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ICRISAT Research Program
Markets, Institutions and Policies

Development and Diffusion of Pearl Millet Improved Cultivars in India:
Impact on Growth and Yield Stability

D Kumara Charyulu, Cynthia Bantilan, A Rajalaxmi, KN Rai, OP Yadav, SK Gupta, NP Singh and D Moses Shyam

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International Crops Research Institute
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1. Introduction

Pearl millet (*Pennisetum glaucum* (L) R.Br. emend. Stuntz) is an important cereal crop in the semi-arid tropics (SAT) of the world. It is the sixth most important cereal worldwide, and is the main food source in the poorest regions of Asia and Africa continents. It is the second largest millet crop in the world after sorghum. Pearl millet is known by various regional names such as *bajra* (Hindi), *sajja* (Telugu) and *kambu* (Tamil and Malayalam) in India. It is also the most drought-tolerant, warm-season coarse grain cereal grown in some of the harshest semi-arid tropical environments. It is a highly cross-pollinated crop with an outcrossing rate of more than 85 per cent.

Pearl millet is well-adapted to growing areas characterized by drought, low soil fertility, and high temperatures. It performs well in soils having high salinity or low pH. On account of its tolerance of difficult growing conditions, it can be grown in areas where other cereal crops such as sorghum and maize cannot even survive. It thrives well in regions with seasonal rainfall in 150-700 mm range. Pearl millet is an important crop in dryland agriculture in India but it also responds well to irrigation and improved management conditions. It is valued for both grain and stover: its grain is a major source of dietary carbohydrates in the human diet in western India, and its stover forms the basis of livestock rations during the dry period of the year in northern Indian states. Pearl millet grain have high protein content, a balanced amino acid profile, and also high levels of iron, zinc and insoluble dietary fiber. The forage is excellent because of its lower hydrocyanic acid content than sorghum.

Pearl millet cultivation is confined to the drier tracts of South Asia (mainly India) and Africa (Nigeria, Niger, Mali, Chad, Tanzania, Sudan and Senegal), where it is grown for grain and fodder purposes. In USA, Canada, Japan, Italy and Australia, it is grown over a small area, but mainly as a fodder crop. The global acreage under millets is around 34.79 m ha. India has a lion share (32.05%) of the area (FAOSTAT 2012), followed by Niger (20.84%), Nigeria (10.75%), Sudan (5.78%), Mali (4.2%), Burkina Faso (3.91%), Senegal (2.96%) and ROW[1] (19.28%).

Global millet production was estimated at 31.58 million tons in 2010-11. Pearl millet accounts for approximately 80% of this. India is the largest producer (42.08%) in the world followed by Nigeria (13.05%), Niger (12.12%), Burkina Faso (3.61%), Mali (4.31%), Senegal (2.56%) and Sudan (1.49%) and ROW (around 20.71%). The major share of global production comes from Asia (49.62%). Among Asian countries, India's share is around 84% followed by Pakistan and Yemen. All African countries together contribute half of the global millet production.

During the last three decades (1980-2010), the global area and production of millets reported an annual growth rate of -0.22% and 0.52% respectively. Between 1960 and 2010 (Fig. 1), the global area declined moderately (around 19%) while global production increased nearly 23%. However, the global average productivity of millets increased from 648 kg ha^{-1} to 900 kg ha^{-1} during the last three decades because of the adoption of improved cultivars and better management practices. The marginal increase in productivity levels was just able to stabilize production despite the decline in the cropped area in recent times. Productivity levels were higher in developed countries (1500-1800 kg ha^{-1}) than in Asia (900-1000 kg ha^{-1}) and sub-Saharan Africa (800 kg ha^{-1}).

1. ROW: Rest of the World.

Globally, pearl millet is distributed over 83 countries (Table 1). Nearly 37 African countries are dependent on the crop for subsistence. Millet area expansion has been rapid with an annual growth rate of 2.45% in West and Central Africa (WCA) due to the rising food demand during the last three decades. However, in Eastern and Southern Africa (ESA), crop area growth has been at a snail's pace because of strong competition from maize. Relatively, due to the low remunerative income from pearl millet, the crop has been losing its appeal in South, Southeast and East Asia in the recent past. However, India holds the prime position in terms of area and production of pearl millet (CGIAR Final Proposal on Dryland Cereals, 2012).

In India, pearl millet occupied the first place (9.61 m ha) in terms of the area under different coarse cereals in 2010-11 while in terms of production it stood third (10.36 million tons). From the early 1950s to 2010, pearl millet acreage in India showed wide fluctuations due to outbreaks of downy mildew and other biotic and abiotic stresses. However, productivity increased remarkably over a period of four decades from 430 kg ha^{-1} to 1079 kg ha^{-1}. Development and diffusion of improved cultivars along with suitable agronomic practices facilitated this sharp rise.

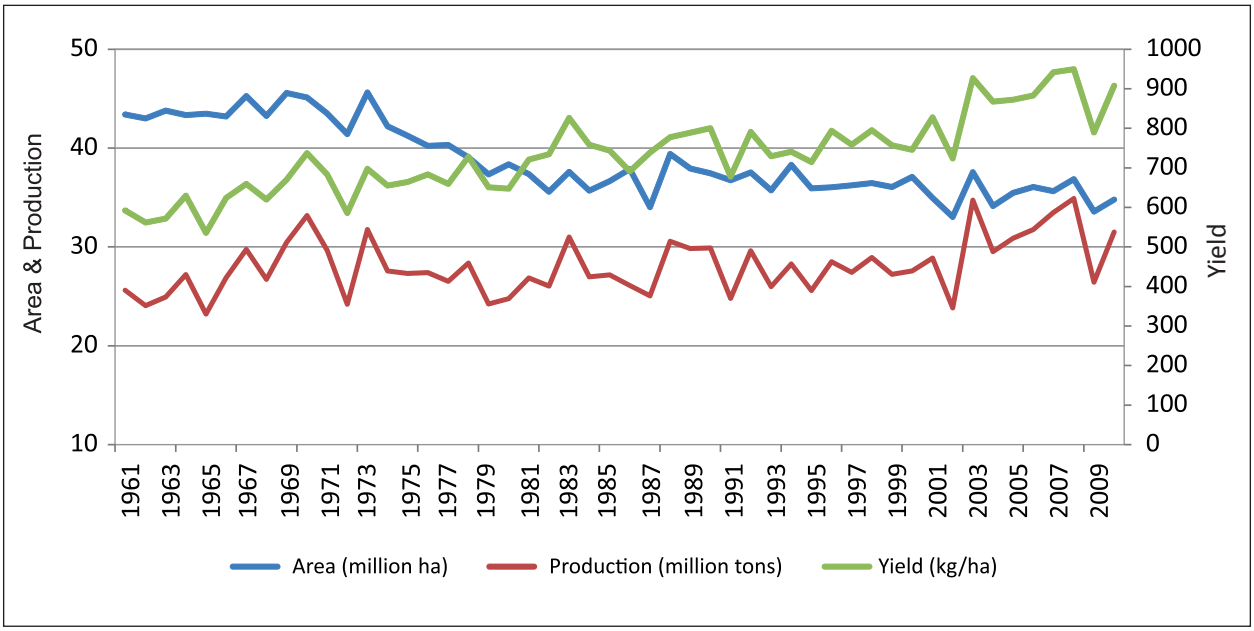


Figure 1. Global scenario of millets, 1961-2011.

Table 1. Global distribution of pearl millet, 2010-11.

Region	No. of countries	Area (m ha)	% of total	Production (mt)	% of total	Productivity (kg ha^{-1})
World	83	34.79	100.00	31.58	100.00	907.80
Asia	24	13.18	37.88	15.67	49.62	1189.30
Africa	37	21.11	60.68	15.26	48.32	722.90
Australia	1	0.03	0.09	0.03	0.09	966.00
America	3	0.15	0.43	0.27	0.85	1752.90
Europe	18	0.29	0.83	0.33	1.04	1113.70

Objectives of the Study

Given the importance of pearl millet, this paper studied the development and diffusion of pearl millet improved cultivars in India over the last five decades (1960-2011). The Indian Council of Agricultural Research (ICAR), through the All-India Coordinated Pearl Millet Improvement Project (AICPMIP), has been working for pearl millet crop improvement in the diverse agroecological zones of India from the early 1960s. Similarly, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), an International Agricultural Research Centre (IARC) established at Patancheru, Hyderabad, Telangana, has pearl millet as one of its five mandate crops and has been working on its development since 1972. ICRISAT has been playing a catalytic role in the maintenance and distribution of pearl millet core germplasm as well as development of parental lines in Asia (especially in India) and open-pollinated varieties (OPVs) in sub-Saharan Africa (SSA) during the past three and a half decades. Private seed companies (around 35) have been another key stakeholder in the rapid development of pearl millet in India, playing a very active role from the mid-1980s.

A comprehensive and systematic study of the development and diffusion of pearl millet improved cultivars in the major states of India would throw interesting insights into the history of crop improvement and its impacts on productivity and yield stability. Reliable information on crop varietal adoption is an important determinant of the food security and poverty benefits generated by investments in crop genetic research and development. However, current knowledge about the spread and impact of pearl millet improved cultivars in India is incomplete. Very little statistically valid information is available on the extent of adoption both at the national and subnational levels. Also, information on the rate at which recent vintages of improved varieties are replacing the earlier vintages, the sources of seeds and varieties (public and private) and the rate of seed replacement is absent/ insufficient. With these issues in mind, the present study made an effort to understand the benefits of pearl millet improved cultivars for small and marginal farmers in the semi-arid tropics (SAT) of India.

2. Pearl Millet Trends in India

In terms of area, pearl millet is the third most important cereal in India after rice and wheat. It is predominantly grown as a grain crop but is also valued for its stover and fodder. During the 1970s, pearl millet production in India was characterized by subsistence cultivation with a small marketable surplus. But in recent years it has become a more market-oriented crop owing to the change in its utilization; apart from mainly food uses, it is now put to many other alternative uses such as animal feed, potable alcohol, processed food, etc. In spite of a lot of systematic pearl millet research conducted in India since the 1960s, the cropped area witnessed a fall from 12.23 m ha to 9.61 m ha between 1966 and 2010. This declining trend has been much more evident from the early 1980s to the present day. Farmers have moved away from pearl millet cultivation due to the frequent outbreaks of downy mildew, changing consumption habits, lower remuneration from pearl millet cultivation compared to other commercial crops and lack of good demand for grain. However, despite the fall in acreage, production has more than doubled from 4.5 m tons to 10.36 m tons during the same period (Fig. 2). This was made possible by increasing productivity levels through adoption of improved cultivars. Research efforts during this period were aimed at breeding high-yielding cultivars and identifying innovative production and protection practices/management. Improved cultivars suited to arid and semi-arid environments were developed and quality seed of these cultivars was made available to farmers, which resulted in a significant increase in productivity from 323 kg ha^{-1} in 1950-54 to 950 kg ha^{-1}in 2006-10. The average annual increase in productivity was around 11.1 kg ha^{-1} per year from 1950 to 2011 (Fig. 3).

While acreage under pearl millet showed an annual growth rate of -0.80% over a period of three decades (1980-2010), production grew 1.94% (Table 2). Growth in pearl millet productivity has been much higher than the other two coarse cereals, i.e., maize and sorghum.

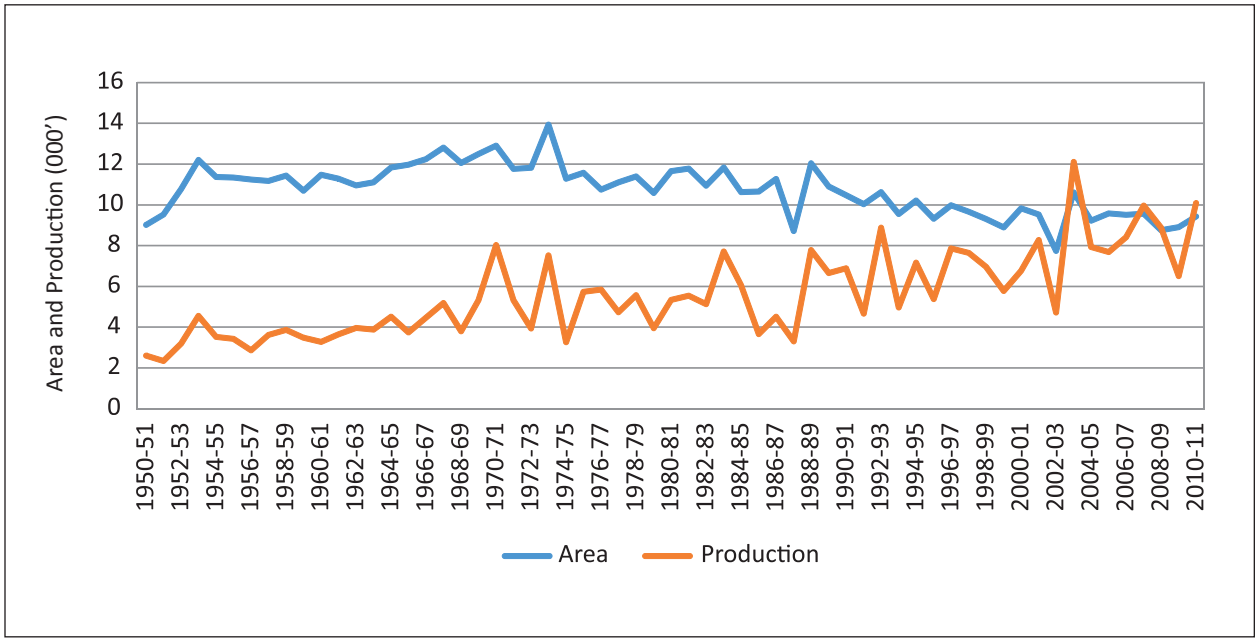


Figure 2. Performance of pearl millet in India, 1951-2011.
Source: Ministry of Agriculture, India.

