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CURRENT STATUS AND STRATEGY FOR PROMOTING HYBRID SORGHUM AND PEARL MILLET TECHNOLOGY

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INTRODUCTION

4.1 Sorghum (***Sorghum bicolor***) and millets are important sources of food, feed and fodder in the Asia-Pacific region. Several millets are grown, with the predominant species including proso millet (***Panicum miliaceum***) in the former USSR, foxtail millet (***Setaria italica***) in China, finger millet (***Eleusine coracana***) in Nepal, and pearl millet (***Pennisetum glaucum***) in India, Pakistan, and Yemen (Rachie, 1975). In this region, sorghum and pearl millet grain crops are most important in economies of the large semi-arid tracts of the Indian sub-continent. The use of these grass species for fodder, especially sorghum and sorghum-sudangrass hybrids, is much more widely distributed. In climates where their maturing grains are not exposed to high humidity and/or rainfall, these cereals are important sources of carbohydrates in human diets, especially in rural areas. In these areas, stover from sorghum and pearl millet grain crops is often an important source of dry season maintenance rations for livestock. In parts of the region having higher rainfall or higher humidity, and in areas where prices of other grains are subsidized, food use of sorghum and millets is limited.

SCOPE OF SORGHUM AND PEARL MILLET IN DIVERSIFIED NEEDS

4.2 As the production of other cereal grains increases, and transportation becomes easier, direct human food use of sorghum and pearl millet grain may decline in the Asia-Pacific region and elsewhere. Direct human consumption of rice and wheat will likely increase, in both absolute and relative terms, at the expense of these coarse grains. However, it is likely that use of sorghum and pearl millet for livestock feed will increase considerably as incomes in the region rise and demand for animal products increases. Indeed, projections suggest that demand for coarse grains may rise by 2 to 2.5% per annum for the next several decades. Grain of both sorghum and pearl millet will be used much more extensively than today in concentrates to feed poultry, swine, cattle and fish. Industrial use of pearl millet and sorghum grain may also increase, but probably to a lesser extent. Use of sorghum for dry fodder will continue at present levels, or even increase, as no crop can replace it for this purpose. Finally, both sorghum and pearl millet will be used much more extensively as sources of high quality green fodder in the future in this region.

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4.3 Given the above considerations, it is difficult to predict the direction that future production of sorghum will take in this region (Murty, 1992). Rainy season grain sorghum sowings may continue to decline, especially in South Asia, unless demand for hard red grain increases substantially. Mold on soft red and white grain types, which is common in rainy season sowings, reduces grain quality for most purposes. Sorghum grain production in the region will likely continue to increase slowly since yield increases resulting from improved cultivars and management practices should more than compensate for any reduction in area. Post-rainy (rabi) season sorghum production may also decline in the Indian sub-continent, but can be expected to increase in other parts of the Asia-Pacific region as irrigated agricultural production systems are further intensified.

4.4 It is not likely that production of pearl millet grain will decline markedly in the future in India, Pakistan and Yemen, as no other cereal is suitable in most of the areas where this crop is currently grown, and pearl millet also serves as a valued source of fodder in many of these areas. However, area sown to pearl millet grain crops may decline in these countries as yields improve. Better quality land released from pearl millet cultivation may instead be sown to cash crops like groundnut (*Arachis hypogea*) and sesame (*Sesamum indicum*). Provided that markets for their grain develop, short-season pearl millet grain hybrids should fit into suitable rainfed and irrigated cropping systems throughout the region. Under good moisture and fertility conditions, two to four tons of dry grain can be harvested from currently available hybrids, just 75 days after sowing. In the future, such hybrids should find a place in many parts of the Asia-Pacific region where this crop is currently unknown.

4.5 Keeping the past and present patterns of area, production and yield of sorghum and pearl millet in India in view and given the predominant place of Indian production of these crops in the region, one can assume that regional patterns will not differ markedly from this on the whole, although patterns in individual countries may do so. Overall production and yields can be expected to increase while area sown remains stable or declines.

4.6 Pearl millet and sorghum are most similar to maize (*Zea mays*). For hybrid seed production, maize has a major advantage over both sorghum and pearl millet in that detasselling of the female parent permits efficient hybrid seed multiplication without the complications of fertility restoration and sterility maintenance necessary when using cytoplasmic male-sterility systems available in all three species. However, seed multiplication rates are higher and seeding rates are lower (in terms of kg/ha^{-1}) for sorghum and pearl millet than for maize.

