	3.9	5.0	9.1	8.1	6.1	7.8
Crude protein	0.80	0.79	0.55	0.71	1.28	1.16	0.87	1.10
DCP	0.45	0.40	0.26	0.37	0.72	0.59	0.41	0.57
TDN	5.4	5.3	3.8	4.8	8.6	7.7	6.0	7.4

1. DDM = Digestible dry matter; DCP = Digestible crude protein; TDN = Total digestible nutrients.
Source: Chauhan et al. (1990).

Intercropping of fodder sorghum with legumes such as cowpea, soybean *(Glycine max),* horse gram (*Dolichos uniflorus),* and velvet bean (*Mucuna deeringiana)* resulted in better green forage, dry matter and CP yields than fodder sorghum alone (Sood and Sharma 1992, Mishra et al. 1997, Ram and Singh 2001a, 2001b). Forage sorghum-chickpea (*Cicer arietinum)* produced highest green fodder under normal conditions, but under drought, pearl millet-pearl millet ratoon prevailed over sorghum + pigeonpea *(Cajanus cajan)*-fallow or pearl millet-safflower (*Carthamus tinctorius)* (Ali and Rawat 1986). Compared to sole crop, pearl millet mixed or intercropped with cowpea or soybean produced more *CP,* ether extract (EE), minerals, crude fiber and N-free extract (NFE) (Singh and Narwal 1987, Yadav and Sharma 1995).

Nutritional amendments

Nitrogen application has been found to have greatest effect on forage yield and quality. Several studies have shown that forage sorghum responded well to increased levels of N by producing significantly higher green forage, dry matter content and CP (Patel et al. 1992, Sood and Sharma 1992, Vashishatha and Dwivedi 1997, Ram and Singh 2001a, 2001b, Reddy et al. 2003). The response of fodder pearl millet was positive for forage production up to 120 kg N ha^{-1} (Randhawa et al. 1989, Sharma et al. 1996). Application of N also improved forage quality, CP, mineral matter, EE and NFE (Table 14). Increase in N application was also accompanied by increase in stover production, plant height and tillers $plant^{-1}$ (Singh 1985). But forage pearl millet following postrainy berseem (*Trifolium alexandrinum)* required less N application than pearl millet following wheat, oat (*Avena sativa)* or turnip *(Brassica rapa),*

Table 14. **Response of forage pearl millet to nitrogen application[1].**

Genotype/ Fertilizer	GFY (t ha^{1})	DFY (t ha^{1})	Plant height (cm)	No. of tillers m^{-1}	Leaf: stem ratio	Crude protein (%)	Mineral matter (%)	Ether extract (%)	Crude fiber (%)	NFE (%)
Genotype										
L72	51.1	9.6	241	19.3	0.66	7.0	9.4	1.45	26.5	56.3
C 5	58.3	17.6	266	19.6	0.54	6.6	7.8	1.34	32.1	53.6
PCB 15	53.6	10.0	248	18.3	0.62	7.2	10.0	1.30	9.2	52.9
CD at 5%	4.4	1.2	-	-	-	-	1.1	-	-	-
Nitrogen (kg ha^{-1})										
0	38.3	8.5	230	19.2	0.69	5.3	8.7	1.30	32.1	55.4
50	53.3	12.1	253	18.1	0.64	6.2	8.0	1.31	30.1	55.2
100	63.6	14.0	265	20.0	0.58	7.1	9.9	1.39	26.4	55.5
150	62.4	14.7	266	18.6	0.55	7.6	11.5	1.44	22.4	57.2
CD at 5%	5.1	1.4	-	-	-	-	1.28	-	-	-

1. GFY = Green fodder yield; DFY = Dry fodder yield; NFE = Nitrogen-free extract.
Source: Randhawa et al. (1989).

resulting in a saving of 50% N (Harika et al. 1986). Following the application of P, pearl millet produced more green and dry fodder yield than sorghum, maize, cowpea or cluster bean (Ram et al. 1988). Sulfur (S) application increased CP, sugars, methionine, cell contents, S:P ratio, and S:zinc ratio (Tripathi et al. 1992a) and decreased NDF, ADF, N:S ratio and Ca:P ratio up to 40 kg S ha^{-1} in forage sorghum (Tripathi et al. 1992b). Treatment of forage sorghum with *Azospirillum lipoferum* (Pahwa 1986) or with *Azotobacter* (Patel et al. 1992, Reddy et al. 2003) resulted in significant increase in dry matter production than without *Azospirillum* or *Azotobacter.* The rhizosphere was enriched with N, and resulted in a saving of 15 kg N ha^{-1}.

Commercialization potential

Economics of seed production

In India, forage sorghum-sudangrass seed is produced during the postrainy season, while grain/forage pearl millet seed is produced during the hot summer season. The chief seed production area is in Nizamabad district of Andhra Pradesh. Some seed production is also evident in Bellary district of Karnataka. Congenial climate, pest-free environment, assured irrigation and the desire to maximize economic returns have all contributed to successful seed production in Nizamabad.

A system of one-year rotation, rice-pearl millet in alluvial soils is followed. In the two-year rotation, first year sequence of maize-turmeric (*Curcuma domestica*) -pearl millet (seed crop) is followed by maize-forage sorghum (seed crop) during the second year. The intensive cropping, particularly seed production, ensures stability and high economic returns to the farmer. Forage sorghum as well as grain pearl millet acreage continue to spread following good monsoon, but tend to shrink following partial failure of monsoon.

Forage sorghum seed production is profitable with yields ranging from 2.5 to 4.0 t ha^{-1} under irrigation. Forage pearl millet seed production is small, compared to sorghum-sudangrass or grain pearl millet seed. Some case studies regarding forage pearl millet hybrids will provide an insight into profitability of seed production. Area planted to pearl millet seed fluctuates widely as water becomes more and more limiting. Secondly, compared to forage sorghum, the seed yields of forage pearl millet hybrids are significantly lower, and vary between 1.0 and 2.5 t ha^{-1}. Farmers undertake pearl millet seed production with the express understanding that it is a catch crop between postrainy season turmeric and rainy season maize/rice.