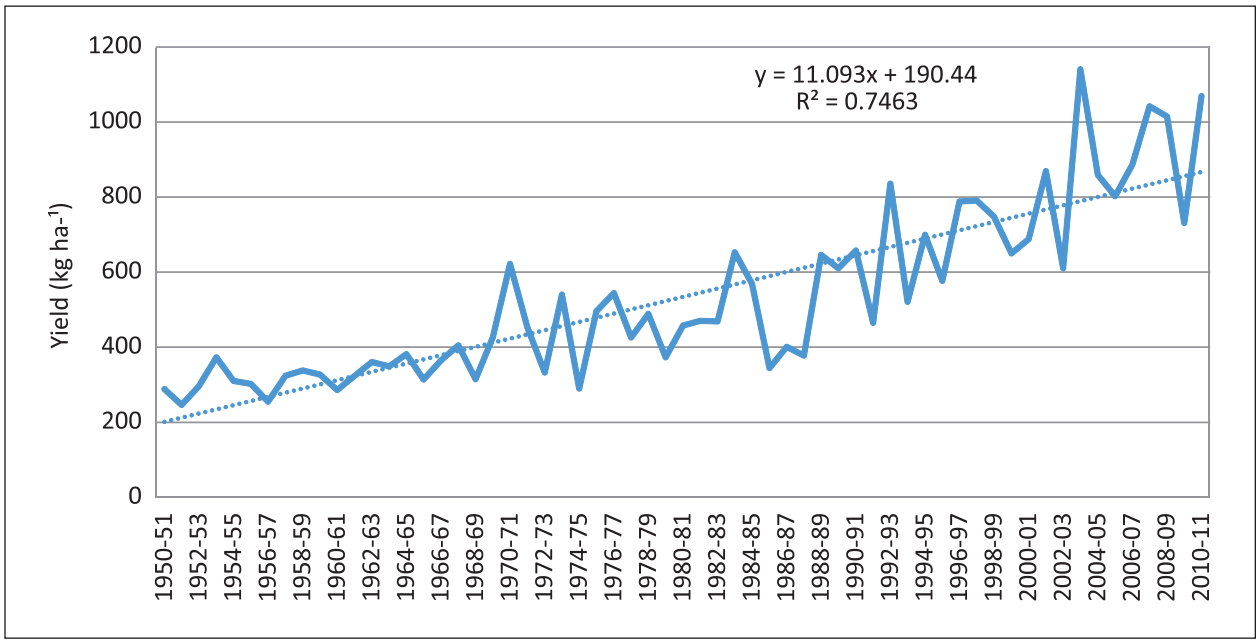


Figure 3. Productivity of pearl millet in India, 1951-2011.

Table 2. Growth (%) of pearl millet area, production and productivity in India, 1980-2010.

Period	Area	Production	Productivity
1980-85	-1.94	-3.41	-1.49
1986-90	0.79	16.75	15.82
1991-95	-1.84	0.68	2.57
1996-00	-1.13	-5.66	-4.57
2001-05	1.88	3.75	1.84
2006-10	-0.51	-0.12	0.38
1980-10	-0.80	1.94	2.76

Performance of Pearl Millet Across Major States

Out of India's total pearl millet acreage of 9.61 m ha (2010-11), the lion's share is occupied by Rajasthan (57%) followed by Maharashtra (11%), Uttar Pradesh (10%), Gujarat (9%), Haryana (7%) and Karnataka (3%) states. Rajasthan's share of the cropped area increased significantly from 39% to 57% between 1966 and 2010. Rajasthan, Uttar Pradesh, Gujarat, Haryana and Maharashtra together contribute nearly 93.5% of the total area. Similarly, the major share of India's total pearl millet production (10.36 m tons in 2010-11) is contributed by Rajasthan (45%) followed by Uttar Pradesh (15%), Haryana (12%), Gujarat (11%) and Maharashtra (11%). The highest productivity levels were observed in Madhya Pradesh and Haryana with 1898 kg ha^{-1} and 1793 kg ha^{-1}respectively in 2010-11. Average yields were the lowest in Rajasthan because of low adoption of improved cultivars.

Long-term growth rates in pearl millet area, production and productivity are summarized state wise in Table 3. All the states except Rajasthan exhibited negative growth in area during the 1970-2010 period. The highest negative growth rate was observed in Andhra Pradesh followed by Tamil Nadu and Gujarat. Similarly, the decline in production was also the highest for Andhra Pradesh (-4.5%) followed by Tamil Nadu (-3.58%). Significant positive growth in production was observed in Rajasthan, Maharashtra and Karnataka. Interestingly, the overall (1971-2010) productivity growth rates were positive for all the states, with Haryana registering the highest followed by Rajasthan and Maharashtra.

Productivity Growth Across Major States

Mean productivity levels across the major pearl millet growing states showed a consistent improvement over the study period (1971-2010). The highest productivity levels (>1200 kg ha^{-1}) were observed in Haryana, Uttar Pradesh, Madhya Pradesh and Gujarat during the last decade, i.e., 2001-2010. During the first decade of the study (1971-80), productivity levels in these states had only been around 600-800 kg ha^{-1}. In other words, yields have almost doubled. This could only have been possible through development of improved cultivars and ensuring their availability to farmers. Figure 4 shows the consistent improvement in productivity across the major states during the last four decades.Phenomenal growth in productivity was seen in Haryana followed by Uttar Pradesh. Long-term (1971-2010) average yields in states like Maharashtra and Karnataka were in the region of 500-600 kg ha^{-1}. The lowest productivity levels (400 kg ha^{-1}) were observed in Rajasthan. But yields increased remarkably in that state between the third and fourth study periods. Development of public and privately bred pearl millet cultivars and their adoption, particularly in Rajasthan, helped to push production and productivity significantly. Overall, India's productivity levels improved significantly from 440 kg ha^{-1} in 1971-80 to 870 kg ha^{-1} during 2001-10.

Table 3. Statewise growth rates (%) in pearl millet area, production and productivity, 1971-2010.

State	Item	1971-80	1981-90	1991-2000	2001-2010	1971-2010
Andhra Pradesh	Area	-0.72	-8.68	-4.13	-6.85	-6.51
	Prod.	4.41	-8.49	-0.96	-0.81	-4.50
	Yield	5.17	0.21	3.30	6.49	2.14
Gujarat	Area	-3.83	-2.28	-2.77	-3.04	-1.94
	Prod.	1.05	-4.05	-8.66	-2.39	-0.28
	Yield	5.66	-1.81	2.00	-1.55	1.54
Karnataka	Area	5.44	-1.61	2.03	1.47	-1.43
	Prod.	4.63	-1.61	3.69	7.13	0.04
	Yield	-0.77	1.39	1.62	5.58	1.49
Maharashtra	Area	1.48	2.23	-0.58	-4.80	-0.71
	Prod.	10.30	7.34	0.17	-0.54	2.52
	Yield	8.69	4.99	0.75	4.48	3.26
Rajasthan	Area	-1.72	0.09	-1.10	2.21	0.17
	Prod.	-5.04	5.78	2.34	4.93	3.75
	Yield	-3.38	5.69	3.48	2.67	3.57
Tamil Nadu	Area	-2.44	-2.70	-6.55	-11.23	-5.32
	Prod.	2.09	-0.18	-4.78	-6.06	-3.58
	Yield	4.65	2.59	1.89	5.83	1.84
Madhya Pradesh	Area	-1.95	-0.22	-0.49	-0.49	-0.41
	Prod.	-7.29	5.21	4.84	4.62	-0.41
	Yield	-5.45	5.44	5.35	5.14	2.93
Uttar Pradesh	Area	-1.01	-2.95	1.47	0.54	-0.53
	Prod.	-1.42	1.02	4.83	4.42	-0.53
	Yield	-1.05	4.09	3.31	3.86	2.88
Haryana	Area	-0.73	-3.69	0.60	1.36	-1.38
	Prod.	-4.76	-1.31	5.50	6.40	-1.38
	Yield	-4.06	2.47	4.87	4.95	3.83

Statewise Shifts in Pearl Millet

Details of the shifts in the pearl millet cropped area across major states between 1966-68 and 2008-10 are summarized in Figure 5. At the national level, cropped area declined significantly from 12.33 m ha in 1966-68 to 9.09 m ha in 2008-10 due to the crop losing considerable ground in states like Punjab followed by Andhra Pradesh and Tamil Nadu. In addition, there was also a notable drop in cropped area during the same period in Madhya Pradesh, Haryana and Maharashtra. With the introduction of Green Revolution technologies, Punjab totally lost its area under pearl millet. Improved irrigation facilities in other states encouraged farmers to shift from pearl millet to new commercial crops like cotton, soybean and maize. However, in Rajasthan, pearl millet area increased from 39% to 57%, making it the single largest bajra growing state in India. Cropped area was more or less stable in states like Karnataka, Uttar Pradesh and Gujarat .

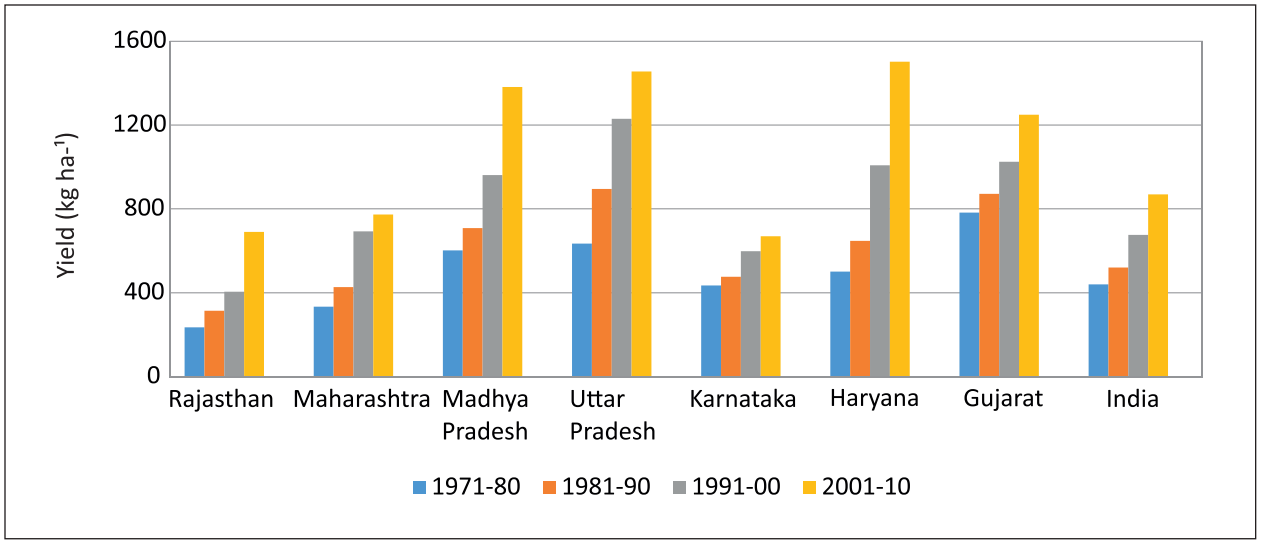


Figure 4. Mean productivity levels of pearl millet in major states of India, 1971-2010.

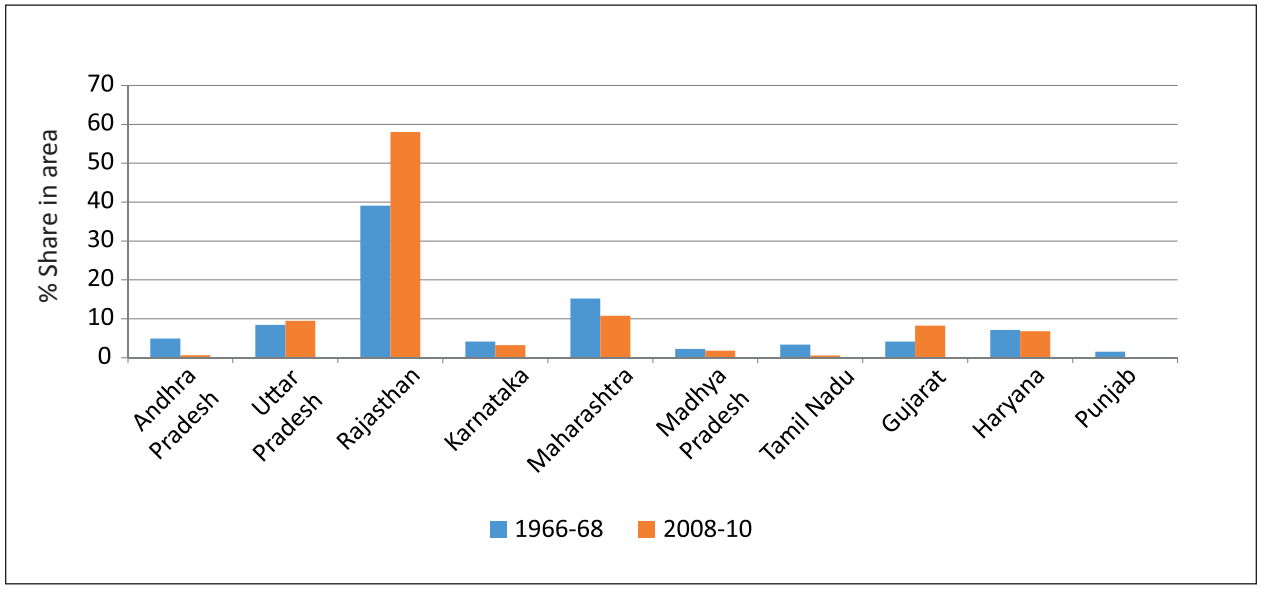


Figure 5. Statewise shifts in pearl millet cropped area, 1966-2010 (% area).

Source: Directorate of Economics and Statistics, Government of India.

Despite the decline in cropped area, production has increased in all major pearl millet growing states. This is attributed to increased productivity due to the adoption of CMS-based improved technology and introduction of high-yielding hybrids in the late 1980s (Bidinger and Parthasarathy Rao 1990). Rajasthan's share of production increased significantly from 23% in 1966-68 to 42% in 2008-10 (Fig. 6). In contrast, Gujarat's share dropped from 21% to 12% during the same period. Other major states exhibited stable production trends over time.