4.7 There have been a number of conferences over the past two decades that focused on utilization of sorghum and millets (e.g., Gomez et al., 1992). Information on the nutritional quality of sorghum compared to maize is now widely available (e.g., Doggett, 1988; Ejeta et al., 1990). Briefly, low tannin sorghum grain (red, yellow, or white) has about 95% of the feed value of maize. The difference is due to the lower fat content of sorghum, which results from its relatively smaller embryo. High tannin sorghum grain (brown) has a lower feed value, unless germinated or treated with alkali to reduce its tannin content. However, high tannin sorghums are less damaged by birds prior to grain harvest than are low tannin sorghums, and are often less damaged by grain molds as well. Compared to maize, grain sorghum is more tolerant of water-logging and better able to withstand both mid-season and terminal drought stress. However, since the grain of sorghum and pearl millet is located on top of the plant, and is not protected (from fungi, insects and birds) by husks as in case of maize, there are several problems with their production in more humid areas. Grain molds, head bugs, and birds can each be devastating reducers of sorghum grain yield and quality, and interactions of head bugs with grain molds can be particularly damaging. Bird damage on sorghum and pearl millet is most effectively controlled by sowing large areas that will mature at about the same time, or by manually protecting small isolated plots.

4.8 Information from studies directly comparing the nutritional value and potential for feed use of pearl millet with maize and sorghum is available (Sullivan et al., 1990; Andrews and Anand Kumar, 1992), but has not been well publicized. Compared to these two other coarse grains, pearl millet grain often has a higher content of protein and essential amino acids, especially lysine, in addition to having a higher fat content. These factors contribute to its high nutritional value for use as human food and as livestock feed. In fact, the nutritional value of pearl millet grain can exceed that of both sorghum and maize (Sullivan et al., 1990). However, due to its small individual grain mass, many of the more popular methods for preparing animal feeds (e.g., steam flaking and roller mills) from sorghum and maize may be difficult to apply to pearl millet. Further, the high fat content of pearl millet grain causes whole grain products to go rancid quickly. Semi-wet milling (Cecil, 1986) and parboiling (Rooney, 1989) have been suggested as methods for producing shelf-stable products from processed pearl millet grain.

4.9 Pearl millet is the major cereal crop grown in the hottest, driest areas of the world where rainfed agriculture is practised. It is the most reliable producer of biomass and grain in these environments due to its rapid growth rate, short growth duration, tremendous developmental plasticity, and adaptation to high temperatures and low soil fertility (Rachie and Majumdar, 1980). It is also very tolerant of acid soil conditions (Flores et al., 1991). Additional advantages of pearl millet include its excellent ability to ratoon following green fodder harvest, and the ease with which it can be transplanted compared to sorghum and maize. Finally, pearl millet, especially cultivars with medium or small grain size, stores better than either sorghum and maize.

SPECIFIC REQUIREMENTS OF HYBRIDS

4.10 If sorghum and pearl millet hybrids are to contribute to increased productivity and production, the most important requirement will be that their good quality seed should be reliably available at the right time, in the right place, and at a reasonable price. Several seed production factors need to be met if this is to be accomplished without difficulty. In many cases, these seed production factors may override other important criteria, even yield potential, in determining whether a new hybrid is useful. In the case of sorghum and pearl millet hybrids, desirable seed production characteristics may include many of the following:

- resistance of hybrid parents to major soil-borne diseases and insect pests prevalent in seed production areas,
- similar photo-period and thermal sensitivity of hybrid parents to facilitate their simultaneous flowering across a range of environments,
- complete sterility maintenance of male-sterility in the seed parent,
- adequate duration of stigma receptivity in the seed parent and its insensitivity to temperature variation,
- adequate pollen production capacity in pollen parent and maintainer of the seed parent,
- height of the pollinator should equal or exceed that of the seed parent,
- lodging resistance of seed parent,
- high yield of seed parent to keep production costs low, and
- good seed storage characteristics of seed parent(s).