Seed trade

The sale price of forage sorghum-sudangrass fluctuates between Rs 15 kg^{-1} and Rs 20 kg^{-1} (US$0.25-0.45 kg^{-1}), depending on the market demand. Though the margin of profits is not substantial, the volume and the recurring demand sustain the interest of the seed industry. The recent entry of a large number of marginal traders has discouraged the registered seed industry. There is a need to curb unregistered trade firms not supported by scientific and technical personnel, and to encourage seed companies with research, production, processing and marketing support.

The sale price of Rs 30-50 kg^{-1} (US$0.70-1.10 kg^{-1}) of forage pearl millet hybrid seed is not attractive to the farmers in view of limited harvests (cuts) and low forage yield. Low seed yields, limited area and lack of recurring demand are discouraging the seed industry to venture into forage pearl millet research and development.

Future outlook

Any-time forage

Sorghum and pearl millet either alone or in mixed or intercropping system are cultivated for stover and forage. Sorghum stover scores over pearl millet, but forage pearl millet is rich in protein, Ca, P and minerals, and oxalic acid content is within safe limits. Being any time forage, pearl millet, unlike sorghum, can be grazed, or cut and fed at any growth stage. However, forage sorghum is more popular than forage pearl millet. Low green fodder yield, poor ratoonability (ability to regenerate), limited market demand, variable prices and lack of private industry support and research support have discouraged pearl millet as forage. Concerted efforts are, therefore, required to ameliorate this situation.

Geographical preferences

Sorghum and pearl millet green fodder is fed to ruminants in northern India, while stover is common in sorghum and pearl millet growing areas in southern India. Intensive cropping, short growing season, poor growth of perennial grasses during winter, nutritional quality and the need for continuous supply of green fodder created demand for forage sorghum and forage pearl millet in northern India. Sorghum varieties and sorghum-sudangrass hybrids are grown for forage in northern India while in southern India, perennial grasses are cultivated as annual forage is required for supply between harvests, and for supplementing the stover. Development of annual multi-cut high-yielding forage sorghum and pearl millet is needed to correct the regional imbalances.

Multi-cut varieties

To overcome limited ratoonability, forage sorghum and pearl millet varieties are repeatedly planted (staggered) for sustaining the green fodder supply chain. High plant density ensures high yields, thinner stems and more palatability. Efforts should, therefore, be directed at designing forage sorghum and forage pearl millet that tiller, grow tall and ensure multi-cuts.

Varietal choice

Many forage sorghum varieties are under cultivation, but there are very few forage pearl millet varieties. Recurring demand and/or volume turnover are product-driven, while public and private seed industry are market-driven. Development of multi-cut annual forage sorghum and pearl millet hybrids, rather than varieties, will be of interest to the seed industry. There is also scope for the development of intra- and interspecific forage hybrids.

Forage sorghum

Development of multi-cut, intra-specific, single-cross, white-grained forage hybrids would offer the widest choice for realizing forage potential of sorghum. These hybrids provide a better alternative to forage varieties grown during the rainy season. Diversification of interspecific, sorghum-sudangrass hybrids for increased productivity and nutritional quality also requires attention. Sorghum-sudangrass three-way hybrids are by far the most popular forage hybrids, and are based on red-grained sorghum male-sterile lines. Limited variability in red-grained sorghum seed parents, and sudangrass pollinators further impose restrictions on the exploitation of the interspecific forage hybrids. Focused efforts to improve the seed parents and pollinators for forage traits like high tillering, fast growth, stay-green and brown midrib characters, resistance to foliar diseases and stem borer, high stalk sugars, forage intake and digestibility in animals will add further diversity to the forage cultivar development. Large-seeded, red- or white-grained high-density panicles should be deployed in seed parents. The sudangrass pollinators can be improved for resistance to foliar diseases and high sugar content.

Forage pearl millet

Single-cut pearl millet varieties with limited forage potential of 30 t ha^{-1}, and 0.27 to 2.24 t day^{-1} ha^{-1} are currently dominating the forage market. Development of intra-specific forage hybrids that combine the ability for repeated harvests (multi-cuts), earliness to first harvest (cut), short harvesting intervals, quick regeneration, the built-in tillering potential, high green fodder yield, high quality factors and low anti-nutritional factors like oxalic acid and nitrates has tremendous opportunity to improve pearl millet as a forage crop. Efforts should also be directed at identifying seed parents for high seed yield. Alternatively, the feasibility of F_1 male sterile seed parents and three-way forage hybrids should be examined.

The interspecific *napier-bajra* hybrids give year round forage production. Improving the nutritional quality of pearl millet and napier grass could enhance opportunities for clonal selection. The hybrids of *P. glaucum* x *P. purpureum* x *P. squamulatum* developed by GW Burton, Agricultural

Research Station, Coastal Plain Experimental Station, Tifton, Georgia, USA and tested in India (Ramamurty and Shankar 1998) had shown promise for forage yield and quality among perennial grasses. Probably, such tri-species hybrids could be developed in sorghum as well!

Nutritional quality

Forage quality as determined by CP, IVDMD, NDF and ADF reflecting degradable and non-degradable proteins, structural and non-structural carbohydrates, lignin and celluloses, and anti-nutritional attributes such as HCN, oxalic acid, tannins and phenolics have received greater research attention elsewhere in the world, but not in the arid and semi-arid tropics. Forage quality research is complex, expensive and laboratory dependent calling for multidisciplinary approach and multi-institutional alliances.

Public-private partnerships

Inter-institutional partnerships involving international agricultural research centers (IARCs), national agricultural research systems (NARSs) and private agricultural research systems (PARSs) could forge strong interlinks for sustaining forage sorghum and pearl millet research. Crop scientists, chemical technologists, and animal health and nutrition experts have a role to play in the forage development scenario.