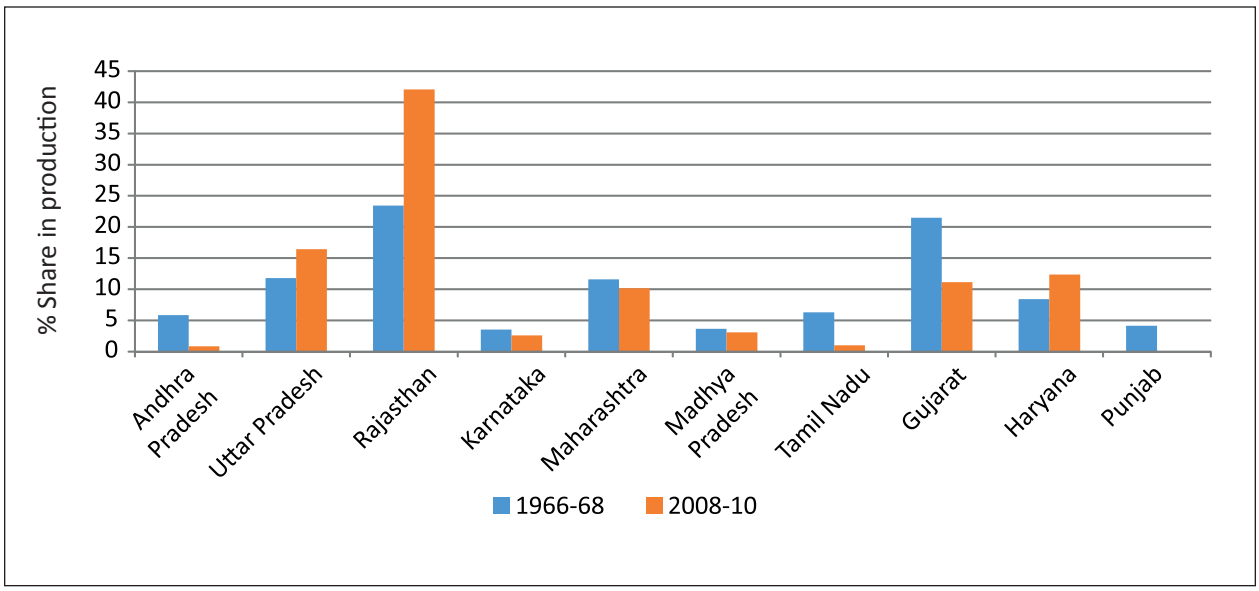
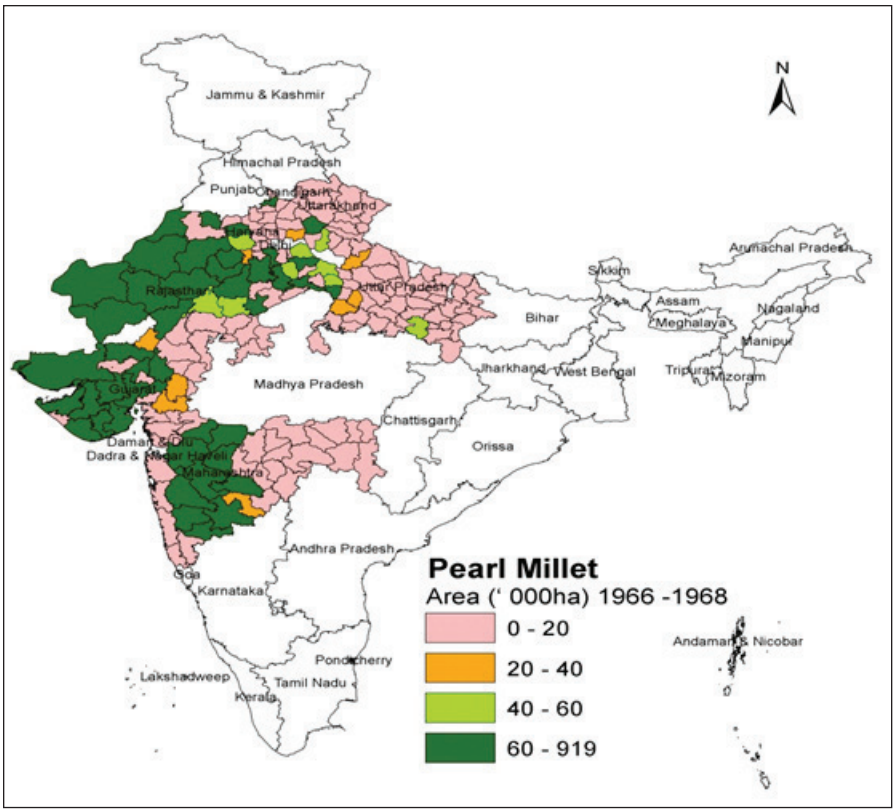


Figure 6. Statewise shifts in pearl millet production, 1966-2010.

Districtwise Spatial Distribution of Pearl Millet Among Major States

Figure 7 and Figure 8 summarize the spatial distribution of pearl millet cropped area over two time periods, i.e., from 1966-68 to 1986-88 (Period -1) and from 1991-93 to 2005-07 (Period-2) respectively. During the first period, the pearl millet cropped area was much stable among major states. But, higher concentration (> 60,000 ha) of district-wise spatial distribution of crop could be observed in case of Rajasthan, Gujarat and Maharashtra. It was sparsely distributed in case of Uttar Pradesh, Uttarakhand and Haryana states. Similarly, between 1991-93 and 2005-07, the high cropped area concentrations (> 120,000 ha) were more confined to Rajasthan and Western Maharashtra. Significant cropped area has lost in case of Gujarat state while the same was more or less stable in Uttar Pradesh and Haryana states.



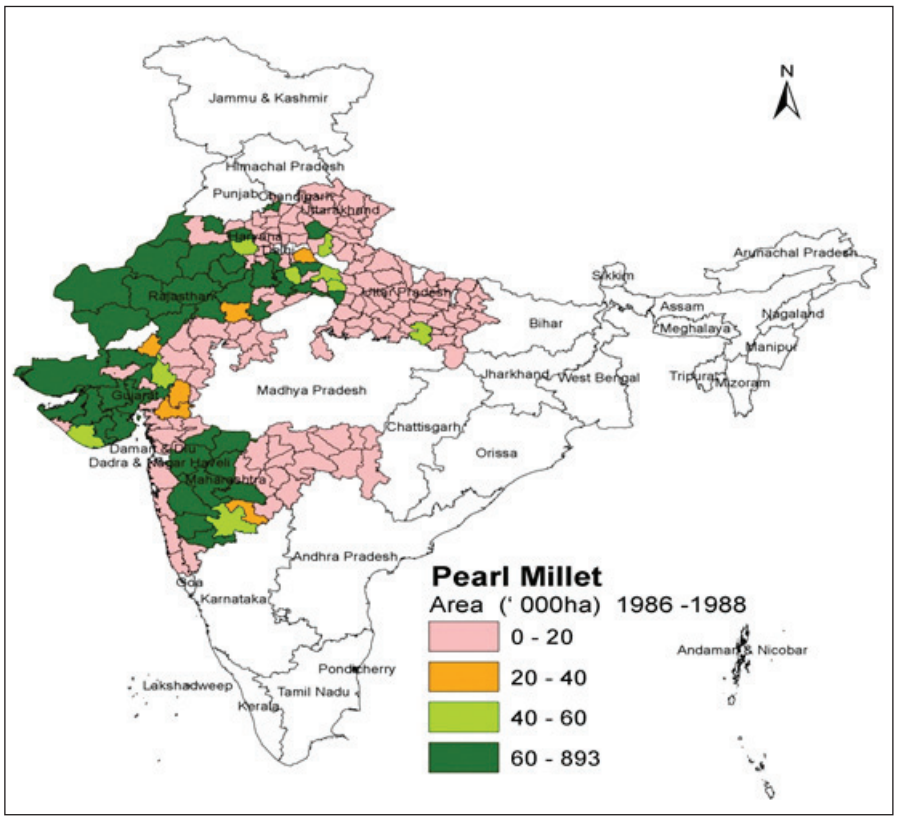
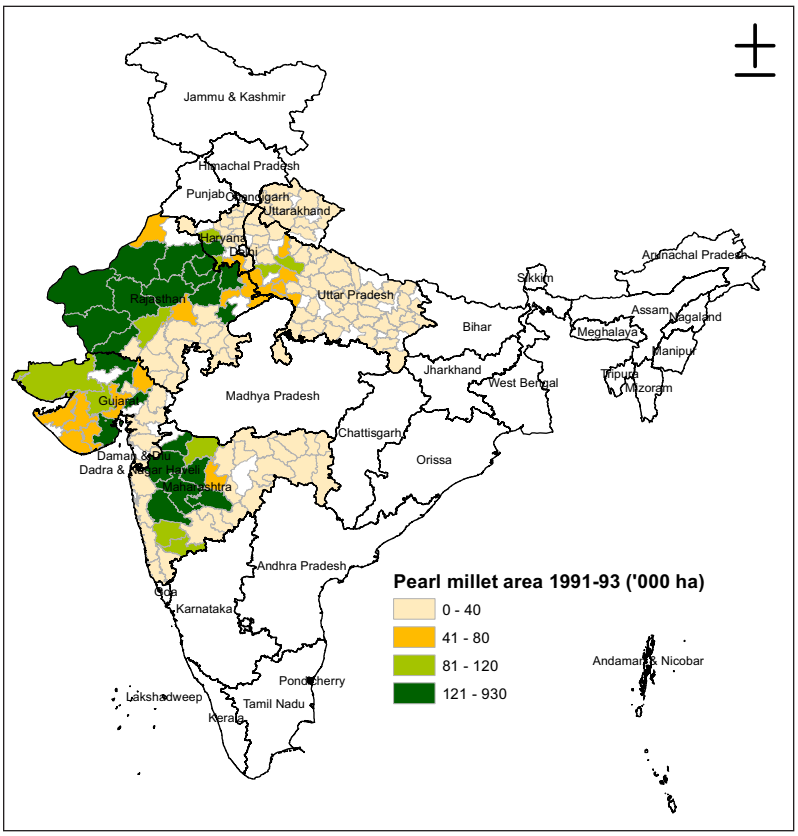


Figure 7. Districtwise spatial distribution of pearl millet cropped area, 1966-68 to 1986-88.



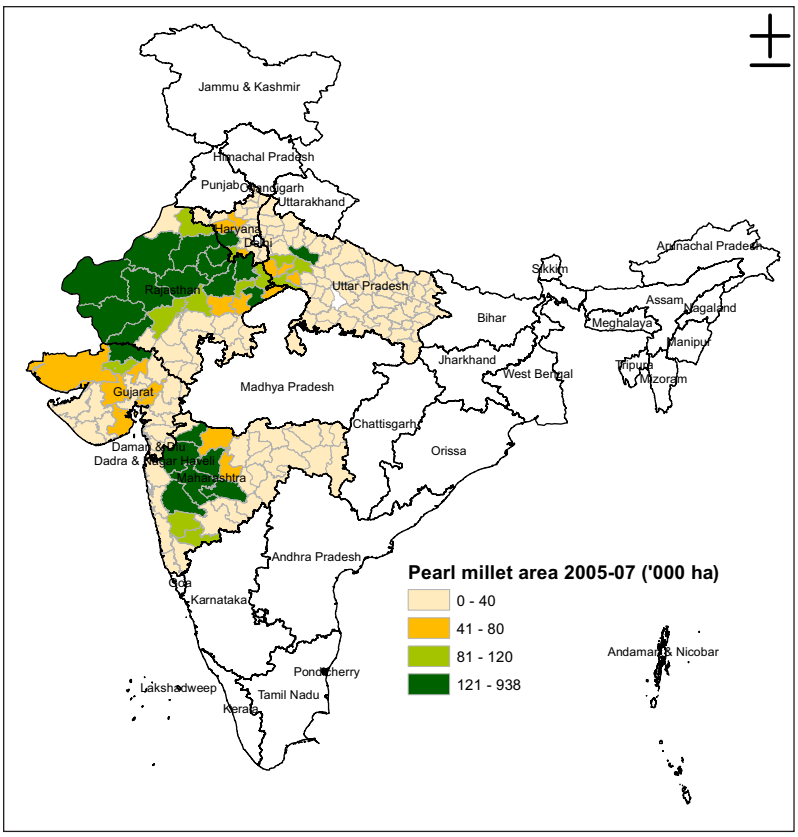


Figure 8. Districtwise spatial distribution of pearl millet cropped area, 1991-93 to 2005-07.

Utilization Pattern of Pearl Millet in India

Over the last four decades, utilization of pearl millet in India has spread from traditional use as food to alternative uses as feed and raw material in the alcohol and food processing industries. Consumption has been moving in tandem with the production curve as pearl millet is finding demand from the industrial sector in addition to the food demand (Fig. 9). Pearl millet is consumed mainly in the rural areas of western and central India. However, since the Green Revolution, there has been stagnation in consumption for the cereal group in general and coarse cereals like sorghum and pearl millet in particular. The annual per capita consumption of pearl millet in India has declined by 57% from an average of 14 kg in 1998 to only 6 kg in 2003 (CWC 2003); the current level is about 5 kg (Parthasarathy Rao et al. 2006). Among the major pearl millet producing regions, per capita consumption was highest (92 kg) in rural Rajasthan and the dry areas of Gujarat. In those two regions, pearl millet accounts for more than 50% of cereal consumption, contributing about 20-40% of the total energy and protein intake. Consumption in both rural and urban India has decreased owing to the availability of rice and wheat through the Public Distribution System (PDS), which require less preparation time. Moreover, pearl millet and sorghum are perceived as an inferior grains. Some of the other contributing factors to this trend are the increase in per capita income, growing urbanization and changing tastes and preferences (Radhakrishna 2005).

According to Parthasarathy Rao et al. (2011), per capita consumption of pearl millet, across income groups both in rural and urban areas, showed an inverse relationship with income in all the three major states (Rajasthan, Gujarat and Haryana). There was not much variation in consumption of pearl millet between the middle and low-income groups in Rajasthan and Haryana, and to some extent in Gujarat, due to the cold winter climatic conditions. Lower income groups (involved in farming) in the rural areas of Rajasthan have the highest per capita consumption of pearl millet (32.8 kg) annually followed by Gujarat (28.6 kg) as it provides more energy compared to the fine cereals.

In contrast, the urban areas showed significant variation in consumption of pearl millet across income groups. Consumption sharply declines as we move from the low- to high-income groups. Low-income groups in the urban areas of Rajasthan and Gujarat consume 9.4 kg and 9.2 kg per person per annum respectively. In Haryana, however, consumption is very low irrespective of the income level, with the

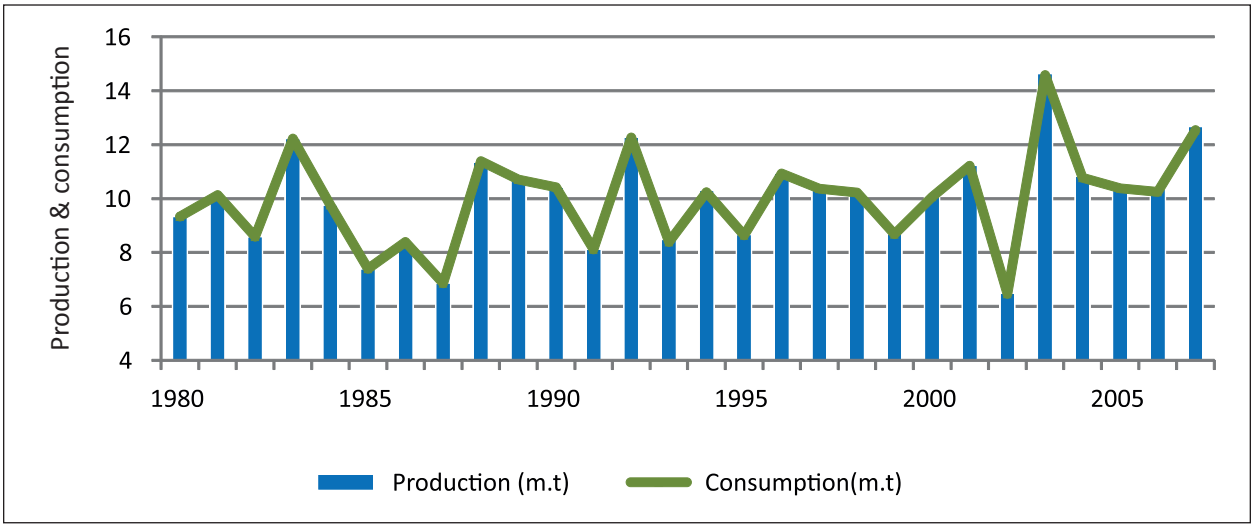


Figure 9. Production and consumption of pearl millet in India.

low-income group consuming around 0.4 kg. The major factors explaining this declining consumption trend are the low keeping quality of pearl millet, more cooking time, special skills required in preparing *rotis,* etc. While food consumption of pearl millet is declining, industrial demand has been picking up over a period of time. To meet the changing utilization pattern there is a need to tailor research objectives to attain higher productivity as well as production levels.