4.11 Another factor that has occasionally been overlooked in breeding grain and dual-purpose hybrids of sorghum and pearl millet, whose seed production is currently based on cytoplasmic-genetic male-sterility systems, is that fertility restoration must be sufficient to ensure seed set in isolated fields. While it may not be necessary for every hybrid plant to be completely pollen fertile, the frequency of well-restored plants should be high to minimize problems with seed set and grain replacement diseases [e.g., pearl millet smut (***Tolyposporium penicillariae***) and ergot (***Claviceps fusiformis***)] in unfavourable conditions. Adequate seed set in trials is not sufficient, as several experienced breeders can testify.

4.12 Specific requirements for sorghum hybrids in humid regions are likely to also include foliar disease resistance (especially for anthracnose, ***Colletotrichum graminicola***) and grain mold resistance. The latter may most easily be accomplished by breeding for hard red grain (Anonymous,1993), but a more open panicle architecture may also help. In the case of pearl millet hybrids, short protogyny and high levels of fertility restoration will be necessary to ensure seed set and avoid grain replacement diseases in humid conditions. Compact panicles that quickly shed most incident rain drops may contribute to reduced grain mold problems on pearl millet.

4.13 Breeders of forage hybrids of both pearl millet and sorghum should strongly consider incorporation of well-characterized brown mid-rib genes (Andrews and Anand Kumar, 1992; Cherney et al., 1991) into their parental lines. These, and similar genes (Degenhart et al., 1991), can markedly improve forage digestibility resulting in higher productivity of livestock. Sorghum forage breeders may also find selection for low dhurrin content useful.

STATUS OF HYBRID RESEARCH AND DEVELOPMENT

4.14 Sorghum and pearl millet hybrids in India have been major success stories. The impact of *zera-zera* sorghums in increasing grain yield and improving foliar disease resistance and grain quality of rainy season sorghum hybrids in India, and elsewhere, has been remarkable. An example of this is the partially converted derivative of IS 3541, namely CS 3541. This conversion line, bred and released as a dwarf pure line variety in India, has been extensively used by sorghum breeders world wide. Its direct use as a male parent of successful released hybrids in India is shown in Fig. 1.

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             Partial
            conversion
IS 3541——————————> CS 3541   =  CSV 4 ----------------┐
                                                      |
                    CSH 5    =  2077A x CS 3541  <-----┘
                    CSH 6    =  2290A x CS 3541  <-----┘
                    CSH 9    =   296A x CS 3541  <-----┘
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Fig 1: Impact of zera-zera sorghum germplasm on public bred sorghum varieties and hybrids in India: the case of CS 3541. Genotypes connected by arrows (————>) are related by descent. Those connected by dashed arrows (------->) are identical.

4.15 A number of related pearl millet hybrids have been released over the years in India (Dave, 1977), and several of these have been very successful. Epidemics of pearl millet downy mildew, caused by the fungus *Sclerospora graminicola*, have resulted in the replacement of several of these hybrids much earlier than would have been otherwise warranted. Early flowering hybrid 'HB 3' was released in 1968 and soon covered 20% of the area sown to pearl millet in India. Disease outbreaks on this hybrid in the early 1970s led to a succession of related hybrids (Fig. 2), several of which appeared and then disappeared in a classic boom-bust cycle. Despite having to pay considerable attention to ensuring the downy mildew resistance of new hybrids and parental lines, breeders have had continued success in increasing productivity of pearl millet hybrids in India (**Table 1**).

4.16 The Indian data suggest that research on sorghum and pearl millet has contributed to substantial productivity gains over the past three decades. Advances continue in both of these species. Sorghum seed parents with resistance to sorghum midge are in hand, and considerable work is underway at ICRISAT Centre to introduce genes for resistance to a wide range of biotic stresses (diseases, insects and *Striga*) into agronomically elite sorghum seed parent backgrounds. Products of this research are imminent, and will be available in the form of agronomically elite, resistant maintainer progenies and A/B pairs.

HB 3 = Tift 23 A x J 104
HB 4 = Tift 23 A x K 560

BJ 104 = MS 5141 a x J 104
BK 560 = MS 5141 a x K 560-230
HHB 45 = MS 5141 a x H 90/4-5

Pusa 23 = ICMA 841 x K 560-280-23
Pusa 322 = ICMA 841 x PPMI 301

ICMH 451 = 81 A x ICMP 451
HHB 50 = 81 A x H 90/4-5
HHB 60 = 81 A x H 77/833-2

HHB 67 = 843 A x H 77/833-2

HHB 66 = 843 A x H 77/833-2
ICMH 356 = ICMA 88004 x ICMR 87003

Fig 2: Selected public-bred pearl millet hybrids released in India, 1968-1993, and relationships between their parental lines. Parents connected by arrows (——————>) are related by descent. Parents connects by dashed arrows (---------->) are identical.

