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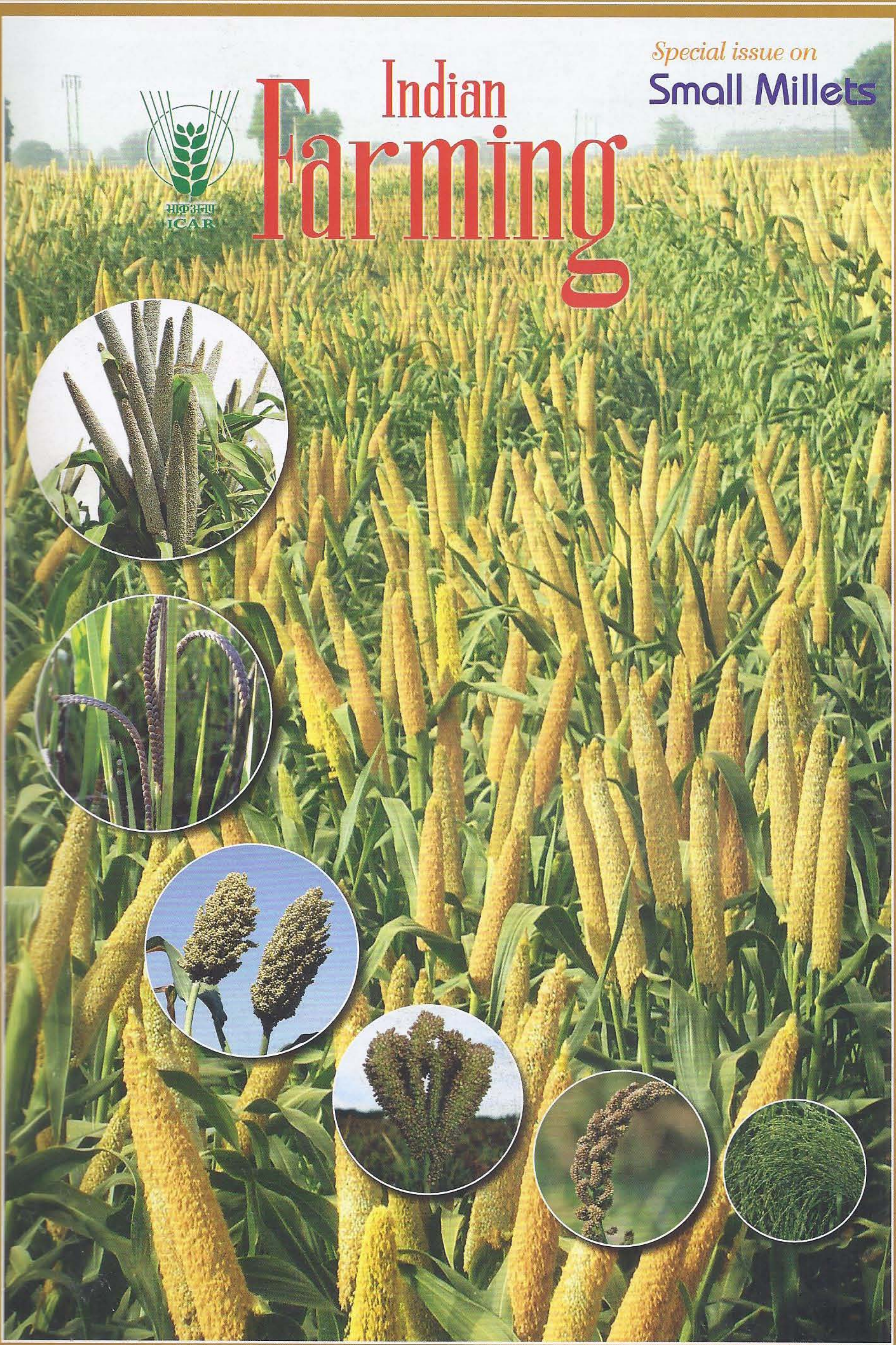

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Pearl Millet Improvement

for enhanced productivity-strategies and impact

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WITH the continuing degradation of natural resource base, adverse climate change effects on crop production and increasing crop cultivation cost, there is growing awareness of the significant role, pearl millet can play in addressing the national food security. Further, with the increasing incidence of various life style diseases and emphasis on food-based solutions, there is a re-appraisal of its nutritive value contributing to nutritional security. Considering the relatively limited investments both from public and private sector in pearl millet improvement in India, and negligible strategic research information generated elsewhere, it is prudent to rationalize research priorities in terms of target environments, germplasm to be used, plant traits to be improved, and cultivar types to be developed, all of which contribute to enhanced breeding efficiency and improved cultivar development.