3. Research Organization and History of Crop Improvement Strategies

NARS Crop Improvement Strategies

In the early 1940s, sporadic efforts were initiated by the Indian Council of Agricultural Research for pearl millet crop improvement in India. However, systematic research was only started in the late 1960s with the establishment of the All-India Coordinated Millets Improvement Program (AICMIP) with its headquarters at the Indian Agricultural Research Institute (IARI), New Delhi. The headquarters was shifted to Pune in 1977. In 1985, pearl millet was separated from the other millets, and the All-India Coordinated Pearl Millet Improvement Project (AICPMIP) was initiated, with its headquarters also in Pune. After ten years, in July 1995, ICAR shifted the headquarters of AICPMIP to Mandore, Jodhpur in Rajasthan. Currently, AICPMIP is mandated to conduct and coordinate research activities in the improvement of pearl millet. It has a network of 14 AICRP (All India Coordinated Research Project) centers located at 12 state agriculture universities (SAUs) and the University of Mysore and 17 volunteer centers (see Fig. 10 and Table 4).

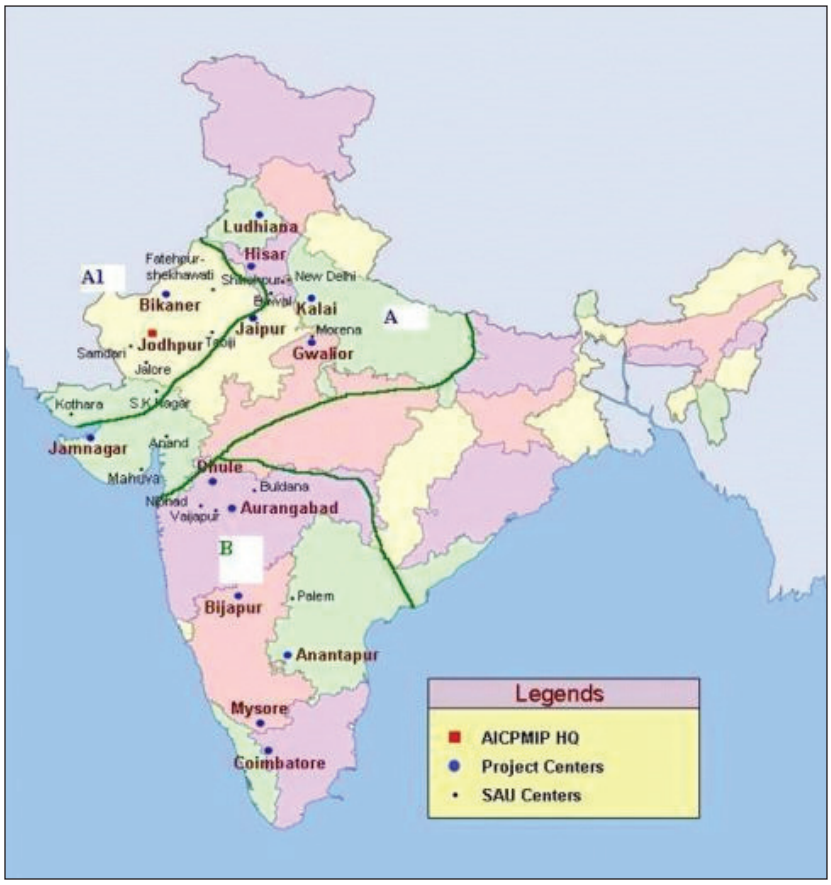


Figure 10. Pearl millet NARS research organization in India.

Table 4. AICPMIP main and voluntary centers in India.

Project Coordinated Centers	Voluntary Centers
CCS Haryana Agricultural University, Hisar	IARI, New Delhi
JAU, Millet Research Station, Jamnagar, Gujarat	CAZRI, Jodhpur, Rajasthan
SKRAU, Jaipur,Rajasthan	SKRAU, Mandor, Rajasthan
TNAU, Coimbatore,Tamil Nadu	SKRAU, Samdari, Rajasthan
MPKV, Dhule, Maharashtra	SKRAU, FatehpurShekhawati, Rajasthan
UoM, Mysore,Karnataka	SKRAU, Tabiji, Ajmer, Rajasthan
UAS,Bijapur, Karnataka	SKRAU, Jalore, Rajasthan
PAU, Ludhiana,Punjab	SDAU, Kothara, Rajasthan
RVSKVV, Gwalior,Madhya Pradesh	SDAU, S.K Nagar, Rajasthan
ANGRAU, Anantapur, A.P.	GAU, Mahuva, Gujarat
SKRAU, Bikaner,Rajasthan	AAU, Anand, Gujarat
MAU, Aurangabad, Maharashtra	CCSHAU, Bawal, Haryana
CSAUA&T, Aligarh,Uttar Pradesh	IARI (KVK)Shikohpur,
	RVSKVV, Morena,
	MPKV, Niphad, Maharashtra
	PDKV, Buldana, Maharashtra
	MAU, Vaijapur,
	ANGRAU, Palem, A.P.

Source: AICPMIP Annual Report, 2009

The AICPMIP is also one of the National Active Germplasm Sites (NAGS) working actively in the area of collection, conservation, characterization, evaluation and documentation of pearl millet genetic resources in cooperation with the National Bureau of Plant Genetic Resources (NBPGR) and ICRISAT as part of the effort to build a pearl millet gene bank. In fact, the collection and assembling of pearl millet germplasm began in the 1970s. As there is great variability in pearl millet germplasm, selection is possible for most traits of economic importance. This germplasm has contributed significantly to crop improvement in terms of yield, resistance and utilization/quality traits.

In addition, AICPMIP also conducts strategic research activities on pearl millet in the areas of germplasm utilization, crop improvement, crop management, value addition, etc. Initially its emphasis was on organizing research activities and conducting multilocational experimental trials to identify cultivars with high grain yield and broad-adaptation OPVs by using simple plant selection and mass selection. Later, during the 1970s and 1980s, the focus spread to the development of cultivars resistant to biotic and abiotic stresses along with yield enhancement. After discovery of cytoplasmic male sterility (CMS), the focus of NARS research shifted to development of hybrids to overcome downy mildew infestation and yield enhancement. The AICPMIP has played a significant role in developing a diverse range of improved breeding materials and parental lines of hybrids. These lines have been used extensively to develop and commercialize a large number of hybrids. By the end of 2011, 208 improved cultivars were released and notified. This includes both national and state releases.

Through ICAR, AICPMIP collaborates extensively with international and national organizations in developing and sharing germplasm and improved breeding material and in conducting strategic

research in diversification of hybrid parental lines, trait-based breeding, marker-assisted selection and biofortification. This partnership has been critical for research in crop improvement. Equally, AICPMIP also has close collaborations with private seed companies.

Pearl Millet Crop Improvement Strategies at ICRISAT

Owing to the importance of pearl millet for food, feed and fodder purposes, ICRISAT has been engaged in research on improvement of the crop since the late 1970s. ICRISAT has a global mandate for conserving the genetic resources of pearl millet and enhancing its productivity in Asia and Africa, and considerable efforts have gone into improving productivity through genetic enhancement. These efforts included participating in collaborative research with multiple partners in the national agricultural research systems (NARS), advanced research institutes (ARIs), private sector and nongovernmental organizations (NGOs). ICRISAT has been involved in pearl millet crop improvement through prebreeding as well as breeding research methods since the late 1970s.

Prebreeding research. The broadly focused research effort in the initial years led to the collection of a wide variety of germplasm in the ICRISAT gene bank at Patancheru in Hyderabad, India. The gene bank now serves as a major repository of pearl millet germplasm in the world. As of December 2010, it holds around 21,594 accessions from 50 or so countries, making it the single largest collection of pearl millet germplasm assembled at one place. It includes samples from institutions (10,201), farmers' fields (6,537), commercial markets (1,681), farmers' stores (1,357) and threshing floors (479) apart from wild species. In spite of such a large collection, very limited use has been made of it in crop improvement programs due to the lack of information about the usefulness of the collection. To enhance the use of this germplasm in crop improvement, the concept of a core collection (2094 accessions) and a mini-core collection (238 accessions) was developed with minimum loss of variability. The mini-core collection captures 90 per cent of the range of variation contained in the core collection. The collected germplasm has been evaluated for economic traits, and is conserved and maintained under controlled conditions. The germplasm is supplied on request to the end users for their crop improvement. Some 52,901 samples from the collection have been supplied to ICRISAT researchers and 93,246 samples to non-ICRISAT researchers during the 1974-2008 period. These samples, belonging to 17,262 accessions representing 80% of the entire collection, were supplied against 1147 requests (from the public and private sectors), from 74 countries (Upadhyaya et al. 2009).

Crop breeding research. Research on pearl millet genetic improvement at ICRISAT began with an emphasis on applied rather than basic research. To complement the NARS system, there was greater emphasis on population improvement and development of open-pollinated varieties (OPVs).The main focus was on enhancing grain yield, developing downy mildew (DM) resistance, explanatory research on ergot, smut and rust resistance and drought tolerance. However, the key biological factors that led to the commercialization of hybrids were the superiority of hybrids over OPVs across environments, the availability of stable cytoplasmic male sterility (CMS) and fertility restorers, and a high degree of heterosis for enhancing grain yield.

In India, the first pearl millet commercial hybrid HB 1 was developed by the Punjab Agricultural University (PAU) in 1965. It had twice the grain yield of the improved OPVs then in use. This demonstration of hybrid potential boosted the struggling hybrid research program that had until then been mostly confined to heterosis studies and development of 'chance hybrids'. However, widespread cultivation of a few single-cross hybrids during the initial phase of the hybrid development program resulted in downy mildew epidemics in India. Therefore, ICRISAT research focused on CMS diversification, and bred genetically diversified hybrid parents. Along with seed parent development,

population improvement and development of composites and synthetics, a major thrust was given for development of OPVs at ICRISAT. The guiding principles behind this cultivar strategy were:

- ICRISAT research would complement the efforts of the NARS by providing genetically diverse populations from which NARS could develop parental lines of potential hybrids.
- High-yielding OPVs competitive with hybrids are possible, and technologies for OPV development and seed production are technically easier and more economical than hybrids.
- OPVs would be less vulnerable than hybrids to diseases.
- OPVs would have more stable yields and would be more widely adapted than hybrids.

Thus, ICRISAT made rapid progress in breeding high-yielding OPVs of pearl millet, releasing its first OPV (WC-C 75) in 1982. This was made possible by the introduction of radically different and more productive germplasm from West and Central Africa (WC-C 75 from Nigeria and ICTP 8203 from Togo). But the sustainability of grain yield improvement through OPVs remained largely uncertain in India. In Africa, OPV breeding had only a limited impact, and there was also a realization that not much headway can be expected in pearl millet productivity unless the private sector got involved in technology upgradation and the seed business.

On the NARS side of pearl millet research, the thrust on hybrids intensified, with increased participation of the private sector in hybrid production, seed multiplication and sale. Since the late 1990s, there has been a significant decline in work related to OPV development in the ICRISAT research program, especially in Asia, primarily because of greater attention was being paid to development of hybrids, which have yield superiority over OPVs. Therefore, ICRISAT gradually reoriented its pearl millet research, bringing it in line with NARS research priorities.

Applied hybrid parent research at ICRISAT (Patancheru) has made significant contributions to enhancing hybrid cultivar diversity and increasing pearl millet productivity in India. More emphasis was placed on hybrid parent development to align ICRISAT's research focus with the regional priorities of the NARS and the rapidly expanding private seed sector. However, pearl millet hybrids have benefited from the relatively better endowed environments in India whereas in marginal environments the challenge still remains. Ultimately, ICRISAT's pearl millet research followed a strategy of developing improved breeding lines and potential hybrid parents, and left the development, testing and release of hybrids to the NARS and the private sector. At ICRISAT, these materials are generated and disseminated as international public goods (IPGs). The hybrid parent research at ICRISAT, Patancheru has a major focus on downy mildew (DM) resistance development followed by smut and ergot resistance with maturity duration, mostly in the range of 75-85 days. However, studies conducted at ICRISAT have found that breeding hybrids and their parents for resistance to smut and ergot—especially the latter—is much more difficult than breeding for resistance to DM. Although drought is a major abiotic constraint in pearl millet production, breeding for tolerance of this trait has been treated as a strategic research issue due to the complexities involved in screening and breeding and the limited success attained through conventional breeding.

In Africa, however, the development of OPVs continues to be the primary objective of pearl millet research. The reasons include: 1) ease and economy of seed production; 2) relatively less vulnerability to DM, smut, ergot, etc; and 3) absence of an organized seed industry. But longer panicles with thicker stems are the other traits that are more preferred in the African region than in Asia. Another character of high priority could be photoperiod sensitivity, which plays a significant role in adaptation. However, in the Southern African Development Community (SADC) region, the initial work done on hybrids has already exhibited more potential than OPVs. The critical need for regionally adapted seed parent research has been recognized in both the African regions (ESA and WCA) for a successful hybrid development program.

In the later stage of research, the biotechnological approach to genetic enhancement is increasingly being integrated with mainstream conventional breeding. It enhances the speed and precision of breeding, giving it a good probability of success with acceptable cost effectiveness. The more intractable problems such as drought tolerance in pearl millet are being addressed through marker-assisted technology. Marker-Assisted Selection (MAS) has proved effective in pyramiding the resistance genes for downy mildew in pearl millet, leading to the development of a resistant version (HHB 67-2) of an extra-early-maturing and highly popular commercial hybrid (HHB 67). In the last four decades, extensive research efforts by ICRISAT in partnership with NARS have helped in the development of various breeding products like improved cultivars with various economic traits (yield, biotic and abiotic stress-resistant cultivars). Around 163 cultivars have been developed globally and released in several countries in Asia (89) and Africa (74). Besides these, breeding efforts at ICRISAT have led to the development of various types of screening techniques for various biotic and abiotic stresses, elite lines and gene pools. During 1981-2010, ICRISAT also developed 162 male-sterile lines (A-lines) and their counter maintainers (B-lines). As a whole about 1731 restorers lines were developed and designated by ICRISAT between 1985 and 2008 (Gupta et al. 2011).

Development of hybrids with high-yield potential and advancement in biotic and abiotic stress-resistant hybrids are the major research foci of ICRISAT at present. Additionally, the institution is concentrating on development of forage hybrids, salinity-tolerant hybrids, biofortification of popular pearl millet cultivars (in collaboration with Harvest Plus), etc.