Table 1: Compound Growth Rates for Area, Production and Yield of Sorghum, Pearl Millet and Maize in India

Period	Sorghum			Pearl Millet			Maize		
	Area	Prod.	Yield	Area	Prod.	Yield	Area	Prod.	Yield
1949-50 to 1990/91	-0.30	1.21	1.52	0.06	1.70	1.64	1.42	2.41	0.99
1949-50 to 1964/65	0.99	2.50	1.50	1.08	2.34	1.24	2.66	3.87	1.18
1967/68 to 1990/91	-0.73	1.30	2.04	-0.80	0.52	1.33	-0.06	1.35	1.41
1980/81 to 1990/91	-1.15	0.53	1.69	1.02	1.17	2.21	-0.06	2.36	2.42

SOURCE: Agricultural Situation in India, 1992. Vol. XLVI, No. 11 (February)

4.17 Pearl millet seed parents with resistance to Asian strains of pearl millet downy mildew, smut, and (in a few cases) ergot are currently available from ICRISAT. Rust resistant pearl millet seed parents are in the pipeline. Pearl millet top-cross hybrids have been demonstrated to be a quick way to combine high grain and stover yield potential with adaptation to local biotic stresses and/or more durable resistance to downy mildew. The potential of three-way hybrids is also being actively explored (Anonymous 1991, 1992a, 1993). High yielding pearl millet hybrids producing forage of excellent quality have been identified for the Republic of Korea (Choi et al., 1990a, 1990b). More recently, these workers have identified similar hybrids, on

ICRISAT-bred downy mildew resistant seed parent 81A, that have resistance to black streaked dwarf virus (B.H. Choi, personal communication).

4.18 National programme of China and India have far greater resources available for research on sorghum and pearl millet (India only) than those of any other country in the region. State and national research organizations in India are complemented by a rapidly growing private seed industry. Because of this, research on these crops in India and China is further ahead than any other country in the region, with the possible exception of Australia and the Republic of Korea (which has a very small but effective programme for pearl millet fodder hybrids). Other countries having relatively strong research programmes on these crops include Pakistan, Thailand and Yemen, but the resources allotted to these crops in these countries are much less than in India and China. From resources available for public-funded research on cereals and millets in India, sorghum is allotted 16% of financial and 11% of human resources (scientific staff), while pearl millet is allotted 8% and 9%, respectively (Makhija, 1993).

4.19 There are several major constraints to research and development for improved sorghum and pearl millet in the Asia-Pacific region. Those that are important in one or more country in the region include the following:

Markets for sorghum and pearl millet are not yet large enough to allow substantial increases in production of these cereals to be economically attractive. In fact, the area sown to these crops tends to drop as grain and fodder yields increase.

Limited facilities for seed storage in the region makes management of carry over stocks difficult.

Lack of effective plant variety protection in much of the region is a strong disincentive for private investment in genetic improvement of these crops. This also results in strong incentives to manipulate markets to produce seed shortages of popular cultivars in the first few years that they are available. This practice serves to maximise short-term profit margins and facilitate control of proprietary hybrid parental lines.

Limited areas in which seed production is easy (adequate infrastructure and experienced farmers) results in inadequate isolation distance and difficulty in maintaining control of proprietary hybrid parental lines.

Limitations on size of agricultural land holdings restrict the ability of private crop improvement organizations to develop adequate testing facilities and sites where they can safely produce base seed stocks of their hybrid parental lines.

National programmes for evaluating experimental hybrids are short on operating funds, limiting their ability to cope with the numbers of test entries that private research organizations would like to test.

POTENTIAL AND FUTURE OUTLOOK

4.20 The prospects for sorghum and pearl millet in Asia were reviewed recently in some detail by Kelley and Parthasarathy Rao (1993), and will not be delved into further here.