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Utilization of Fermented Moldy Sorghum as Cattle Feed

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Abstract

Sorghum is subjected to mold damage if rains continue during grain development, maturation and harvest. Mycotoxins such as aflatoxins and fumonisins are produced by some of the molds that are toxic to humans and animals. Various detoxification methods have been proposed. Among these, biotechnological means of detoxification is gaining significance in recent years. A study was carried out to identify a probiotic organism which can be used to detoxify moldy sorghum. The common homemade liquid cattle feed (kudithi) *was used as a source for isolation. A total of 11 isolates of* Lactobacillus *were tested for their ability to detoxify the moldy sorghum. One isolate was selected and used in fermentation of moldy sorghum. Fermentation of moldy sorghum by addition oj inoculum of* Lactobacillus *decreased aflatoxin B_1 and fumonisin from 42.4 ppb and 5 ppb, respectively to non-detectable level. Feeding trial of fermented moldy sorghum was carried out with the cooperation of farmers at the village level. The study indicated that the feed was acceptable to the animal, milk yield had increased and the farmers were willing to utilize the technology.*

Sorghum (*Sorghum bicolor)* grain is subjected to mold damage if rains continue during grain development, maturation and harvest [Williams and McDonald 1983). These molds have detrimental effects on yield and quality of sorghum grain that include decrease in nutritive value, production of mycotoxins and other secondary metabolites. Many species of *Fusarium* have been isolated from moldy sorghum and were found to produce T_2 toxin, deoxynivalenol and fumonisins (Rukmini and Bhat 1978, Bhat et al. 1997).

Consumption of food and feeds contaminated with these mycotoxins have resulted in food/feed-borne diseases in both human and animal populations (Vasanthi and Bhat 1998). Various detoxification methods have been proposed to combat mycotoxin in grains (Mishra and Chitrangada Das 2003). However, many of these treatments are based on chemical treatments that resulted in residual toxicity and not applicable at the household level. Recently biotechnological means of detoxification of mycotoxins in moldy grains is gaining significance as it does not leave any harmful residues

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(Karunaratne et al. 1990). Such methods are more relevant in India where people have been using biotechnological approaches in microbial fermentation for making products for consumption. A study was carried out to identify microorganisms that can ferment moldy sorghum and improve its nutritive value. The study has three components: (1) field survey; (2) laboratory experiment; and (3) operational research.

Field surveys

To find out a source of microorganism that can be utilized to ferment moldy sorghum, a survey was carried out in Kammala village in Nalgonda district, Andhra Pradesh, India where fermented liquid feed (*kudithi)* was a common form of animal feed among small farmers. The composition *of kudithi* was 80% water, 8-10% rice *(Oryza sativa)* or wheat (*Triticum aestivum)* bran and the remaining 10% kitchen waste (remnants of cooked rice, dal and vegetables). The *kudithi* is fermented for 8-10 h before feeding it to animals. A total of 10 *kudithi* samples were collected from the village for testing and isolating the microflora.

Laboratory studies

Laboratory studies indicated that all the *kudithi* samples had *Lactobacillus* sp and yeasts. These isolates were used in fermentation studies with moldy sorghum. Of the 11 isolates of *Lactobacillus,* only one strain reduced the mycotoxin content and increased the nutritive value. Further, fermentation experiments with isolated strains indicated that fermentation improved all nutrients but more significantly carbohydrates and iron (Table 1). Zinc and fat contents also improved. Energy increased from 340 to 380 calories in 100 g (dry mass) of moldy sorghum grain after fermentation. The initial content of 42.4 ppb of aflatoxin B_1 was reduced to non-detectable level and fumonisin could be detoxified within 24 h of fermentation (Table 2). However,

Table 1. Effect of fermentation time on nutritive value of moldy sorghum[1].

Nutrients	Oh	24 h	36 h
Carbohydrate (g%)	72.4	80.4	82.9
Fat (g%)	1.6	2.2	2.3
Iron (mg%)	3.55	4.19	4.36

1. Estimated in 100 g dry mass of moldy sorghum grain.

Table 2. Effect of fermentation time on aflatoxin, fumonisin and ergosterol contents in moldy sorghum.

Mycotoxin	Oh	24 h	36 h
Aflatoxin B_1 (ng g^{-1})	42.4	ND[1]	ND
Fumonisin (ng g^{-1})	5.0	ND	ND
Ergosterol (µ g^{-1})	200.0	50.0	50.0

1. ND = Non-detectable.

fermentation had no effect on tannins. Based on the laboratory studies, field studies were planned with milch cattle.

Operational research

A field trial was carried out with *Lactobacillus* sp-fermented *kudithi* made from moldy sorghum, with three animals chosen from farmers of Masanipalli, a village in Cheekatimamidi Mandal of Nalgonda district with the help of volunteers of PEACE, a non-governmental organization (NGO) working in this area.

One buffalo from each farmer was taken for the study and farmers were asked to collect milk everyday separately from these buffaloes for six consecutive days to arrive at a mean milk yield before starting the feeding of experimental diet. Except the addition of fermented moldy sorghum to the *kudithi* there was no difference between the diet fed before the experiment and experimental diet. This data formed the baseline data. One hundred ml of liquid culture *of Lactobacillus* (10^{-7} cfu) was given to each farmer along with 500 g of moldy sorghum. Five hundred ml of water was added to the moldy sorghum, mixed with 100 ml culture and covered with a lid to create anaerobic conditions. The mixture was kept for 24 h for fermentation. Just before feeding, fermented moldy sorghum was mixed well and 8 to 10 L of kitchen waste (rice washings and stale food) were added and fed to the animals by the farmers. This process was repeated everyday consecutively for a month.

Animal preference for the moldy sorghum *kudithi* was observed through intake of *kudithi,* milk yield and apparent animal health. Results indicated that animals accepted the fermented *kudithi.* Milk yield increased (Table 3) and farmers showed keen interest in further use of the technology. Three farmers who have successfully used this technology will in turn share the

Table 3. Effect of feeding fermented moldy sorghum on milk output (L day[1])[1].

Buffalo no.	Before feeding	After feeding
1	0.92 ± 0.062	1.34 ±0.130
2	1.46 ±0.046	1.66 ±0.160
3	3.65 ±0.012	3.83 ± 0.090

1. Data are means of 15 days.

inoculum of *Lactobacillus* culture with 3 other new farmers, and thus the technology will be adopted by all the 52 farmers in the village.

Conclusion

Moldy sorghum can be used as cattle feed after fermentation with *Lactobacillus* sp. Fermentation improves nutritive value and degrades mycotoxins. However, actual economics of the entire operation needs to be calculated before it can be recommended to the farmers.

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Cereals in Alcohol Industry: An Industry Perspective

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Abstract

Alcohol demand will increase due to its new applications especially as biofuel. Global alcohol production needs to reach 40 billion L by 2010. About 33% of alcohol is produced from grain stocks and maize contributes the largest share. Major alcohol usage is for fuel. Many countries opted for alcohol blend in auto fuel. India plans to blend petrol with up to 10% alcohol in auto fuel.