Pearl Millet — Hybrid Parents Research Consortium (HPRC)

The partnership between ICRISAT and the private seed sector strengthened with the formation of a Hybrid Parents' Research Consortium in 2000 with the basic objective of increasing farmers' accessibility to better hybrids through effective public-private partnerships. As of 2010, 25 seed companies were members of the consortium, benefitting from the pearl millet research conducted at ICRISAT. The consortium has helped in increasing accessibility to improved cultivars and their adoption as well.

The potential hybrid JKBH 26, developed by JK Agri Genetics, is based on an A-line that has no other hybrid, public or private, in the market. This hybrid has been under cultivation since 1996, and has retained its initial high level of downy mildew resistance. The hybrid has been adopted by an increasing number of farmers for its high grain and stover yield as well as its high level of downy mildew resistance. It reached a peak adoption level of more than 400,000 ha in 2005. Another hybrid, 9444, was developed by Pro-agro Seed Company (now Bayer Bio Science). It too is highly valued for its high grain and stover yield, good stover quality (farmers' perception), and downy mildew resistance. This hybrid is also tolerant of temperatures as high as 45°C during flowering time. The adoption of this hybrid rapidly increased from 60,000 ha in 2001 to more than 400,000 ha in 2006 (Mula et al. 2007; Pray and Nagarajan, 2009).

A total of 103 hybrids were developed between 2000 and 2010 by the seed companies, of which 62 (60%) used ICRISAT-bred materials (A-, B- or R-lines). The longevity of the hybrids developed from ICRISAT-bred genetic materials ranged from 2–10 years in the market, mostly due to resistance to downy mildew disease. This compared well to the hybrids of non-ICRISAT-bred lines, whose longevity ranged from 2–6 years. One hybrid developed using ICRISAT-bred parental lines has been in the market for 20 years and another for 26 years. Results indicate that the hybrids developed using ICRISAT-bred materials had a high impact in terms of numbers and sustainability.

About 5 million ha of pearl millet in the country (60%) is planted with more than 70 hybrids, of which 60 of these hybrids are based on ICRISAT-bred hybrid parents. These hybrids have made substantial contributions to enhance genetic diversity, productivity, yield stability, and ultimately improvement in the livelihoods of poor farmers in the dry areas (Gowda et al. 2003).

Impact on Genetic Base of Hybrid Breeding Programs

Since 1986 (when the first ICRISAT-bred hybrid was released) and until 2004, 72 pearl millet hybrids have been released in India, of which 43 (60%) are based on ICRISAT-bred A-lines (Table 5a). Of the 58 hybrids evaluated in the AICPMIP initial hybrid trial (IHT) in 2003, 45 (77%) were based on ICRISAT-bred A-lines. Similarly, out of the 144 hybrids evaluated in the AICPMIP trial in 2004, 119 (83%) were based on ICRISAT-bred A-lines. Thus, development and dissemination of a diverse range of trait-specific materials combined with high yield potential and resistance to diverse pathotypes of the DM pathogen have made substantial contributions to diversifying the genetic base of hybrid parent breeding programs in India. Similarly, the extent of utilization of ICRISAT-bred A/B-lines in developing hybrids by both private and public sector are summarized in Table 5b for the period 2000-2010.

About 12 private seed companies have developed and marketed 62 hybrids by utilizing ICRISAT-bred A/B-lines between 2000 and 2010 (Table 5b). Nearly 40 per cent of them were directly used in the breeding for development of hybrids. Similarly, five public sector research organizations marketed 25 hybrids during the same period. But, 19 of them developed directly by using A-lines while the remaining was used R-lines. At least, 87 hybrids marketed during the last decade from ICRISAT-bred materials by both private and public sectors. This clearly reflects the extent of utilization of ICRISAT-bred materials in hybrid development in the country.

Role of Private Sector

Till the mid-1980s, crop genetic improvement was dominated by public sector research. Since 1986, the private sector has been playing a significant role in pearl millet crop improvement, especially in the development of hybrids for various niche environments in India. However, the private sector gives greater priority to better-endowed environments for hybrid development whereas the public sector's emphasis continues to be on rainfed arid environment/ecology. The public sector research system

Table 5a. Pearl millet hybrids based on ICRISAT-bred A-lines released in India during 1986-2004.

		Hybrids based on ICRISAT-bred A-lines	
Research sector	No. of released hybrids	Number	Percentage
Public sector	43	26	60
Private sector	29	17	59
Total	72	43	60

Source: Rai et al. 2006.

Table 5b. Extent of utilization of ICRISAT-bred A/B-lines in developing hybrids during 2000-2010.

	No of hybrids with ICRISAT A-line use			
No. of hybrids marketed	Direct	Selection from IC-A/B pairs	A-line from IC-B-line conversion	A-line from IC-B-line selection
Private sector (62)	25	7	3	3
Public sector (25)	19	NA	NA	NA
Total (87)	44	7	3	3

continues to provide new technological opportunities for the public and private seed industry to develop profitable products. Private companies began to breed their own pearl millet varieties in the 1970s, but it took a decade to produce the first commercially successful improved cultivars. In general, private companies with research programs acknowledge the contribution of public research (Pray et al. 1988). The development of in-bred lines or restorers takes a long time—usually up to nine seasons. For private firms, their association with ICRISAT or ICAR and state universities is thus invaluable as these public institutions provide knowledge and breeding materials to private breeding programs.

All the pearl millet hybrids developed by private firms in the late 1980s (with the exception of a few developed by multinational corporations) used at least one ICRISAT line. In the early 1990s, small private seed firms began to "bulk up" publicly bred varieties and began distributing the seed through their own networks of private dealers. Pray et al. (1991) estimated that in the late 1980s, private investments in pearl millet improvement were of the same order as public investments, but the share has increased considerably since then. This might appear surprising, as pearl millet is grown largely by subsistence farmers in India. However, the large size of the market together with the fact that farmers were already used to regular seed replacements provided a sufficient business incentive. Moreover, as all pearl millet hybrids periodically develop diseases, there is ongoing demand for new and better products. The Reserve Bank of India Annual Report 2005 concluded that nearly 80 percent of the commercial seed sales of pearl millet are marketed by private seed companies. More than 50 private seed companies marketing approximately 75 hybrids of pearl millethave based their production on seed and pollen parents from ICRISAT. By 2009, private sector participation in pearl millet seed distribution stood at 61% and its share in the supply of high-yielding varieties (HYVs) of pearl millet accounted for 82% (Pray CE and Nagarajan L. 2009).

4. Current Research Focus/Thrust

The National Agricultural Research System (NARS) and ICRISAT have been working for the last five decades on pearl millet genetic enhancement of traits of national and regional importance. These extensive research efforts have resulted in impressive gains,improving productivity, addressing biotic and abiotic challenges such as downy mildew, smut, rust, stem borer, white grubs, ear head worms, terminal drought stress, soil salinity, high temperature and forage/stover quality and quantity traits, etc.

For a better focus of research, India has been divided into two major zones— Zone A and Zone B —for effective targeting and evaluation of pearl millet breeding materials. Zone A was further divided into Zone A_1 which includes arid regions receiving an annual rainfall of less than 400 mm. Details of the pearl millet growing states included in these zones are given in Table 6.

Further, the different breeding strategies/traits targeted for development of hybrids in different environments are given in Table 7.

Correspondingly at ICRISAT, the new research avenues identified in response to the emerging challenges and opportunities are: hybrid parent development with high grain Fe,and Zn (biofortification); high fodder pearl millet cultivars; development of salinity-tolerant cultivars, heat-tolerant hybrids, diversification of CMS system and their restorers; smut and leaf blast resistance etc.

Table 6. Pearl millet research target zones in India.

Zone	States covered
Zone A : northwestern zone	Rajasthan, Gujarat, Haryana, plains of Uttar Pradesh, New Delhi, Madhya Pradesh and Punjab
Zone A_1: less than 400 mm rainfall	Western Rajasthan and drier parts of Gujarat and Haryana
Zone B: Southcentral zone	Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu

Table 7. Hybrid breeding strategies in different environments.

Low-potential rainfed areas (NW India)	High-potential rainfed areas with supplemental irrigation	Irrigated summer areas
Drought tolerance	High potential productivity	High potential productivity
Stable grain and stover productivity	Downy mildew resistance	Heat tolerance
Grain and stover quality	Lodging resistance	Downy mildew resistance
Disease resistance	Grain and stover quality	Lodging resistance
Crop management	Response to improved management	Crop management

Source: Personal communication, OP Yadav.

5. Development of Pearl Millet Improved Cultivars in India

The Indian Council of Agricultural Research (ICAR) was the first institution to take up the responsibility of pearl millet crop improvement in India. During the early 1940 and 1950s, research was sporadic and mainly aimed at improving productivity. Some periodic efforts were made in the 1940s toward varietal improvement through simple mass selection from locally adapted material aimed at improvement of yield. As a result, varieties like Vansari, Kopargaon Local, N 28-15-1, Co 1, K 1,Co2, Co3, AKP 1, AKP 2, RSJ, RSK and T 55 were developed and released. The same method was used with African populations, which resulted in the development of S 530 and Pusa Moti. In order to exploit heterosis, attempts were made to breed 'chance hybrids'. The hybrids thus produced were released in India in the early 1950s (X1, X2, X3)and they outperformed local varieties by 10% in terms of yield. But these hybrids and improved varieties did not become popular because of their limited productivity, narrow range of adaptability and lack of seed production programs.

Overall, there have been four phases in the development of pearl millet improved cultivars in India, covering a period of 60 years (Table 8 and Fig. 11). During the prehybrid phase (1950-1965), improvement efforts largely concentrated on local traditional landrace materials and carried out simple mass selection. This resulted in the development and release of a total of 13 improved cultivars (4 hybrids and 9 OPVs).The average improvement in pearl millet productivity during this period was 5.2 kg ha^{-1} per annum.

During the second phase (1966-80), hybrid breeding received a major impetus when cytoplasmic male sterility (CMS) was discovered. Broadly, there have been three conspicuous phases of pearl millet hybrid development in India. ICAR established the AICMIP in 1965 to conduct intensive and systematic research on millets. The project played a pioneering role in developing a diverse range of improved breeding lines and parental lines of hybrids, conducting multilocation trials and commercializing a large number of hybrids. Later, the project also developed production and protection technologies specific

Table 8. Four phases of pearl millet crop improvement in India.

Phase	Period	No. of hybrids released	No. of varieties released	Most distinguishing features
I	1950-65	4	9	Prehybrid phase; a few OPVs and mostly traditional cultivars grown
II	1966-80	17	13	Witnessed hybrid development in pearl millet; a few hybrids dominated cultivation; periodic downy mildew epidemics were common.
III	1981-95	39	19	A large number of hybrids based on genetically diverse parental lines developed; downy mildew was largely contained.
IV	1996-2010	68	23	A much larger number of highly diverse seed and pollinator parents used in hybrids targeting niche adaptation in different zones.

Source: Yadav et al. 2012.

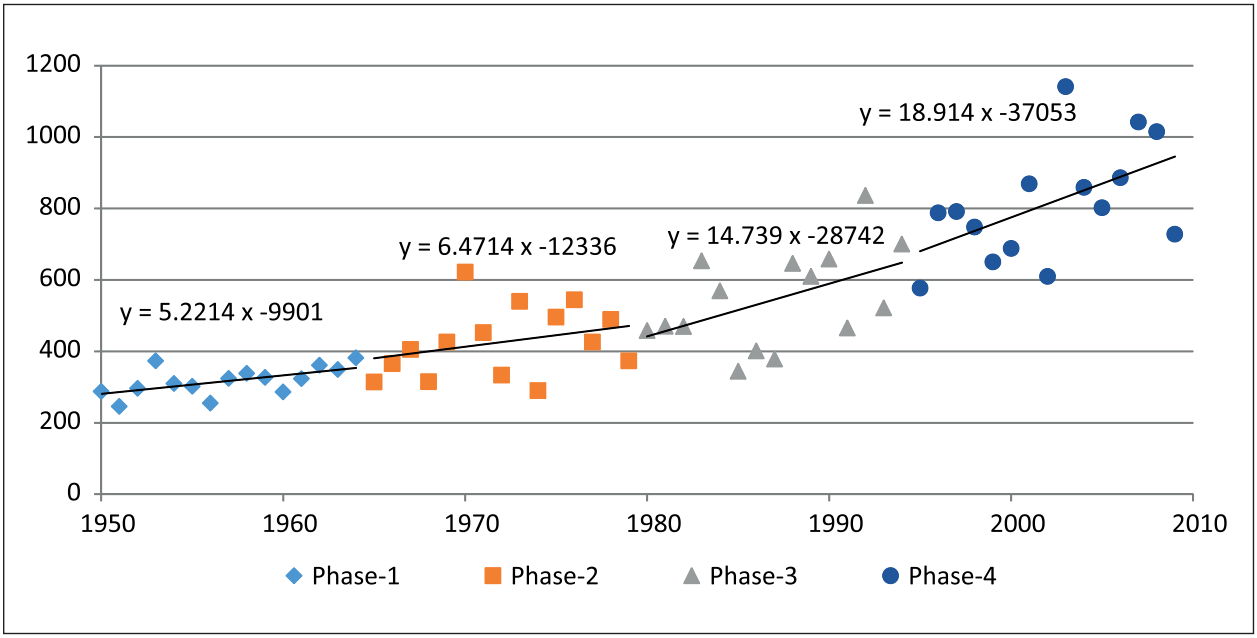


Figure 11. Productivity growth during different phases of crop improvement, 1950-2011.

to agroecological regions in different states. Male-sterile lines Tift 23A and Tift 18A were released in the early 1960s. This laid the foundation for pearl millet hybrid breeding in India. At the same time two additional male-steriles, L 66A and L 67A, were developed at Ludhiana. The male-sterility line Tift 23A was extensively utilized because of its short stature, profuse tillering, uniform flowering and good combining ability.

The first hybrid HB 1 was released in 1965 followed by HB 2, HB 3, HB 4 and HB 5. During this period, 17 hybrids and 13 varieties were developed, and India enjoyed the privilege of being the first country to release pearl millet hybrids. Most of the hybrid releases dominated the cropped acreage during

that period. Among the hybrids of the HB series, HB 3 became the most popular because of its shorter maturity, bold grain and adaptability to moisture stress conditions. Adoption of these hybrids led to a 75-100% increase in yield over local cultivars, and boosted production from 3.5 m tons in 1965 to a record 8.0 m tons in 1970. In the initial years of pearl millet research after ICRISAT was established in 1972, the emphasis was more on population improvement and development of OPVs rather than hybrids and hybrid parents. Overall, there was only a modest increase (6.4 $kgha^{-1}$ per year) in pearl millet productivity during this phase.