Cultivar options

Highly cross-pollinated nature of reproduction and availability of commercially viable cytoplasmic – nuclear male sterility (CMS) system provides for open- pollinated varieties (OPVs) and hybrids as the two broad cultivar options in pearl millet. Since the advent of pearl millet grain hybrids in India in mid 1960s, there had been relatively less effort in breeding OPVs until 1970s when the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) developed a strong OPV development programme as a part of population improvement. WC-C75, the first ICRISAT-bred OPV, was released in 1982 and it was widely cultivated for about 12 years. Encouraged with the success of WC-C75, ICRISAT and its partners several OPVs were in developed subsequent years. During this period, however, it was also shown that the best hybrids had about 30% grain yield advantage over the best OPVs. Further, the rapidly developing private seed sector had little interest in OPVs. It was also observed that farmers had strong preference for cultivars with high phenotypic uniformity, which was only possible in single-cross hybrids. Therefore, for the last two decades there has been almost total shift towards breeding single-cross hybrids.

Germplasm utilization

Prior to the establishment of ICRISAT, pearl millet improvement in India was based largely on indigenous germplasm with limited genetic variability. Progenies derived from the improved composites and OPVs were also used at ICRISAT in pedigree breeding for development and dissemination of elite breeding lines and hybrid parents. These efforts made significant contributions to diversifying the genetic base of both public and private sector breeding programmes, leading to sustained progress in productivity and production.

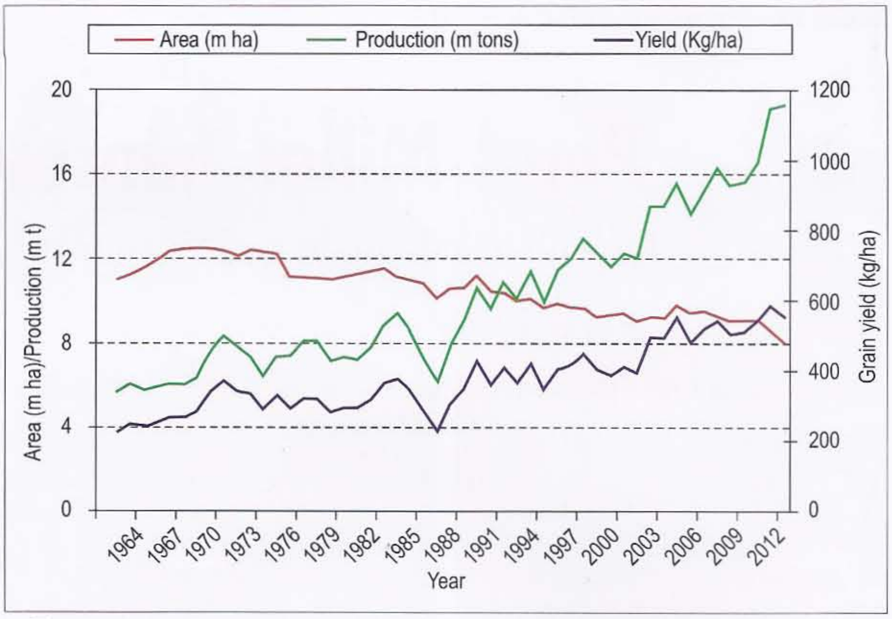
While selecting a germplasm for use in crosses, the big question has always been whether it should be used for crossing with B-lines or R-lines. Research carried out in Western Africa in early 1980s had shown that *iniadi* × non-*iniadi* population crosses were most heterotic. Thus, there has been a greater use of iniadigermplasm in crosses with B-lines and seed parents development, and greater use of non-*iniadi* germplasm in R-lines development at ICRISAT. Elite breeding lines derived from these crosses have been widely disseminated to public and private sector breeding programmes, and have, respectively, been used in their B-line and R-line crosses. This has enabled to maintain adequate diversity between B-group and R-group materials at ICRISAT as well as in other breeding programmes in India.