Asia shares 14% of global alcohol production. Asia produces nearly 44.2 million t of sorghum grain per annum, which is mainly used for food, and partly as feed. India produces nearly 10.5 million t of sorghum per annum, mainly in the states of Andhra Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu and Maharashtra.

Rainy season sorghum often gets infected with grain mold and is not suitable for human consumption. Praj Industries Ltd., Pune, India was asked to work out a solution to use moldy sorghum. A starch-based ethanol process was designed, thus making alcohol a viable proposal from moldy sorghum grain.

Sweet sorghum, which stores sugars in the stalk, can also be used for production of ethanol and has properties comparable with sugarcane. Sugars can be extracted directly from the stalk and fermented for alcohol. Praj has also perfected the technology of alcohol production from sweet sorghum.

Praj Industries Ltd., Pune, India (abbreviated as Praj) is a turn-key project-based engineering company. It has completed turn-key projects in 25 countries in five continents. The main core area of business is the supply of plant, machinery and technology for alcohol production, and also the technology and machinery for brewery and waste water treatment plant. Praj has been involved in shaping some of the most challenging agricultural processing applications for alcohol production. We have accumulated vast experience in installing distillery projects involving different cereals. In order to fulfill the world requirement of fuel-grade ethanol, we have identified different crops for ethanol production, including sweet sorghum *(Sorghum bicolor)* as one of the options.

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Present scenario

The present world industrial production of 33.3 billion L of alcohol is expected to increase beyond 40 billion L by 2010. Currently, alcohol is produced from sugar crops (60% of total alcohol production), grains plus other feed stocks (33% of total alcohol production) (Table 1) and the remaining 7% is from synthetic products. The usage pattern of alcohol produced is 68% in fuel, 21% in industries and 11% in beverages. Use of ethanol for blending in fuel has been taken up by many countries. India has initiated blending of 5% ethanol in petrol; this will increase up to 10% in the second phase.

Table 1. Ethanol yield from various cereal grains.

Cereals/Product	Starch content (%)	Protein content (%)	Ethanol yield (L t^{-1} grain)
Sorghum	66-70	9-11	422 - 48
Moldy sorghum	62-68	8-9	390-435
Broken rice	66-70	2-3	420-445
Maize	58-64	8-10	370-410
Wheat	60-68	10-12	375-425

Rainy and humid conditions during grain filling and after grain setting in sorghum results in heavy infection by several fungi, generally termed as molds. Moldy grain is unfit for feed and food. Therefore, Praj worked out a technically viable solution to use such grains for the production of alcohol (Table 2).

Starch-based process for ethanol

The process of ethanol production is described (Fig. 1). Sorghum grains are stored in a dry place to avoid fungal growth. These grains are then taken for milling where they are cleaned and milled to form flour of suitable particle size. Slurry is prepared from this flour using water. This slurry is then subjected to pre-liquefaction stage with enzyme additions. The slurry is

Table 2. Economics for production of ethanol from moldy sorghum grains.

Description	Amount/Quantity	
	Moldy grain	Clean grain
Cost of moldy grain (Rs t^{-1})	3000	5000
Average ethanol yield (L t^{-1})	410	435
Cost of feed stock (Rs L^{-1})	7.30	11.50