In the third phase (1981-95) of the development of pearl millet improved cultivars in India, the recurring problem of downy mildew epidemics that had been affecting hybrids till 1980 led to strengthening of research on genetic diversification of hybrid seed parents. As a result, a large number of genetically diverse male-sterile lines were developed and utilized in hybrid breeding programs. With hybrids based on Tift 23A succumbing to downy mildew, another male-sterile line 5071A, bred at Delhi by mutational change from Tift 23A and showing less downymildew incidence, was utilized. Three hybrids, NHB 3, NHB 4 and NHB 5, were developed from this line but they did not become popular because of their low yields and continued susceptibility to downy mildew. They were cultivated for no more than a year or two. Two more male-sterile lines were developed and made available from Tift 23A. These lines, 5141A and 5054A, had good downymildew resistance and were widely used. The hybrids BJ104 and BK560 (5141A) and CJ104 (5054A) were widely cultivated during 1977-84. But due to the susceptibility of 5141A and its hybrids to downy mildew resulted in phased out of cultivation of 5141A-based hybrids in 1985.

From the mid-1980s, the private sector started participating actively in pearl millet crop development and seed distribution. A major driver of this spurt in private sector participation was the strong public sector research support program and supply of breeding material from national and international institutions. However, the partnership between ICRISAT, national institutes and the private sector remained informal and passive. It was in the 1990s that ICRISAT changed its research focus from OPV development to hybrid parent development in alignment with the regional priorities of the NARS and the rapidly expanding private seed sector. A total of 39 hybrids and 19 OPVswere released during this period. Downy mildew was largely contained, using the genetic diversity of pearl millet.

A critical analysis of the situation reveals that the absence of long-lasting resistance to downy mildew among hybrids was primarily due to the lack of diversity in their parental lines. This was due to the fact that most of the hybrids were based on Tift 23A and then on 5141A and 5071A. Similarly, the same pollinators were also repeatedly used in combinations with different male-sterile lines. For example, J 104 was used in four hybrids, K 560-230 in three and K 559 in two hybrids. Thus, the outbreaks of downy mildew in hybrids were due to the use of a limited number of parental lines in hybrid breeding rather than the cytoplasm-linked susceptibility (Yadav et al. 1993). Much greater efforts are now being made in developing genetically diverse male-sterile lines. As a result, a large number of male-sterile lines with A1 source of cytoplasmic male sterility (CMS) have been used in hybrid breeding. In addition, CMS sources other than A1 have also been used. The average productivity has been enhanced to about 14.74 kg ha^{-1} per annum during this period.

During the fourth phase (1996-2010), greater emphasis was placed on genetic diversity by using a larger number of highly diverse seed and pollinator parents in hybrid development and targeting adaptation to specific niches in different zones. The highest number of cultivars (68 hybrids, 23 varieties) was released during this period. The hybrids released during the last decade were based on more than 12 generally diverse male-sterile lines and a large number of diverse pollinators. Moreover, several hybrids

developed by the private sector in its sound and well-established research and development programs further helped in diversifying the genetic base of hybrids. Consequently, the problems of downy mildew epidemics were kept largely under control. As a result, improvement in grain productivity further increased to 18.9 $kgha^{-1}$ per year.

The releases of improved pearl millet cultivars by different stakeholders during 1931-2011 are summarized in Table 9. ICRISAT has released around 80 improved cultivars in India either by sharing their germplasm or breeding materials with NARS and private seed companies during 1976-2011. With ICAR assistance AICPMIP released 106 cultivars in major pearl millet states during the period 1931-2011. The major pearl millet states including their respective state agriculture universities released around 22 notified cultivars with location-specific importance during the same period. The number of parental lines developed by NARS during this period was around 215 (Yadav et al. 2012). A total of 208 improved cultivars and 215 parental lines have been made available through NARS in India for pearl millet cultivation in India.

ICRISAT Global Pearl Millet Releases During 1976-2011

Table 10 shows the total number of improved pearl millet cultivars (varieties and hybrids) developed by ICRISAT and released in different regions between 1976 and 2011. A total of 163 improved cultivars were made available in 23 countries of Asia and Africa. Almost 54.6% of these releases were in Asian countries and 45.3% in Africa. The country wise releases during 1975-2011 are depicted in Figure 12. The top three individual country beneficiaries from ICRISAT research and materials were India (80 cultivars) followed by Niger (14) and Senegal (9). The presence of the ICRISAT headquarters in India and the existence of a strong NARS system to make use of breeding materials may have worked to India's advantage. The releases were at their peak (41) during the late 1990s across all regions. The number of countries benefitting from improved cultivars has been increasing over time.

A detailed breakup (variety or hybrid) of the total releases across regions is given in Figure 13. In total, ICRISAT generated 101 varieties and 62 hybrids during 1982-2011 in the three regions (Table 11). Within

Table 9. Development of pearl millet improved cultivars in India.

		NARS releases (1931-2011)		
Release period	NARS-ICRISAT*	ICAR**	Other notified ***	Total
1931-40	0	5	1	6
1941-50	0	4	4	8
1951-60	0	5	0	5
1961-70	0	6	0	6
1971-80	0	21	3	24
1981-90	14	36	1	37
1991-00	35	41	12	53
2001-11	31	58	11	69
Total	80	176	32	208

* Includes cultivars released with ICRISAT-supplied material.
**Includes national releases of hybrids and varieties.
*** Includes state and SAU releases.

Table 10. ICRISAT global pearl millet releases, 1976-2011.

Years	Africa	Asia	Total	India	Other Asia
1975-80	0	0	0	0	0
1981-85	6	3	9	3	0
1986-90	13	11	24	11	0
1991-95	16	20	36	18	2
1996-00	24	17	41	17	0
2001-05	4	17	21	15	2
2006-11	11	21	32	16	5
Total	74	89	163	80	9
% share	45.40	54.60	100.00	49.08	5.52

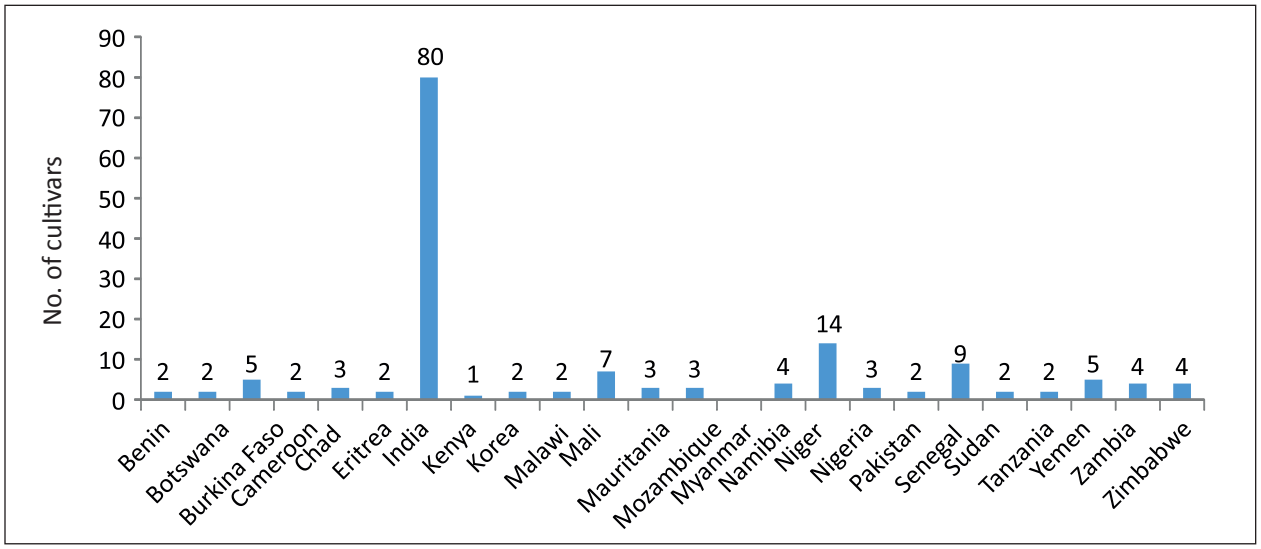


Figure 12. Countrywise pearl millet releases, 1976-2011.

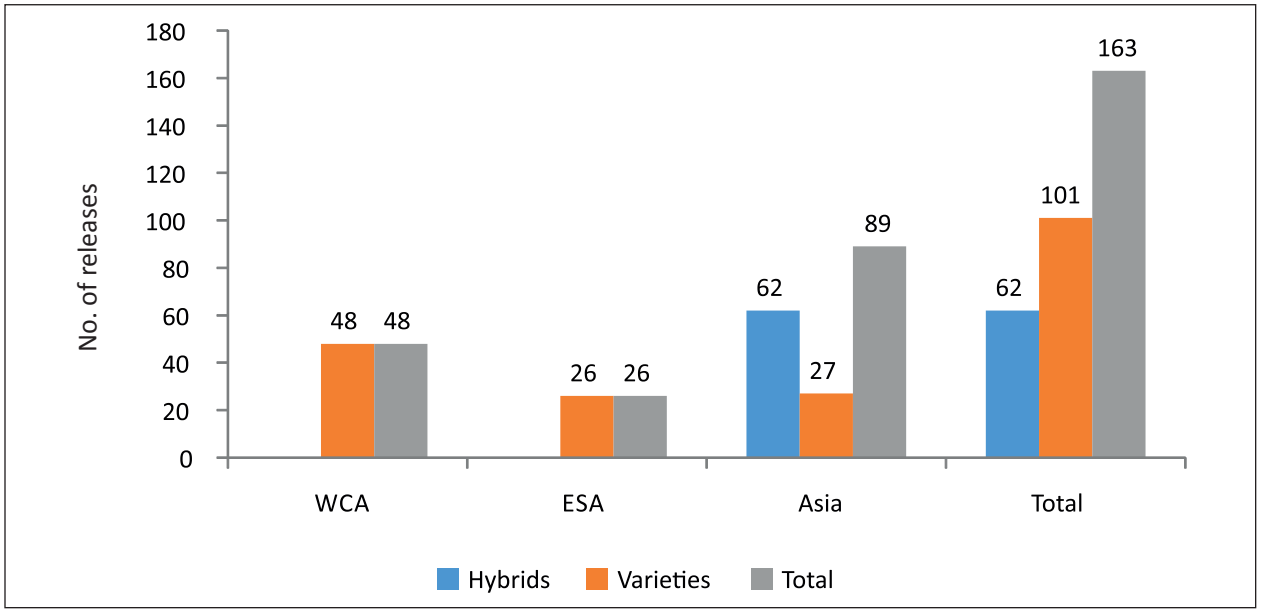


Figure 13. Regionwise pearl millet releases by type of cultivars, 1976-2011.

Africa, more releases took place in WCA (48) than in ESA (26) during the same period. Around 73.26% of the varieties were released in Africa and 26.74% in Asia. A reverse trend was observed in Asia: nearly 69.7% of the cultivars were hybrids and the remaining 30.3% varieties. NARS systems in Africa and Asia benefited primarily from ICRISAT-developed varieties and through technology spillover across regions.

ICRISAT's pearl millet improvement research at Patancheru followed a strategy of developing improved breeding lines along with hybrid parents. A detailed breakup of the year wise development of pearl millet parental lines is presented in Figure 14. The cytoplasmic male sterility source was first identified in 1981. Since then and till date approximately around 324 male-sterile lines (A-lines) and their corresponding maintainers (B-lines) from a diverse genetic base and morphological traits have been developed and released. These lines were designated and disseminated as potential hybrid parents after evaluation for agronomic performance and resistance to diverse pathotypes of downy mildew.

ICRISAT Releases in India

The pattern of pearl millet improved cultivar releases in India during 1981-2010 is summarized in Figure 15 and Table 12. Of the 80 releases in India during this period, 62 were hybrids, and the remaining 18 were varieties. Apart from these releases in India, ICRISAT developed another 9 improved cultivars for other Asian countries. The pattern of development of cultivars was almost consistent and increasing in trend over this period of time (1981-2010). India has benefitted significantly from ICRISAT's research, especially in hybrid development. Since 2001, ICRISAT has been in close collaboration with Hybrid Parents Research Consortium (HPRC) members in India and has been liberally exchanging diverse parental lines and intermediate materials with private seed companies.

Table 11. ICRISAT global releases by region and type of cultivars.

Region	Hybrids	Varieties	Total
WCA	0	48	48
ESA	0	26	26
Asia	62	27	89
Total	62	101	163

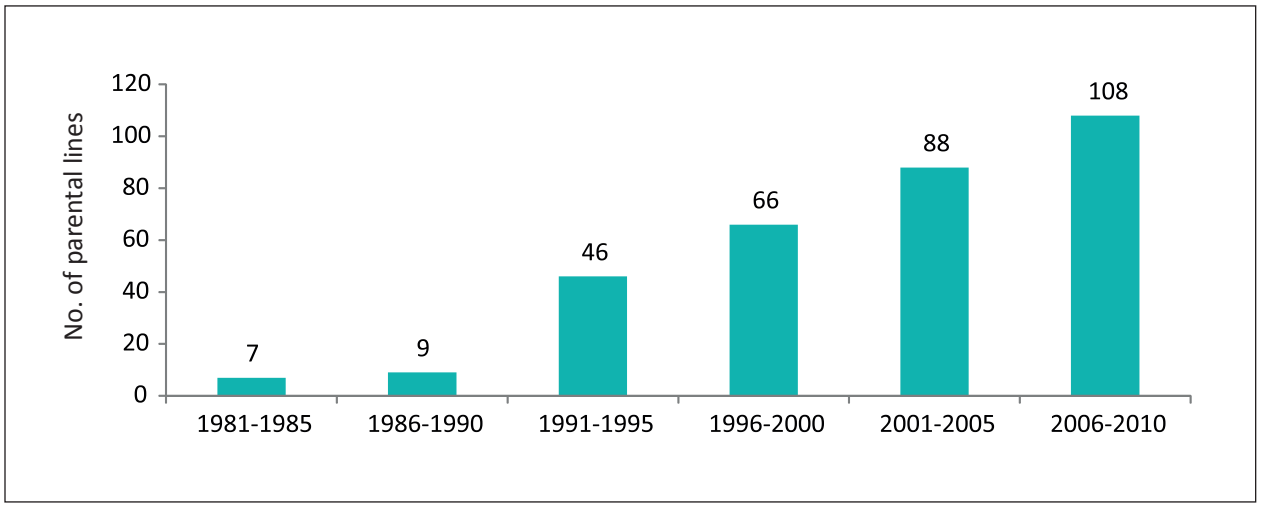


Figure 14. Pattern of development of parental lines at ICRISAT, 1981-2010.
Source: Personal communication from Rai et al. 2009.

Table 12. List of cultivars released in India either using ICRISAT germplasm or breeding materials.