Geographical focus

Pearl millet area in India is divided into three zones: A_1 zone of north-western India receiving <400 mm of

*Pearl millet (*Pennisetum glaucum *(L) R. Br.) is a hardy, dry land cereal, largely grown in the arid and semi-arid tropical regions of Asia and Africa. India is the largest producer of this crop, both in terms of area (9 million ha) and production (10 million tonne). Until very recently, pearl millet, classified as a coarse grain, had been perceived as a poor man's crop of low productivity and thus relegated low on the national food security agenda.*

annual rainfall, and A zone of northern and central India with sandy loam soils and B zone of peninsular India with heavy soils receiving >400 mm of annual rainfall. Most of the breeding materials generated at ICRISAT as well as in the public and private sector programmes have been of medium and mid-late maturity (80-90 days) which are quite appropriate for A and B zones. Most of the stronger public sector breeding programes and the entire private sector programmes are also based in A and B zones. These large numbers of players enabled large number of field trials, and quality data on account of more predictable and relatively less heterogeneous environmental and edaphic factors. Thus, the geographical focus of pearl millet improvement program in India has been on A and B zones rather than on A_1 zone even though pearl millet is the most important cereal in A_1 zone. Such a geographical focus of research has been critically important for achieving the significant progress in pearl millet improvement in India, although it is recognized that improved research infrastructure and policy support can result in greater breeding progress and impact than achieved so far in the A_1 zone.



Three-year moving average for pearl millet area, production and productivity in India

Target-traits

Development of high-yielding hybrids has been possible through genetic manipulations of yield components in the medium, mid-late and late maturity groups. These components include grain size and grain number/unit area, the latter determined by number of productive tillers, panicle size and panicle compactness. Thus, there has been a gradual shift towards breeding hybrids with larger grain and panicle size, and greater panicle compactness even at the cost, to some extent, of tillering ability. Besides the yield potential, there are several biotic and abiotic stress factors that determine the yield of a cultivar. Foremost among the biotic stresses continues to be downy mildew (DM) caused by *Sclerospora graminicola* (Sacc) Schroet. Relatively simple inheritance, development of efficient field and greenhouse screening techniques for large scale applications, and availability of diverse sources of resistance have enabled breeding hybrids that are resistant to diverse pathotypes of DM. This has prevented any recurrence of DM epidemics witnessed during 1960s-1980s. Recently, leaf blast caused by *Pyricularia grisea* (teleomorph; *Magnaporthe grisea*) has emerged as serious as or even more serious problem than DM. Pathogenic variability for blast has been assessed and large-scale effective field and greenhouse techniques have been developed. Blast resistance sources have been identified and these are being used in breeding. Apart from this, smut (*Tolyposporium penicillariae* bref.), ergot (*Claviceps fusiformis*, Loveless) and rust (*Puccinia fusiformis* var. indica) are other diseases of pearl millet. While ergot and smut occur sporadically and occasionally and hence are of minor importance, rust incidence and its severity have increased over time. Simple field evaluation under natural field condition in peninsular India during winter season has been found effective to screen for rust resistance. Greenhouse techniques have also been developed at ICRISAT and rust resistance sources have been identified. But targeted breeding for rust resistance is yet to start, which will be a second priority after DM and blast.

As far as abiotic production constraints are concerned, terminal drought has been shown to have devastating effect on grain yield. However, unpredictable duration, intensity and frequency of drought; lack of repeatable and reliable field screening technique; non-availability of confirmed and stable drought tolerant sources; and complex nature of genetics of this trait have been major barriers to undertaking targeted drought tolerance breeding in pearl millet. Pearl millet is increasingly being cultivated as a summer-season crop during February-May in parts of Gujarat, Rajasthan and Uttar Pradesh on more than 500,000 ha where maximum air


A high-yielding experimental forage hybrid of pearl millet (ICMA 00999 x IP 20485)

Table 1 Some of the promising pearl millet hybrids under cultivation and seed production in India.