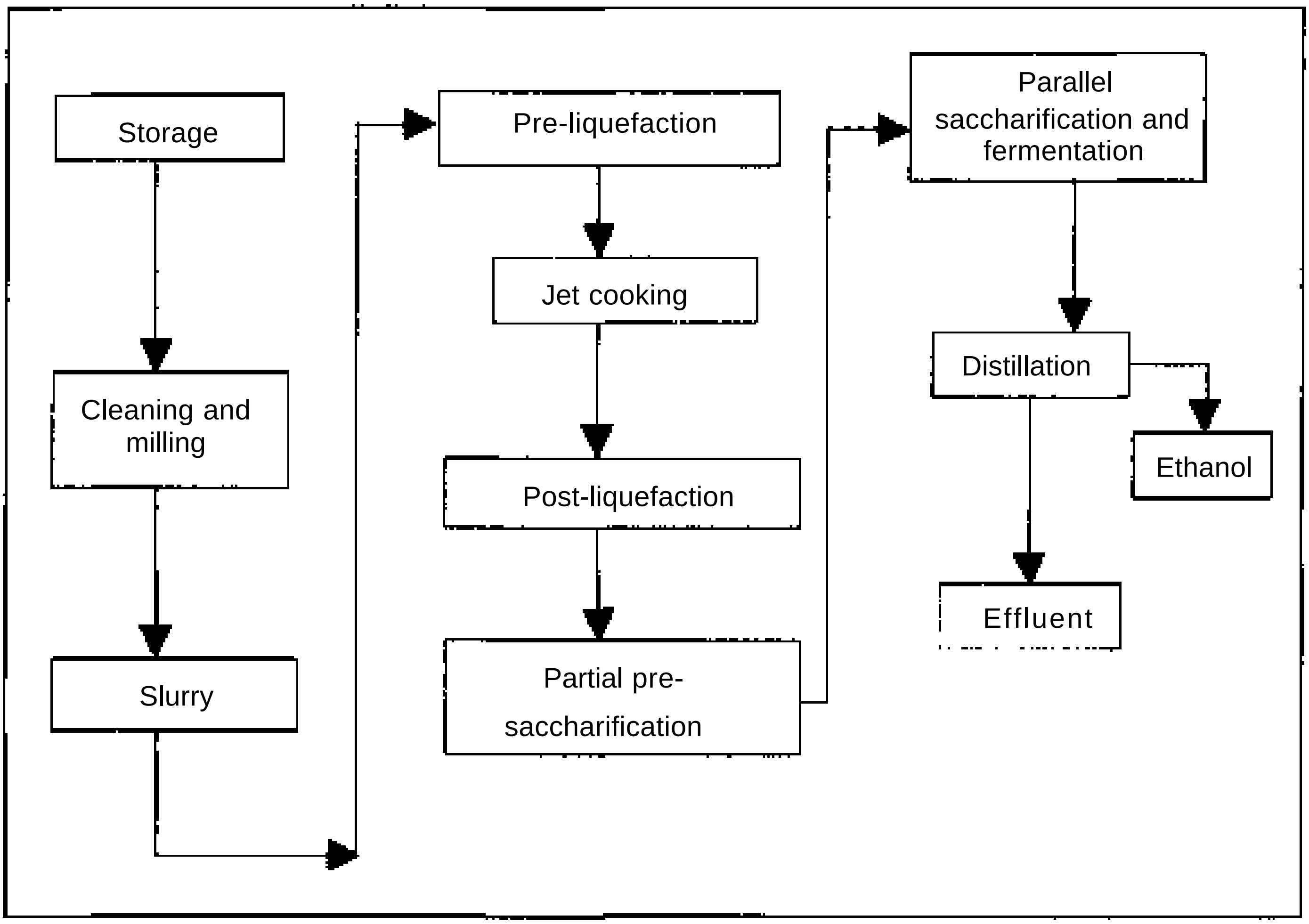

Figure 1. Ethanol production using starch-based process.

heated and maintained at high temperature to gelatinize the starch. This is followed by jet cooking in which the slurry is heated at very high temperature for a short time using high-pressure steam. This slurry is then cooled and again subjected to liquefaction process with enzymes, which is known as post-liquefaction. This process is important in reduction of viscosity, and the starch is broken down from polymeric form to oligomeric forms such as maltose, maltotriose, etc. The liquefied slurry is then subjected to partial pre-saccharification using suitable enzymes and the maltose and maltotriose units of starch are further broken down to glucose units. Glucose is a fermentable form of carbohydrate by yeast and therefore this partially pre-saccharified slurry is then fed to fermentors where the fermentation process begins. However, saccharification still continues simultaneously because of the presence of enzymes and this is known as simultaneous saccharification and fermentation. At the end of fermentation the fermented wash is sent for distillation. Alcohol is separated in the form of rectified spirit or extra-neutral alcohol or absolute alcohol. The effluent may be dried to produce cattle feed or part of the effluent can be recycled back to grain processing as mentioned above.

Sweet sorghum - An alternative for ethanol production

Some sorghum genotypes have high content of sugar in the stems. These genotypes are referred to as sweet sorghums. Sweet sorghum lines have wider adaptability and produce high biomass and sugar similar to sugarcane (*Saccharum officinarum)* (Tables 3 and 4).

In collaboration with the National Research Centre for Sorghum (NRCS), Hyderabad, India, we tested sweet sorghum variety SSV 84 at 7 locations. The crop was grown in summer with irrigation. Biomass, stripped cane yield and ethanol yields were assessed. Crop samples from different areas at varying crop growth stages were analyzed for various traits (Table 5).

Our observations on sugar content in sweet sorghum stalk indicated that sugar level in the stalks decreases rapidly after grain maturity up to 2.5-3.0% w/w. Deheading (removal of earhead) at anthesis initiation stage resulted in

Table 3. Comparison of sugar constituents (% w/w) in sweet sorghum and sugarcane.

Constituent	Sweet sorghum	Sugarcane
Total solids	25-30	25-30
Sucrose	6.5-7	11.5-13.5
Reducing sugars	2.5-4	0.5-0.7
Fermentable sugars	9-11	12-14
Fiber	14-16	14-16
Water	70-75	70-75

Table 4. Comparison of ethanol yield and other properties of sugarcane and sweet sorghum.

Properties	Sugarcane	Sweet sorghum
Crop duration (months)	10-11	3.5-4
Stripped green stalk yield (t ha^{-1})	70-80	47-52 (per crop) (95-105 t yr^{-1})
Sugar content (%)	11-13	9-11
Ethanol yield (L t^{-1})	68-74	55-65
Water requirement (%)	100	30-36 (of sugarcane requirement)
Fertilizers requirement (%)	100	0-25 (of sugarcane requirement)
Bagasse availability (t ha^{1})	20-25	12-13 (per crop) (28-32 tyr^{1})

Table 5. Evaluation of sweet sorghum variety SSV 84 at different locations in India.

Location	Crop age (days)	Stalk yield (t ha^{-1})	Sugar (% w/w) in stalk	Expected alcohol yield (L ha^{-1})	Expected alcohol yield (L t^{-1} stalk)	Remarks
Pune	107	54	5.71	1854	34.26	Without deheading
Kolhapur	115	54	5.76	1870	34.56	Without deheading
	115	54	6.70	2176	40.20	With deheading
Goa[1]	117	32	4.70	902	28.20	Without deheading
Chittur	115	45	5.82	1546	34.92	Without deheading
	115	45	6.70	1780	40.20	With deheading

1. Average of 3 locations.

higher percentage of sugar in stalk 18 days after deheading than without deheaded stalk. Steps involved in the production of alcohol from sweet sorghum stalk are given in Figure 2.

Process of alcohol production from sweet sorghum

The process of alcohol production from sweet sorghum includes the following steps.

Harvesting, transportation and storage of stems

Sweet sorghum stems are harvested mechanically or manually and transported to the alcohol production plant. Maximum storage period allowed (after harvesting) is two days.

Juice extraction operations

Sweet sorghum stems are crushed to extract juice as for sugarcane.

Juice concentration

Dilute juice extracted is evaporated in a multi-stage evaporation unit to convert it to concentrated juice form. This concentrated juice is then fermented to produce ethanol.

Fermentation

The concentrated juice produced as syrup is diluted using effluent recycle from the distillation column and process water. This is then fermented for producing alcohol in a continuous fermentation plant.