S.No	ICRISAT name	Original name	Release year	Cultivar type
1	-	MH 182	1986	H
2	ICMH 451	ICMH 451(MH 179)	1986	H
3	ICMH 501	ICMH 501(MH 180)	1986	H
4	HHB 50	HHB 50	1987	H
5	Pusa 23	Pusa 23	1987	H
6	HHB 60	HHB 60	1988	H
7	ICMH 423	ICMH 423 (MH 423)	1988	H
8	-	GHB 181	1990	H
9	HHB 67	HHB 67	1990	H
10	VBH 4	VBH 4	1990	H
11	Eknath 301	Eknath 301	1991	H
12	MLBH 104	MLBH 104	1991	H
13	RHB 58	RHB 58	1991	H
14	RHB 30	RHB 30	1991	H
15	ICMH 88088	ICMH 312 (Pooja)	1993	H
16	HHB 68	HHB 68	1993	H
17	ICMH 356	ICMH 356	1993	H
18	Pusa 322	Pusa 322	1993	H
19	ABH 251	Devgiri	1994	H
20	GHB 235	GHB 235	1994	H
21	-	Pusa 444	1995	H
22	--	Pusa 325	1995	H
23	--	Pusa 44	1995	H
24	Nandi 30	Nandi 30	1995	H
25	MLBH 267	MLBH 267	1996	H
26	MLBH 285	MLBH 285	1996	H
27	--	SBH 1	1996	H
28	JBH 1	JBH 1	1996	H
29	GHB 183	GHB 183	1997	H
30	JKBH 26	JKBH 26	1997	H
31	GK 1004	GK 1004	1997	H
32	PAC 903	PAC 903	1997	H
33	Pusa 605	Pusa 605	1999	H
34	MLBH 44	MLBH 44	1999	H
35	Nandi 32	Nandi 32	1999	H
36	RBH 90	RBH 90	1999	H
37	HHB 94	HHB 94	2000	H
38	RBH 121	RBH 121	2001	H
39	GHB 526	GHB 526	2002	H
40	HHB 146	HHB 146	2002	H
41	GHB 558	GHB 558	2002	H

Continued...

continued...

Table 12. List of cultivars released in India either using ICRISAT germplasm or breeding materials.

S.No	ICRISAT name	Original name	Release year	Cultivar type
42	GHB 577	GHB 577	2003	H
43	RHB 127	RHB 127	2003	H
44	SAMH 166	SAMH 166	2003	H
45	AHB 166	Pratibha	2004	H
46	GHB 538	GHB 538	2004	H
47	NMH 45	NMH 45	2004	H
48	HHB 67-2 (improved)	HHB 67-2	2005	H
49	MH 1340 (RHB 154)	MH 1340 (RHB 154)	2008	H
50	MH 1351 (SAGAR URMI)	MH 1351 (SAGAR URMI)	2008	H
51	MH 1352 (Bio gene 66)	MH 1352 (Bio gene 66)	2008	H
52	MH 1385 (GK 1051)	MH 1385 (GK 1051)	2008	H
53	GHB 757	GHB 757	2008	H
54	GHB 744	GHB 744	2008	H
55	GHB 732	GHB 732	2008	H
56	HHB 197	HHB 197	2008	H
57	PHB 2168	PHB 2168	2008	H
58	HHB 216	HHB 216	2009	H
59	RHB 173	RHB 173	2009	H
60	HHB 223	HHB 223	2011	H
61	MH 1486 (RHB 177)	RHB 177	2011	H
62	HHB 226	HHB 226	2011	H
63	WC-C75(ICMV1)	WC-C75(ICMV1)	1982	V
64	ICMS-7703(ICMS4)	ICMS-7703(ICMS4)	1985	V
65	HC-4(MP19)	HC-4(MP19)	1985	V
66	ICTP-8203 (MP-124)	ICTP-8203 (MP-124)	1988	V
67	ICMV-155	ICMV-155	1991	V
68	Raj-171	Raj-171	1992	V
69	ICMV-221	ICMV-221	1993	V
70	PCB-164	PCB-164	1993	V
71	RCB-IC 911	RCB-IC 911	1996	V
72	CZP-IC-923 (MP-258)	CZP-IC-923 (MP-258)	1997	V
73	JBV-2 (GKKV-93191)	JBV-2 (GKKV-93191)	1998	V
74	AIMP-92901 (Samrudhi-MP-282)	AIMP-92901 (Samrudhi-MP-282)	1998	V
75	JBV-3 (GICKV -96752) (MP-363)	JBV-3 (GICKV -96752) (MP-363)	2001	V
76	CZP 9802 (MP 406)	CZP 9802 (MP 406)	2002	V
77	KHB-3	KHB-3	2004	V
78	Sagar -205	Sagar -205	2005	V
79	JBV-4(MP-403)	JBV-4(MP-403)	2006	V
80	Pusa composite -443(MP443)	Pusa composite -443(MP443)	2008	V

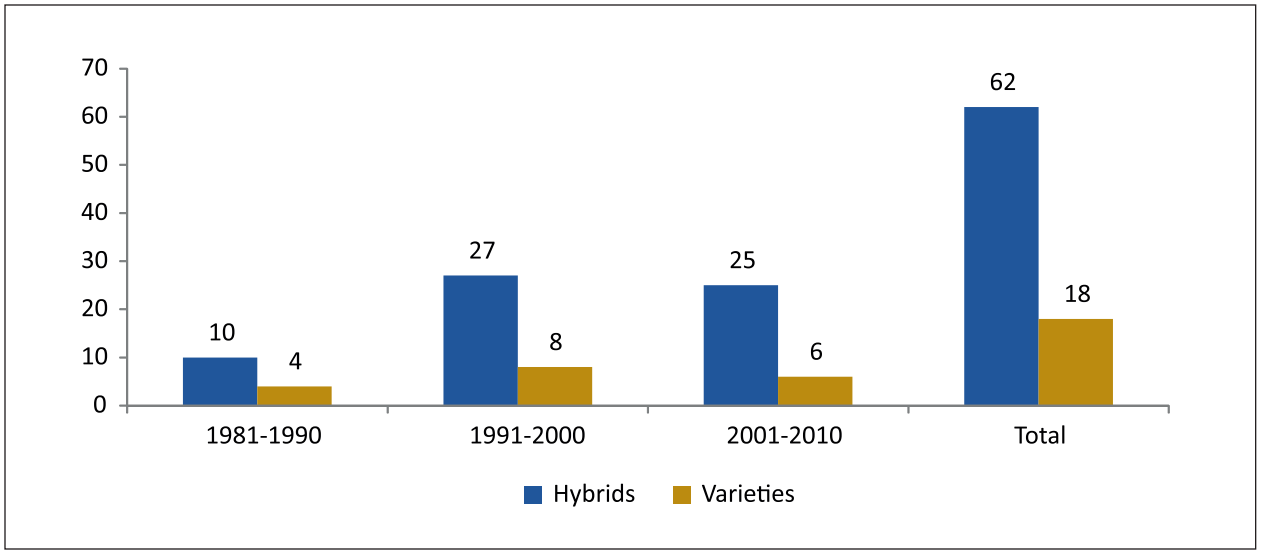


Figure 15. ICRISAT releases in India, 1981-2010.

NARS Pearl Millet Releases

Figures 16 and 17 present data on the release of pearl millet cultivars at the national and state levels during 1931-2011, respectively (see also Annexures 1 and 2 for more details). As we can see from the figures, there is a clear contrast between national and state releases. The national releases were dominated by hybrids whereas the state releases were mainly varieties. Similarly, details of the total number of cultivars notified over the same period are presented in Figure 18. It shows clearly that varieties dominated the situation till the 1970s; the major thrust on hybrids started vigorously 1970s onward.

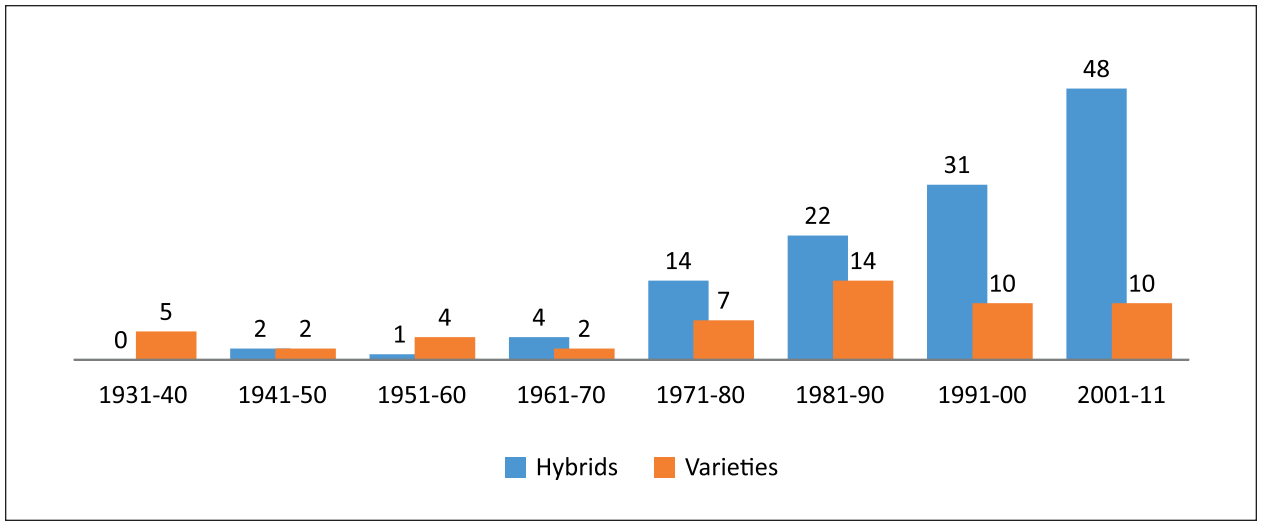


Figure 16. Pattern of pearl millet central releases in India, 1931-2011.

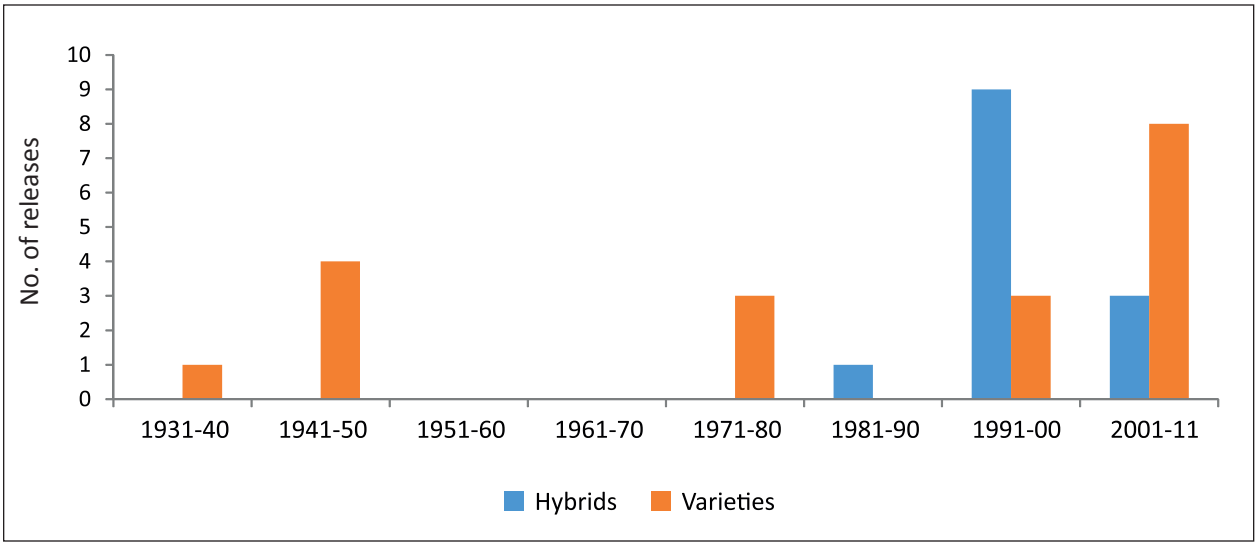


Figure 17. Trends in state pearl millet releases in India, 1931-2011.

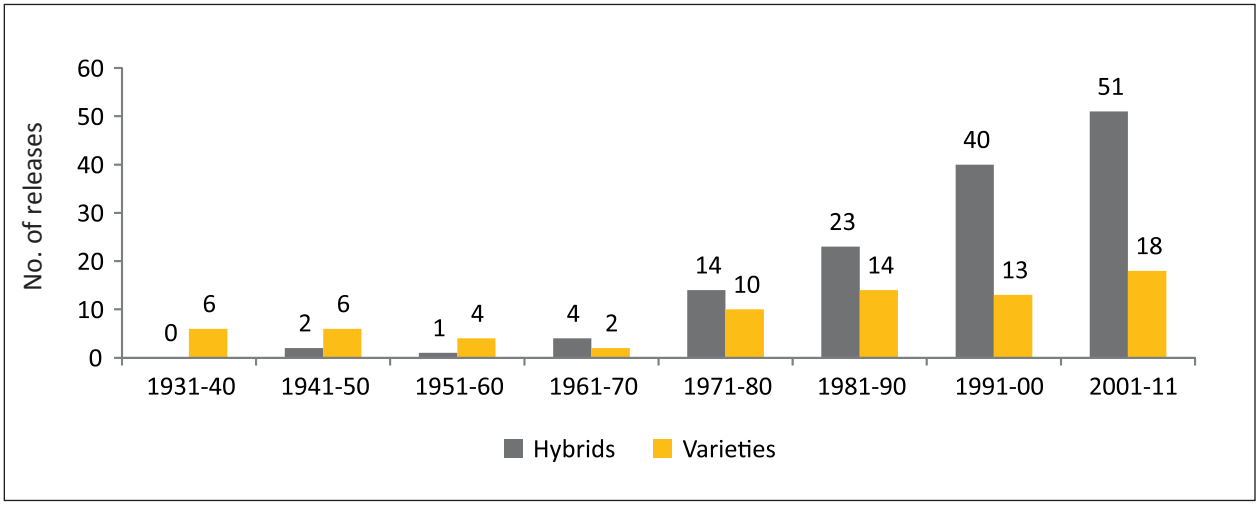


Figure 18. Total notified pearl millet releases in India, 1931-2011.

Table 13 summarizes statewise the total number of cultivar (both national and state) releases and their availability between 1931 and 2011. The hybrid-variety breakup is also furnished across the study states. The data clearly confirm the pearl millet growers' preference for hybrids rather than OPVs in Andhra Pradesh, Maharashtra, Karnataka and Gujarat. However, the reverse trend was observed in Rajasthan and Tamil Nadu. Regions with low and uncertain rainfall in different states are still more dependent on OPVs than hybrids because of the better performance of the former. Therefore, pearl millet stakeholders should focus more on these regions for development of potential drought-tolerant hybrids.