Zone/Environment	Breeding sector	Hybrids
A1 (rainy)	Public	HHB 67 improved, GHB 538, RHB 177, HHB 234
	Private	Bio70,Tejas
A (rainy)	Public	HHB 197, HHB123 ,MPMH 17,GHB 558, GHB 905, RHB 173,
	Private	Proagro 9444, Proagro 9444 Gold, 86 M 86, 86 M 88, Kaveri Super Boss, MP7792, Bio 8494, Nandi 5, Nandi 65, Big B, Guha, KBH 108, JKBH 676, Bio 70
B (rainy)	Public	CO 9, GHB 558
	Private	86M33, Mahyco 204, Kaveri Super Boss, MP 7872, Pratap, Proagro XL51, Ajeet 38, GK 1051, Tilak, Mahodaya 318
Summer	Public	GHB 526
	Private	86M11, 86M74, Proagro 9444, Proagro 9444 Gold, MP 7883, MP 7899, Nandi 5, Sagar 222

temperatures during flowering period exceed 42°C, leading to poor seed set and low grain yield in most of the hybrids. However, few hybrids with excellent seed set have been under cultivation which give 4-5 t/ha of grain yield and 8-10 t/ha dry fodder. Breeding for heat tolerance at ICRISAT and at some of the private sector research centres has been initiated, and several lines with high levels of heat tolerance have been identified.

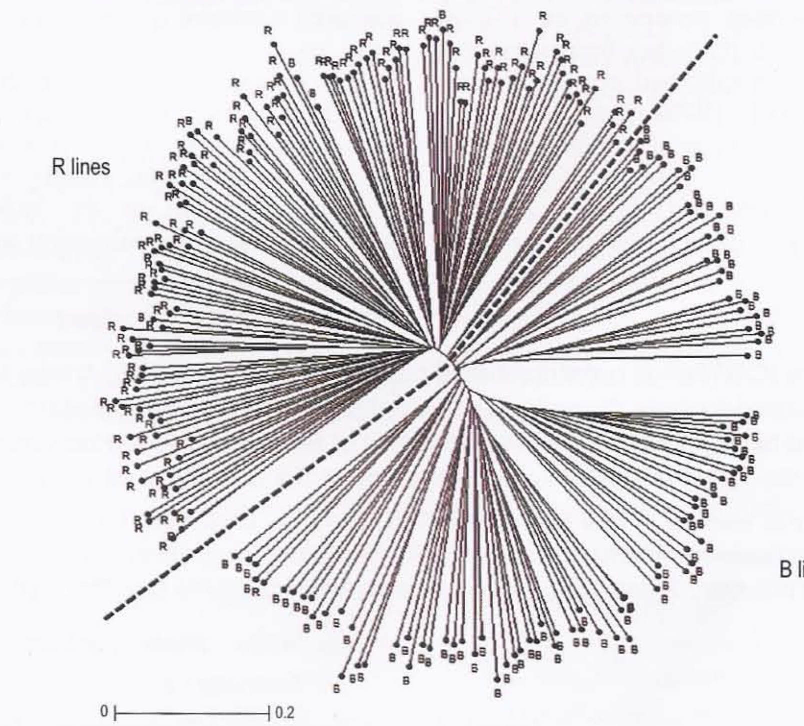
Micronutrient malnutrition arising from iron (Fe) and zinc (Zn) deficiencies has been recognized as serious public health problem worldwide, with India being among those most affected. A decade of biofortification research at ICRISAT with funding support from HarvestPlus Challenge Program of the CGIAR has developed and standardised a rapid, cost-effective and reliable X-ray Fluorescence Spectroscopy (XRF) technique that facilitates screening of a large number of breeding lines. Also, sources of high Fe and Zn contents have been identified and are being used at ICRISAT in breeding for Fe content as a target trait with Zn content being improved as an associated trait. Some of the leading programmes in public and private sectors are also increasing their efforts in breeding for these micronutrients.

CMS diversification

The A_1 CMS system has been in use for A-line breeding for more than half-century in India. Since only about 20% of the random breeding lines are maintainers of this CMS system, scope for genetic diversification for A-lines gets pretty restricted. Further, most of the A_1-system commercial A-lines produce varying, albeit low, frequency of pollen shedders, depending on their genetic backgrounds and the environments. CMS sources identified at various centres were systematically studied at ICRISAT and two of these designated as A_4 and A_5 were found to have more stable male sterility than the A_1 CMS system. Also, about 40% of the breeding lines were found to be maintainers of the A_4 CMS system, and >99% of the breeding lines were found to be maintainers of the A_5 CMS system, thus providing much greater opportunity for genetic diversification of A-lines and high-yielding hybrid development. ICRISAT pioneered the utilization of these two alternative CMS systems, and developed and disseminated 71 A-lines with A_4 cytoplasm and 18 A-lines with A_5 cytoplasm till 2013. Development and dissemination of their restorers is underway. There is also now greater appreciation by other public and private sector breeding programmes of the greater utility of these two CMS systems, who have started breeding their own A-lines and restorers.