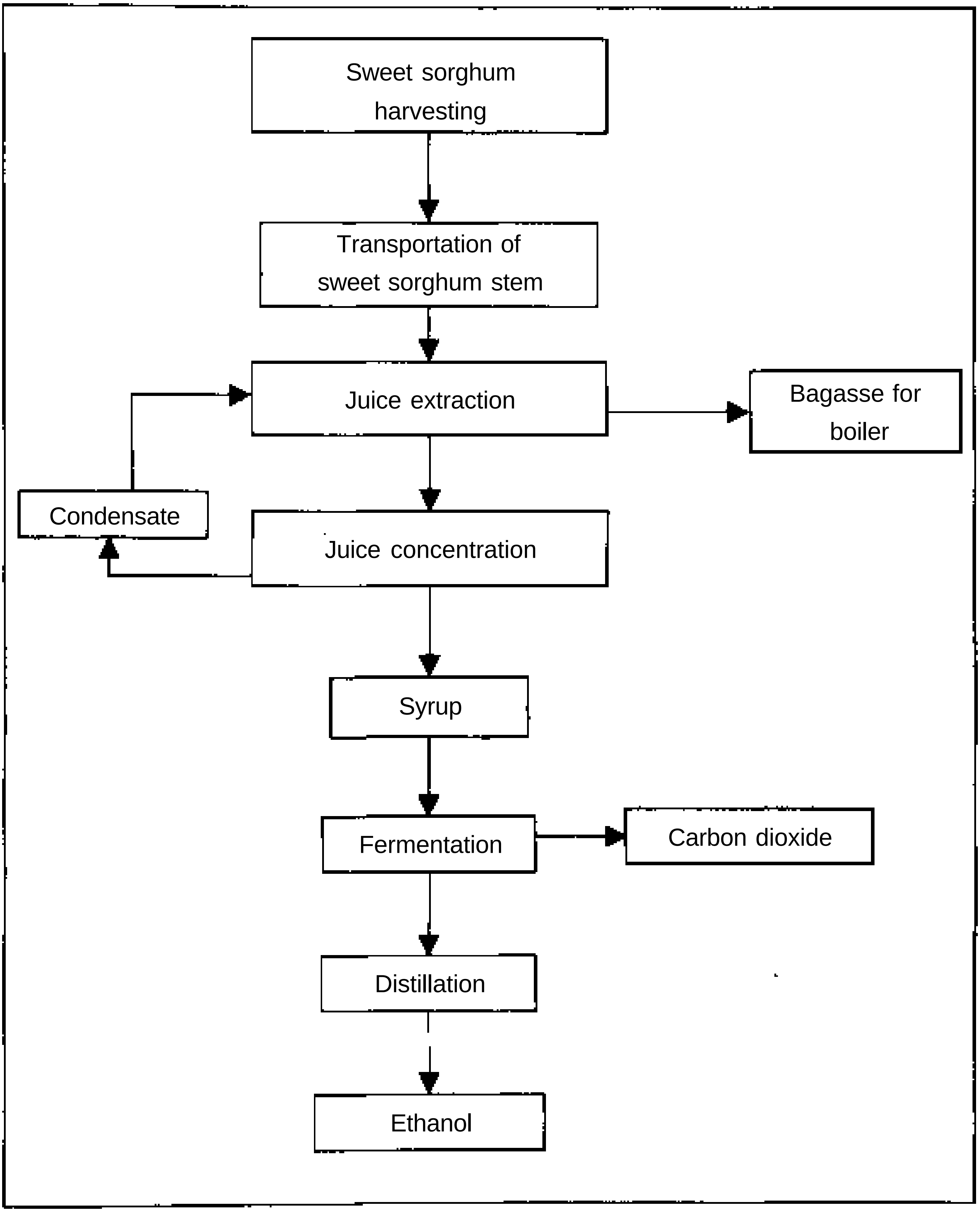

Figure 2. Technology for alcohol production from sweet sorghum.

Distillation and dehydration

The fermented mash is subjected to distillation so that alcohol is separated and concentrated to 99.6% v/v strength.

Salient features of the process offer by Praj

- Complete energy sufficiency using own bagasse.
- Integrated system for high levels of energy and water conservation.
- Extraction of additional fermentable sugars using special chemicals.
- Minimum time required for complete extraction and increased rate of extraction.
- Integration of available water streams for extraction.
- Optimizing of process parameters, viz., temperature, time and pH.

A Trial with Sweet Sorghum

RV Huilgol, Ramkrishna and Govind Misale[1]

Abstract

The pilot project involved three units of Shree Renuka Sugars Ltd., Manoli, India: the Cane Department, Sugar Plant and the Distillery Unit. The work done at the field level by the Cane Department is highlighted in the first section of the paper. The trials at the Sugar Plant, which involved crushing of sweet sorghum are discussed in the second section. The fermentation and distillation processes of the project are discussed in the third section. Finally, the results of this pilot project are highlighted.

Shree Renuka Sugars Ltd. took up a pilot project on sweet sorghum for ethanol and sugar production at Manoli, Belgaum, Karnataka, India in collaboration with the University of Agricultural Sciences (UAS), Dharwad, Karnataka and National Research Centre for Sorghum (NRCS), Hyderabad, India. Shree Renuka Sugars Ltd. is a 2500-TCD (tons crushing daily) sugar factory with a 11.2 MW cogeneration power plant. The sugar plant was commissioned in November 1999 and the cogeneration plant in January 2000. In February 2002 the company commissioned the distillery unit, producing rectified spirit at 60 kl day^{-1}. In February 2003 the ethanol plant was commissioned.

Sweet sorghum (*Sorghum bicolor*) is the only crop that provides both grains and stems that can be used for sugar, alcohol, syrup, jaggery, fodder, fuel and roofing. Shree Renuka Sugars Ltd. initiated this pilot project to find new substrates for producing ethanol for the National Fuel Ethanol program. Another objective was to improve the productivity of the drylands in the factory command area by providing alternative market channel for ethanol production from sorghum.

Work done at field level

Shree Renuka Sugars Ltd. selected few farmers and supplied them with seeds procured from national institutions. The sweet sorghum genotypes SSV 74

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from UAS, Dharwad, Madhura from Nimbakar Agricultural Research Institute, Pune, Maharashtra and SSV 84 from NRCS were supplied to individual farmers at 7.5 kg ha^{-1} after treating with Chloropyriphos and captan for protection against shoot fly and fungal diseases, respectively. A total of 273 farmers in Karnataka were given seeds to cover an area of 220 ha (Table 1). Chemical fertilizers like 10:26:26 NPK complex as a basal dose and urea as top dressing 25 days after sowing were arranged. For the control of shoot fly infestation, Chloropyriphos was supplied for spraying the crop. The crop was harvested at physiological maturity about 100-110 days after sowing.

Crop condition

The crop was sown in June and performed well without any shoot fly infestation as the seed was treated with Chloropyriphos. Due to the long dry spell and erratic drizzling, aphids were observed. Hence spraying of Chloropyriphos in the infested fields was undertaken as a precautionary measure. Wherever supplementary irrigation facilities were available, care was taken to irrigate the fields.