4.21 Conventional plant breeding methods (pedigree, backcross, and recurrent selection in their many variations) continue to hold the most promise for short term improvement of sorghum and pearl millet. However, work to develop molecular marker technologies for these crops is moving rapidly and its application should be routine in the medium and long term if the relative costs of these techniques continue to decline. An informal network has been established to support and assist breeding of sorghum and pearl millet in developing countries. Small meetings of concerned breeders and molecular biologists were held in 1991 and 1993, with support from the Rockefeller Foundation and from the Overseas Development Administration of the United Kingdom. Publication of the proceedings of the most recent meeting is expected in early 1994. Briefly, usable genetic linkage maps based on molecular markers are now available in both species, and their map lengths are smaller than those of other major cereal species. In the case of pearl millet, map length is only about 500 cm. Thus, it should be less expensive to apply DNA marker-assisted selection techniques to these two coarse grains than to do so in maize, wheat or rice. The ICRISAT Cereals Programme is actively pursuing molecular markers for quantitative trait loci contributing to downy mildew resistance and seedling heat tolerance in pearl millet. ICRISAT programme is also attempting to tag fertility restoration and sterility maintenance genes for several cytoplasmic-genetic male-sterility systems in this species. Sorghum workers at ICRISAT, and elsewhere, are seeking tags for genes controlling maturity and photo-period sensitivity, grain hardness, and the "stay green" trait. Additional characters of interest in sorghum molecular mapping work include host plant resistance to shoot fly, ***Striga***, stem borer, and anthracnose. Several sorghum maps have already been published, while that for pearl millet has been submitted for publication (Liu et al., submitted).

4.22 An additional area that may be especially useful in improving sorghum and pearl millet for more marginal production environments is that of farmer participatory breeding bringing farmers into the hybrid identification picture much earlier so as to ensure that research direction does not stray far from farmers' perceptions of their own needs (Anonymous). Private sector breeders have often been better at this than those in the public sector, but the private sector has tended to concentrate on more favourable agricultural environments. If hybrids are to also contribute to increased productivity in marginal agricultural environments, greater involvement of farmers in identifying appropriate hybrids may be needed.

4.23 Potential returns on investment in sorghum and pearl millet research have sometimes been estimated to be lower than that on other commodities, due to the low unit value of their produce, the relatively small human populations that depend on them directly for food, and the realistically long time-frames and high staffing requirements thought necessary to achieve desired objectives in marginal production environments. However, it is not clear that the comparisons made have always been as unbiased as warranted. When one looks to the future, the relative ease, with which it will be possible to apply molecular marker technologies to these crops, given the small size of their genomes compared to wheat, rice and maize, and projected increases in demand for coarse grains worldwide, suggests strongly that returns to investment in pearl millet and sorghum will be good (Anonymous, 1926).

SEED PRODUCTION

4.24 Seed production technology for hybrid sorghum and pearl millet are very well developed in India, with active involvement from both public and private seed production agencies. Hybrid sorghum seed production is also functioning very well in China and Australia. Manuals describing these technologies in detail are now available (Khairwal et al., 1990), and more are in the pipeline (Murty et al., 1994).

Ways and Means to Reduce Seed Production Cost

4.25 There are several approaches that can be taken that will assist in reducing the unit cost of producing hybrid seed of sorghum and pearl millet. These fall roughly into three categories, namely maximization of seed yields, minimization of seed production costs, and minimization of seed storage expenses. The following are relevant here:

Produce hybrid seed in environments where a successful crop is relatively assured. This typically means producing seed on fertile land with an assured water supply in seasons when weather and other factors are unlikely to cause crop failure. To further reduce production costs, several such environments should be available so that monopolistic behaviour by land owners in such environments can be controlled.

Breed more productive seed parents while retaining or improving the combining ability of seed parents that currently give the best hybrids.

Produce three-way hybrids and modified three-way hybrids to increase yield potential of seed parents. This is especially appropriate for forage hybrids and feed grain hybrids, but may also be acceptable for grain and dual-purpose hybrids for marginal areas where within-cultivar heterogeneity might improve stability of hybrid performance across seasons.

- Increase the ratio of female rows to male rows in hybrid seed production plots so that any reduction of seed set in female rows is offset by increases in seed yield of genetically pure seed per unit area.

- Produce top-cross hybrids using a productive pure line (sorghum) or open-pollinated cultivar (pearl millet) as the male parent. This can permit harvest of two-seed crops from one field. Alternatively, seed producers can sell the grain from the male rows, which will generally be more productive than most inbred pollinators currently in use. The result either way is an increase in the value of produce from the male parent rows. This may also permit increasing the ratio of female rows to male rows in the seed production plot.