Cultivar adoption and impact

In the first phase of the hybrid era (1966-1980), few hybrids were available. BJ 104 and BK 560 were the most widely cultivated hybrids. Due to narrow genetic base, both became susceptible to DM. Released in 1982, a highly DM resistant OPV (WC-C75) that had 99% of the grain yield and 20% more dry fodder yield than BJ 104, rapidly replaced BJ 104 and, to a larger extent, BK 560. The all, India cultivation of this variety



Note: "B" represents 98 B lines and "R" represents 1115 R lines

Clustering pattern of B-lines and R-lines of pearl millet based on molecular markers.
Source: Nepolean *et al.* (2012)

lasted about 12 years and it was cultivated on 0.6-1.2 million ha. Breakdown of DM resistance of a large-seeded and early-maturing hybrid MBH 110, which was widely cultivated in Maharashtra in 1980s, paved the way for release and rapid adoption of a large-seeded, early-maturing and DM resistant OPV (ICTP 8203) in 1988. ICTP 8203 was adopted on 0.8 million ha in Maharashtra at the peak of its adoption in mid 1990s.This variety still continues to be under cultivation. Now an improved version of ICTP 8203, designated as 'Dhanashakti', which has higher grain and fodder yield, and higher Fe content than ICTP 8203, is rapidly replacing the ICTP 8203. Other OPVs under cultivation are ICMV 221and Pusa composite 612 recommended for B zone; and JBV 2 and Pusa composite 383 recommended for 'A' zone. Some of the OPVs adapted to specific states are: PCB 164 (Punjab), HC-20 (Haryana), CoCu 9 (Tamil Nadu) and ABPC4-3 (Maharashtra). All these OPVs put together are cultivated on <500,000 ha.

Hybrids are the farmer-preferred cultivars in India owing to their grain yield advantage and phenotypic uniformity compared to OPVs. Although there has been a gradual decline in cultivated pearl millet area since early 1970s, there has been a gradual increase in production since mid-1990s, principally due to development and adoption of higher-yielding hybrids and consequently higher productivity. Hybrids are cultivated on more than 4.5 million ha. It is estimated that at present more than 120 hybrids (by name), mostly from private sector, are under cultivation, with the area covered by them dependent on their yielding ability, specific adaptation, seed cost, and marketing strategies of seed companies. This remarkable genetic diversification of on-farm hybrid cultivar base has contributed not only to higher productivity but also to stability of production. The productivity improvement has especially been remarkable during the last 15 years when pearl millet yield improved at the rate of 20 kg/ ha/ year (7% per year).

A comparison of average grain yield increase in 2006-2010 over the base level of 1986-1990 has shown that pearl millet yield increased by 73%, which was higher than that of maize (55%) and much higher than those for sorghum, rice and wheat (about 30%). Pearl millet area has steadily declined in relatively better-endowment environments of Punjab, Haryana, Uttar Pradesh, Maharashtra and Gujarat, but not so in the arid and low productivity environments of north-western India. In other words, the relative proportion of the A1 zone area compared to the combined area under A and B zone has increased over time. Yet there has been this remarkable increase in average productivity. A large number of productive hybrids are available for cultivation. Some of the most popular hybrids under cultivation and seed production are given in Table 1. Clearly there are very few options for A1-zone where only six hybrids are under cultivation, with HHB 67 improved being most popular. Four of these six hybrids are from public sector. While in A-zone there are several hybrids from the public sector, in B-zone as well as in the summer season most of the hybrids are from private sector. Thus, there is an obvious need to increase resources allocation, both from public and private sector, to breed hybrids for A1-zone; and from public sector for B- zone and summer season hybrid development. The highest priority, however, must continue for A and B zones.

SUMMARY

ICRISAT collected, introduced and assembled a large number of germplasm from various sources worldwide, and most significantly from western and central Africa (the primary center of diversity). It also developed a large number of trait-specific composites, and improved these by recurrent selection. These improved composites and OPVs as well as progenies derived from them were widely distributed to public and private sectors for utilization in their breeding programmes.

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