Yields

Under normal conditions the yield was about 25-30 t stalk ha^{-1} and 2.0-2.5 t grain ha^{-1}. The yield varied from field to field and results were noted during final harvesting. For grain yield, Madhura and for stalk yield, SSV 84 are found to be good.

Table 1. Sweet sorghum varieties grown by farmers in different circles in Karnataka, India.

	Madhura		SSV 74		SSV 84		Total	
Circle	No. of farmers	Area (ha)	No. of farmers	Area (ha)	No. of farmers	Area (ha)	No. of farmers	Area (ha)
Manoli	19	15	3	3	50	38	72	56
Yakkundi	27	25	0	0	24	22	51	47
Yaragatti	1	1	29	18	30	26	60	45
Ramadurg	7	10	23	17	29	27	59	54
Bailhongal	8	4	0	0	23	14	31	18
Total	62	55	55	38	156	127	273	220

Trial with sugar division

We crushed sweet sorghum in our sugar mill without any modification in milling tandem and preparatory devices. Sorghum was unloaded on the feeder tables and fed on to the main cane carrier, which leads it to the mill. Sorghum was prepared for crushing by the preparatory devices like chopper, leveler and fibrizer. Juice from mills 1 and 2 was taken for processing after screening. Compound imbibition system was followed; imbibition water was added before last mill and juice from the last mill was sprayed on the preceding mill and so on. Percentage of imbibition was 35.46% sorghum cane.

Due to huge amount of trash (29.45% sorghum stalk), there were problems in preparation. The main carrier slipped frequently, which affected continuous feeding to the mills. We encountered frequent jamming of preparatory devices. The crushing report is given in Table 2 and the analysis of crushed sweet sorghum stalk is given in Table 3. The juice analysis indicates that sweet sorghum juice is very rich in total reducing sugars (TRS) and comparatively poor in sugar content; hence, it is suitable for making alcohol.

Trial at the distillery

The sweet sorghum juice extracted from the mills was pumped to the distillery through a separate pipeline. The juice was collected in a tank and was diluted by adding water. The diluted juice quantity kept for fermentation was 66,000 L. The diluted juice had the following properties: juice brix 12.0%; specific gravity 1.048; pH 5; and TRS 8.64%.

For fermentation, 10 kg of baker's yeast was added along with nutrients like urea (2 kg) and diammonium phosphate (DAP) (0.5 kg) and antibacterial sodium metabisulphite (1 kg). The diluted juice was fermented for 24 h. The fermented wash quantity was reduced to 56,000 L due to sludge formation.

Table 2. Crushing of sweet sorghum stalk.

Particulars	Quantity (t)	% Crushed
Sorghum stalk crushed	112.00	
Juice quantity	66.00	58
Added water quantity	39.71	35
Bagasse quantity (including trash)	85.00	75
Trash	32.92	29
Actual bagasse	52.02	46

Table 3. Analysis of crushed sweet sorghum stalk.	
Description	Amount/Units (%)
Mixed juice	
Brix	12.00
Pol (sucrose)	4.41
Purity (sucrose % with respect to brix)	36.75
Reducing sugars (RS)	4.19
Total reducing sugars (Pol + RS)	8.60
Total reducing sugars (for 100 brix)	71.67
Bagasse	
Moisture % bagasse	44.10
Bagasse % Pol	2.58
Fiber % bagasse	45.44
Fiber % sorghum	21.10

The alcohol content in fermented broth was 2.82%. This fermented wash was taken for distillation. The expected yield was 1674 L for 56,000 L of fermented wash, but the actual yield was 1835 L of total spirit.

Initial reports from the sugar factory show that 112 t sorghum stalk has 23.47% juice with 8.5% TRS. Therefore, theoretical yield at 94.281% purity = 1361 L of alcohol for 112 t of stalk. Table 4 shows the comparison of the actual results and those reported in literature.

Conclusions

- Due to less rain, crop got affected which resulted in low yield.
- Sowing should be completed before mid-June, otherwise pest infestation will increase. Once the crop is affected it is difficult to control pests and diseases.

Table 4. Comparison of the actual results and those reported in literature.

Description	Actual results	Reports in literature
Stalk production (t ha^{-1})	25	35 - 40
Total reducing sugars (%)	8.50	16-19
Juice (%)	23.47	45
Alcohol yield (L t^{-1} stalk)	16.38	66 - 75
Juice brix (%)	12	14-21
Juice pH	5	4.8-5.2

- We encountered difficulties in the processing stage. The processing system to handle sorghum has to be studied and worked upon for better extraction and to ensure continuous feeding to the mill.
- Sorghum stalk juice is more suitable for producing alcohol as it contains more reducing sugars than sugarcane (*Saccharum officinarum)* juice.
- Since this is our first trial of alcohol production from sorghum, we could get actual yield less than 50% of reported yields in literature.
- Low juice content and low fermentable carbohydrates may be reasons for low yield.

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Group Photograph

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Program for the Expert Meeting on Alternative Uses of Sorghum and Pearl Millet in Asia

Tuesday, 1 July 2003

0815-0900	*Registration* [*near Conference Center Foyer*]	
Session 1	**Inaugural**	**[Master of Ceremony: *Farid Waliyar*]**
0900-0910	Welcome address by Director General	William D Dar
0910-0920	Remarks by CFC Representative	Andrey Kuleshov
0920-0930	Message from FAO	FAO Representative
0930-0940	Objectives of the meeting	C L L Gowda
0940-1000	*Group photograph and coffee break*	

Session 2

Chair : Dyno Keatinge
Rapporteur : Belum V S Reddy

1000-1050	Importance and economics of cereals (sorghum and pearl millet) production in Asia	B Dayakar Rao, B S Rana, S Hyma Jyothi, K Karthikeyan, K A Bharath Kumar, and N Seetharama
1050-1140	Sorghum and pearl millet - health foods and industrial products in developed countries	J Dahlberg, J P Wilson, and T Snyder
1140-1230	Recent technologies in pearl millet and sorghum processing and food product development	Salil Sehgal, A Kawarta, and G Singh
1230-1330	*Lunch break*	