- The route that many private companies choose, when permitted, is to market seed on the strength of their own brand name rather than waiting to obtain official certification of its purity. In the case of pearl millet in India, this is done in part to ensure that seed reaches buyers in the shortest time possible. It minimizes expenses on seed storage and interest on borrowed capital. This practice generally requires an increase in the number of border rows sown to pollen parents in hybrid seed production fields to prevent contamination that would otherwise be detectable only in time-consuming grow-out tests. An added advantage of this option is that it reduces the expenditure of resources in mollifying recalcitrant certification officials in regions where this is a problem.

4.26 In addition to the above, additional factors may be necessary to ensure that prices paid by farmers for hybrid seed actually reflect any reductions achieved in production cost. A public sector agency that is active in ensuring adequate stocks of breeder and foundation seed of good hybrid parents can help avoid shortages of popular genotypes. Similarly, such agencies can ensure that seed of well-adapted open-pollinated cultivars is widely available, providing seed purchasers a lower cost option should profit margins on hybrid seed sales exceed reasonable levels.

Seed Production Technology - Issues and Strategies

4.27 Several areas of research related to sorghum and pearl millet hybrid seed production technology are currently being pursued by workers in India. Targets of this research include the following:

- There is a need to document the efficacy of physical barriers to reduce isolation distance requirements for hybrid seed production. If found effective, their use should not be hindered by seed certification regulations.

> There is a need to better document any yield reduction in hybrids that is attributable to pollen shedders in sterile lines in hybrid seed production fields. This information should then be used to establish reasonable and enforceable standards for maximum permissible pollen shedder incidence in breeder seed, foundation seed, and certified seed production plots. Standards currently in place in India in the case of pearl millet are unreasonably high and practically unenforceable.
>
> Feasibility of rainy season hybrid seed production in non-traditional seed production areas (Seth, 1989) is being explored as a means to facilitate timely supply of seed and provide a greater range of options in seed production environments available to seed producers.

4.28 It may be possible to extend the above research areas to allow exploration of the potential for local village-level seed production. In this scheme, state seed corporations would supply limited quantities of foundation seed of open-pollinated cultivars (and perhaps parents of public-bred hybrids) to farmers through local non-governmental organizations (NGOs). These farmers, with assistance from the NGOs, would then produce seed in the village where it is needed. Potential advantages of such a system are that it would greatly reduce the burden on state seed corporations if they only need ensure timely delivery of small quantities of foundation seed to the remote areas where reliable and timely supply of large quantities of commercial seed is difficult. Further, it would increase pressure on public and private sector seed producers to provide a good quality product, in a timely manner, and at a competitive price. Potential disadvantages of this system are that village-level seed production might be more subject to the vagaries of weather than that in commercial seed producing regions, storage facilities may be inadequate, and if successful, it might come into direct competition with commercial seed producers. Finally, the very concept of returning to village-level seed production might be taken as an affront by the pure seed establishment. For areas that are outside the reach of the mainstream seed suppliers, it would be worthwhile to explore this option.

Potential Regions, Seasons, and Systems for Effective Hybrid Production

4.29 By far the biggest producer and consumer of seed of sorghum and pearl millet in the Asia-Pacific region is India. Hybrid cultivars of these crops, bred by public and private research organizations, play a large and increasingly important role in this country. Grain hybrids of sorghum are also commonly used in Australia, China and Thailand. Fodder hybrids are being exploited in these countries as well as in Japan and the Republic of Korea. Other opportunities certainly exist in the region, but the greatest area sown to open-pollinated cultivars of these species remains in the Indian sub-continent. Hybrids adapted to northern India should be evaluated in Myanmar and Pakistan, if not more widely in the region. Similarly, hybrids adapted to peninsular India should be evaluated in Indonesia, Myanmar, Philippines, and

Thailand. Observation nurseries of elite hybrids and parental lines of these crops, for grain and dual-purpose use, are available from ICRISAT in limited numbers.

4.30 Areas in which it is possible to reliably produce excellent quality hybrid seed of pearl millet and sorghum at a relatively low cost are not common. The cool, dry postrainy (**rabi**) season and the following hot, dry summer season provide near ideal environmental conditions for sorghum and pearl millet seed production in a number of irrigated areas of western, central, and southern India. Indeed, with its low labour costs and economies of scale, India is a potential supplier of low cost, high quality hybrid sorghum and pearl millet seed for much of the Asia-Pacific region, as well as for large areas in eastern and southern Africa. However, similar environmental conditions are found in parts of Australia, China, Indonesia and Myanmar, and may be worthy of greater exploitation for this purpose.

POLICY ISSUES

Research

4.31 Several research issues need be considered when policy makers are devising strategies to increase use of sorghum and pearl millet hybrids in the Asia-Pacific region. The most important of these is the role, if any, to be accorded to researchers in the private sector. It has been widely demonstrated that a competitive private sector (as opposed to a monopolistic private sector) is more efficient than public sector organizations in getting good quality seed of adapted hybrids to farmers in a timely manner in areas where demand for such seed is reliable. Further, public sector agencies are often reluctant to handle a wide range of cultivars of a given species, potentially reducing the genetic base of the crop in farmers' fields to dangerously low levels. Thus, it may be useful to promote private sector research with the objective of maximising the degree of useful genetic variability that can be retained in farmers' fields.

4.32 In the absence of effective plant variety protection, it is necessary to permit private sector agencies to keep secret the pedigrees of their proprietary hybrids. They cannot be required to submit the A-, B-, and R- lines of their elite experimental hybrids for any purpose to any agency (public or private) where pilferage is possible. Attempts to require such evaluation will result in either submission of substitutes, or in withdrawal of private investors from research on the crop in question. Further, if private sector research is to be promoted, it will be necessary to have a national testing system that is strong enough to satisfactorily evaluate products of that research. This may mean that private researchers are asked to pay a fee, perhaps on an entry x site basis, to cover at least the operating expenses of conducting such trials. Many private organizations will find such a system very attractive as it permits them to rapidly obtain an unbiased evaluation of their products across a much wider array of environments than would otherwise be possible. Public research programmes that have a large salaried staff and limited operating funds may also find such an arrangement attractive. Several countries having similar production environments may wish to join together in offering such facilities to the private sector.

4.33 Once the role, if any, of private research is settled, it will be possible to determine appropriate roles for publicly-funded researchers in state, national and international research organizations. Given the increased ability of public and private researchers in national programmes in the region to develop locally adapted hybrids, research at ICRISAT centre has been moving away from direct development of finished cultivars, and in the future will be largely limiting itself to the breeding of composite populations and hybrid parental lines. It will continue to supply improved segregating materials to organizations preferring to have their own unique parental materials. The resources made available by this reduction in applied and adaptive research at ICRISAT will be directed upstream in an attempt to resolve strategic problems such as ways to develop pearl millet hybrids with durable resistance to downy mildew.

Seed Production, Storage and Marketing

4.34 A major issue that needs to be resolved if farmers are to be assured timely supply of good quality seed is the time that is required to complete certification formalities. In the case of pearl millet in India, early rains may arrive before seed has been delivered following harvesting and conditioning. Farmers sow what seed is available, even if it is grain harvested from a hybrid grown in the previous season. If seed arrives in the villages after sowing is completed, it must be returned to the warehouse for storage until the following year. Interest expenses are potentially enormous so seed producers take whatever measures necessary to ensure that seed reaches in time. Unfortunately, this may mean circumventing official seed certification procedures, even for officially released public- bred hybrids, and marketing hybrid seed on the strength of a company's brand name.

4.35 Proper storage of seed in the hot, humid climates that are common through much of the Asia-Pacific region is a costly affair. Improper storage can be even more costly. That banks are reluctant to accept seed as collateral for loans to seed suppliers is largely due to this reason. Steps need to be taken to stimulate the development of adequate seed storage facilities for seed in this region. In addition, or perhaps as an alternative, restrictions on the movement of seed in commercial quantities need to be lifted wherever quarantine restrictions are not applicable. This will facilitate timely availability of good quality seed at minimum cost to farmers.

4.36 There is, however, a need for regulation of the sorghum and pearl millet seed trade (by itself or otherwise), particularly in the international arena, to monitor seed quality for exports. The objective of this regulation should be to avoid development of a bad reputation for the industry as a whole, due to a few unscrupulous seed suppliers interested only in short term profits. Provided that a satisfactory regulatory climate can be established, it should be possible for farmers throughout much of the Asia-Pacific region to enjoy the benefits of high quality, low cost hybrid seed that is available when it is needed and where it is wanted.

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CONTENTS

Page

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