Session 3

Chair : M C S Bantilan
Rapporteur : R P Thakur

1330-1415	Dynamics of utilization, markets, trade and coalitions: sorghum and millets in Asia	P Parthasarathy Rao, AJ Hall, and M C S Bantilan
1415-1440	Demand driven sorghum and millet utilization - failures, successes and lessons learned	Lloyd W Rooney
1440-1505	Effects of mycotoxins on cereals grain feed and fodder quality	F Waliyar, S V Reddy, and R P Thakur

1505-1525	*Coffee break*	
1525-1550	Cereal grain procurement, drying and storage for commercial use	Sivakumar, P S Dravid, and C Ramakrishna
1550-1615	Sorghum: A potential source of raw material for agro-industries	R B Somani and J R N Taylor
1615-1640	Processing of sorghum and pearl millet for promoting wider utilization for food purposes	S Z Ali
1640-1715	Discussion	
1900	Welcome dinner (Gazebo) — (Hosted by Dr William D Dar, DG, ICRISAT)	

Wednesday, 2 July 2003

Session 4

Chair : Farid Waliyar
Rapporteur : P Parthasarathy Rao

0830-0855	Methods and feasibility for alternative ises of sorghum: Indian perspectives	C V Ratnavathi, P K Biswas, M Pallavi, M Maheswari, B S Vijay Kumar, and N Seetharama
0855-0920	Alternative uses of sorghum - methods and feasibility: Chinese perspectives	Li Guiying, Lu Qingshan, and Zou Jianqiu
0920-0945	Cereals alternative uses - methods and feasibility: Pakistani perspectives	S R Chughtai, J Fateh, M H Munawwar, and M Aslam
0945-1015	*Coffee break*	
1015-1040	The commercialization of sorghum and pearl millet in Africa: Traditional and alternative foods, products, and industrial uses in perspective	D D Rohrbach and A B Obilana
1040-1105	Cereals alternative uses - methods and feasibility: Thailand perspectives	Prasit Jaisil
1105-1130	Sorghum and pearl millet for poultry feed	C L N Rao, D Sudhakar, A R Reddy, and V L K Prasad
1130-1200	Forage potential of sorghum and pearl millet	G Harinarayanaa, N P Melkania, Belum V S Reddy, S K Gupta, K N Rai, and P Sateesh Kumar
1200-1300	*Lunch break*	

Session 5

Chair : P S Dravid
Rapporteur : K N Rai

1300-1315	Strategy for commercialization using product centric and value chain approach	I R Nagaraj
1315-1340	Utilization of fermented moldy sorghum as cattle feed	V Sudershan Rao, S Vasanthi, and Ramesh V Bhatt
1340-1405	Cereals in alcohol industry: Industry perspective	Anil D Mandke
1405-1430	Trial with sweet sorghum	R V Huilgol, Ramakrishna,and Govind Misale
1430-1445	Potential of sorghum as feed grain for Thailand and Indonesia	B Boonsue
1445-1500	Potential of sorghum development in Indonesia	M Dahlan
1500-1530	*Coffee break*	

Session 6 ***Group meeting* [*concurrent*]**

1530-1730 Working Groups on
- Novel foods and health
- Livestock feed and forage
- Industrial products

1900 Workshop dinner (204 Banquet Hall) - (Sponsored by JK Agri-Genetics, Proagro Seed Co., Ganga Kaveri Seeds, Prabhat Agri Biotech, and Pioneer Overseas Corporation)

Thursday, 3 July 2003

0830-1230 **Group meeting [*continues*)**
[*Coffee break - 1040-1100*)
Tasks of the Working Groups are to identify research and development priorities and potential partners from various sectors for developing project proposal

1230-1330 *Lunch break*

Session 7 Plenary

Chair : J Dahlberg
Rapporteur : S Pande

1330-1400 Report by the Working Group and discussion on Novel foods and health - research and development issues and institutional alliances

1400-1430	Report by the Working Group and discussion on Livestock feed and forage - research and development issues and institutional alliances
1430-1500	Report by the Working Group and discussion on Industrial products - research and development issues and institutional alliances
1500-1520	*Coffee break*

Session 8 Planning

Chair : Andrey Kuleshov
Rapporteurs: K N Rai and Belum V S Reddy
Facilitator : Alan D Marter

1520-1800	Identification of research components, outputs and institutional alliances for project development and implementation
1900	Workshop dinner (Swimming Pool) - (Sponsored by Effem India Private Limited, Banjara Hills)

Friday, 4 July 2003

0830-1030	Planning session (*continues*)
1030-1100	*Coffee break*
1100-1230	Presentation of research components, outputs, and potential partners (by Alan D Marter, Consultant)
1230-1300	Closing remarks by CFC and ICRISAT
1300-1400	*Lunch break*
1400-1500	Press Conference (W D Dar, A Kuleshov, C L L Gowda, F Waliyar, P S Dravid, and G Warrier)
1500	Departure

About CFC

The Common Fund for Commodities (CFC) is an autonomous intergovernmental financial institution established within the framework of the United Nations. The Agreement Establishing the Common Fund for Commodities was negotiated in the United Nations Conference on Trade and Development (UNCTAD) from 1976 to 1980 and became effective in 1989. The first project was approved in 1991.

The CFC forms a partnership of 106 Member States plus the European Community (EC), the African Union (AU) and the Common Market for Eastern and Southern Africa (COMESA) as institutional members. Membership is open to all Member States of the United Nations or any of its specialized agencies, or of the International Atomic Energy Agency, and intergovernmental organizations of regional economic integration which exercise competence in the fields of activity of the Fund.

CFC's mandate is to enhance the socioeconomic development of commodity producers and contribute to the development of society as a whole. In line with its market-oriented approach, the Fund concentrates on commodity development projects financed from its resources, which are voluntary contributions, capital subscriptions by Member Countries. Through cooperation with other development institutions, the private sector and civil society, the Fund endeavors to achieve overall efficiency in and impact on commodity development.

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, chickpea, pigeonpea and groundnut - five crops vital to life for the ever-increasing populations of the SAT. ICRISAT's mission is to conduct research that 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 supported by the Consultative Group on International Agricultural Research (CGIAR), 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 United Nations Development Programme (UNDP), the International Fund for Agricultural Development (IFAD) and the World Bank. ICRISAT is one of 15 nonprofit CGIAR-supported Future Harvest Centers.

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