Table 14 summarizes the variability in annual varietal releases by different stakeholders in India between 1934 and 2011. The highest coefficient of variation (CV) was observed in the case of state releases

followed by ICAR and ICRISAT releases. The highest mean annual release rate was observed in the case of ICRISAT, which is around 2.67, but the number of years with zero releases was five during 1982-2011. In the case of ICAR, the mean annual release rate was at 2.26 and there were 29 years with zero releases during 1934-2011. Since releases by states and SAUs were lower than for ICAR and ICRISAT, the coefficient of variation was significantly high. When we combine the NARS and ICRISAT (supplied material) releases in India, the mean annual release rate increases to 2.67 and the number of years with zero releases goes down. However, the CV has significantly declined to 113.8%. The details of denotified pearl millet cultivars in India are summarized in Table 15.

Table 13. Statewise releases of improved cultivars in India, 1931-2011.

Type	Andhra Pradesh	Maharashtra	Karnataka	Rajasthan	Gujarat	Tamil Nadu	Others
Hybrids	24	22	6	7	29	9	37
Varieties	11	7	0	11	3	14	24
Total	35	29	6	18	32	23	61

Table 14. Variability in annual varietal releases of pearl millet in India, 1934-2011.

Institutions	Mean annual release rate	Years with zero releases	Standard deviation	Coefficient of variation
ICRISAT (1982-2011)	2.67	5	2.19	82.0
ICAR* (1934-2011)	2.26	29	2.64	117.0
State releases**(1940-2011)	0.44	52	0.85	192.1
India#(1934-2011)	2.67	28	3.04	113.8

* Includes national hybrids and varieties
** Includes state and SAU releases
# Exclusive of parental lines

Table 15. Denotified cultivars of pearl millet in India.

Cultivar	Denotified no.& date	Release type
HB-1	661(E)/17-9-97	Central
HB-2	661(E)/17-9-97	Central
HB-3	661(E)/17-9-97	Central
PHB-10	661(E)/17-9-97	Central
PHB-14	661(E)/17-9-97	Central
BD-111	661(E)/17-9-97	Central
Pusa 763	661(E)/17-9-97	Central
MBH 110	661(E)/17-9-97	Central
MBH 130	661(E)/17-9-97	Central
Co-6	1999	Central

The details of the classification of pearl millet cultivars based on their duration are summarized in Table 16. During the early 1950s and 1960s, state-level pearl millet releases were almost absent. Central releases were at a peak during 1970-1990. Nearly 50% of total improved cultivars are targeted for long duration (80-90 days) followed by medium (45.2%) and short duration (4.8%).

6. NARS Research Strength and Investment Pattern in Pearl Millet Crop Improvement

This section discusses the scientific manpower deployed in pearl millet crop improvement research in international (ICRISAT) and national institutes (AICPMIP) in India. In 2010-11, the total number of scientists involved in this effort stood at 121 (Table 17), including agronomists, crop physiologists, genetic resource specialists, entomologists, pathologists, social scientists, etc. Of this, the NARS scientific strength was 76, including personnel stationed at the main and voluntary centers. Ten scientists from IARC, including ICRISAT, and nearly 35 from the private sector (members of the Hybrid Parents Research Consortium) were also engaged in pearl millet crop improvement research in India.

Table 16. Classification of improved cultivars based on duration (days).

	Hybrids						Varieties					
	Central			State			Central			State		
Year	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3	D-1	D-2	D-3
1931-40	0	0	0	0	0	0	0	3	2	0	0	1
1941-50	0	0	2	0	0	0	0	1	1	0	3	1
1951-60	0	0	1	0	0	0	0	2	2	0	0	0
1961-70	0	0	4	0	0	0	0	0	2	0	0	0
1971-80	0	4	10	0	0	0	0	5	2	0	1	2
1981-90	1	8	13	0	1	0	1	2	11	0	0	0
1991-00	0	17	14	1	4	4	0	6	3	0	1	1
2001-11	5	27	16	0	2	1	2	5	4	0	2	7
Total	6	56	60	1	7	5	3	24	27	0	7	12

D-1: 65-70 days; D-2: 70-80 days; D-3: 80-90 days

Table 17. Scientific personnel engaged in pearl millet crop improvement, 2010-11.

Organization	Actual staff*	FTE**
AICPMIP (main center)	45.0	33.75
AICPMIP (voluntary centers)	31.0	17.05
IARC including ICRISAT	10.0	9.50
Private seed companies	35.0	28.00
Total	121.0	88.30

*Only scientific staff considered.
**FTE: Full-time equivalent.

The details of NARS personnel involved in pearl millet crop improvement in 2010-11 are summarized in Table 18. Among the total of 109 personnel engaged by AICPMIP, nearly 45 were scientific staff from the main centers and the remaining 64 technical staff. Similarly, another 31 scientists were working on pearl millet crop improvement at the AICPMIP voluntary centers and state agricultural universities (SAUs). In terms of the full-time equivalents (FTEs), the number of NARS scientific staff specializing in pearl millet crop improvement was 50.8 as of 2010-11 (Table 18). The gap of 25.2 scientists were engaged in other purposes such as teaching, guiding students, conducting training programs, extension activities, etc. In terms of educational qualifications, around 45.05 FTEs were doctorates and 5.75 FTEs master's degree holders (Table 19).

Pearl millet production per crop improvement scientist marginally increased from 106,000 tons to 112,000 tons between the tenth and eleventh Five Year Plans (Fig. 19), despite the decline in acreage. This may be due to increased funding for crop research and higher productivity due to increased adoption of improved cultivars across India.

Table 18. Scientists from different disciplines involved in pearl millet crop improvement, 2010-11.

	Scientific staff at AICPMIP		Total actual scientific staff	FTE
Discipline	Main centers	Voluntary centers		
Agronomy	11(8)	3(1.55)	14	9.55
Plant breeder	18(13.7)	22(12)	40	25.70
Entomology	2(1.55)	2(1)	4	2.55
Pathology	9(6.7)	3(1.85)	12	8.55
Physiology	2(1.45)	0(0)	2	1.45
Biochemistry	1(0.75)	0(0)	1	0.75
Economic botany	1(0.85)	0(0)	1	0.85
Horticulture	0(0)	1(0.65)	1	0.65
Statistics	1(0.75)	0(0)	1	0.75
Total	45(33.75)	31(17.05)	76	50.8

Figures in parentheses denote the FTE value.

Table 19. Full-time equivalent* (FTE) of NARS scientists by qualification, 2010-11.

Organization	FTE equivalents	Ph.D.	M.Sc.
AICPMIP (main centers)	33.75	30.75	3.00
AICPMIP (voluntary centers)	17.05	14.30	2.75
Total	50.8	45.05	5.75

*Only NARS scientists considered

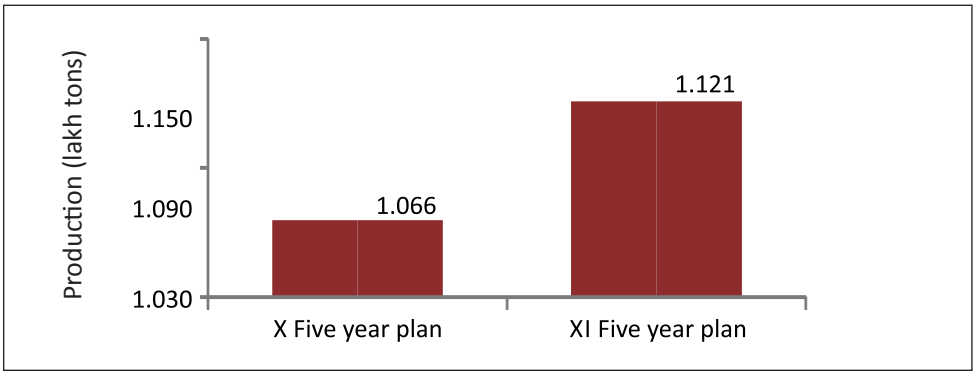


Figure 19. Pearl millet production across two Five-Year Plans.

Investment Pattern in Pearl Millet Crop Improvement

Table 20 summarizes the NARS research allocations for pearl millet crop improvement in India during the tenth and eleventh Five-Year Plans. Allocations increased very sharply during these two plans, almost doubling over than the previous allocations. In the total budget allocation, the state share was 20-25% and ICAR contributed 75-80%. Research allocation per scientist worked out to Rs 2.18 million during the tenth Five-Year Plan and increased to Rs 3.66 million during the eleventh, clearly indicating ICAR's emphasis on pearl millet crop improvement.

In terms of research allocations per each FTE scientist, they went up significantly between 2007 and 2011 (Table 21). With increasing research support, pearl millet production also rose due to adoption of improved cultivars. Research costs per ton of pearl millet production in India went up significantly till 2009-10, but decreased slightly during 2010-11.

Table 20. NARS research allocation (₹ million) during the tenth and eleventh Five-Year Plans.

	AICPMIP Five-Year Plan budget					
	State contribution		ICAR contribution		Total	Expenditure per scientist*
Plan period	Plan	Non-plan	Plan	Non–plan	Plan	
2002-2007	59.00	-	106.63	-	165.63	2.18
2007-2012	53.07	-	225.10	-	278.16	3.66

*Only NARS scientists considered

Table 21. Research expenditure (₹ millions) on pearl millet crop improvement, 2007-2011.

Year	ICAR share	State share	Total AICPMIP	Allocation per scientist*	Pearl millet production (million tons)	Research cost per ton (₹)
2007-08	35.1	8.37	43.55	0.86	9.97	4.37
2008-09	38.73	9.10	47.83	0.94	8.89	5.38
2009-10	55.50	12.96	68.47	1.35	6.51	10.52
2010-11	58.72	14.74	73.46	1.45	10.36	7.09

*Only NARS FTE scientists considered.

Table 22 presents the state-wise break-up of research allocations for pearl millet crop improvement during 2009-10. The state-wise actual and Full-Time Equivalent (FTE) scientific staff working for pearl millet crop improvement are calculated and summarized. Among the total FTE of 50.8, nearly 10.5 per cent of the scientific staff were working in Rajasthan followed by 4.5 FTEs each in Maharashtra and Gujarat. Nearly 42 per cent of the total research allocations goto Rajasthan followed by Maharashtra (13.3%). The research allocation per each FTE scientist was the highest in the case of Rajasthan followed by Maharashtra and Uttar Pradesh.

7. Tracking of Improved Cultivars in India

In India, the pearl millet breeding program has been fully backed up by a strong seed production and marketing system in the both public and private sectors. Substantial amounts of money have been invested in crop improvement in the recent past by both national and international research centers. International research institutes in partnership with the national research systems (both public and private) have made concerted efforts to develop improved cultivars and better management practices to increase yield and ultimately the social well-being of pearl millet producers and consumers in India.

However, the benefits of research can reach farmers only when the released cultivars are adopted by them. In India, adoption of improved pearl millet cultivars has increased significantly over time, starting from very low levels in the late 1960s and reaching 80 per cent in most districts of Maharashtra, Gujarat and Tamil Nadu by the early 1990s. About 40 districts of India have adoption rates of more than 80 per cent (Joshi et al. 2005). Adoption of hybrids in India has been very fast since the release of the hybrid HB 3 (Fig. 20). Since the early 1980s, even though there has been a declining trend in cropped area, area under improved cultivars has increased significantly.

Table 22. Statewise research expenditure allocations, 2009-10 (₹ million).

State/Centre	Actual staff			Strength FTE*	Research allocation 2009-10	Share (%)	Allocation / FTE scientist
	Technical	Scientific	Total				
Maharashtra	8	6	14	4.50	9.106	13.30	2.024
Andhra Pradesh	2	1	3	0.75	1.448	2.11	1.931
Madhya Pradesh	3	2	5	1.50	2.304	3.37	1.536
Tamil Nadu	3	3	6	2.25	4.077	5.95	1.812
Rajasthan	25	14	39	10.50	28.567	41.72	2.721
Haryana	6	5	11	3.75	7.252	10.59	1.934
Gujarat	6	6	12	4.50	6.658	9.72	1.480
Karnataka	5	4	9	3.00	4.405	6.43	1.468
Punjab	1	2	3	1.50	1.738	2.54	1.159
Uttar Pradesh	5	2	7	1.50	2.914	4.26	1.943
Main centers total (A)	64	45	109	33.75	68.469	100.00	2.029
Voluntary centers (B)	0	31	31	17.05	0.00	-	-
Total (A+B)	64	76	140	50.8	68.469	100.00	1.348

*Including NARS scientific staff only.

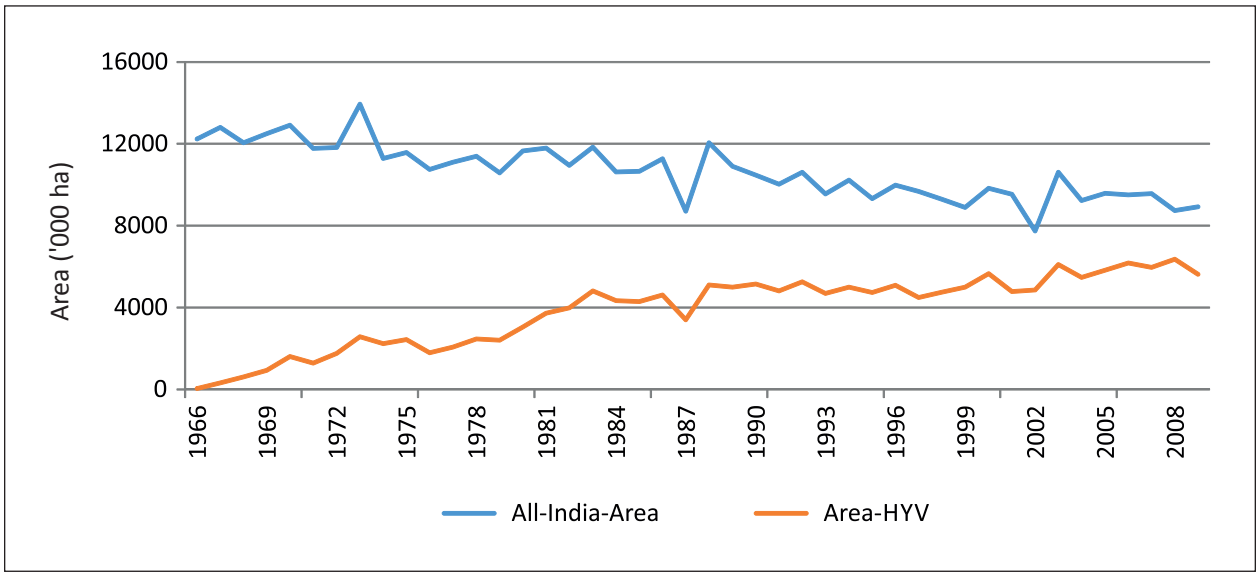


Figure 20. Total cropped area and area under pearl millet improved cultivars in India.

If we examine the pattern of diffusion of pearl millet improved cultivars across different states from 1966 to 2008 (Table 23), we find that Maharashtra, Gujarat and Karnataka top the list with more than 95 per cent adoption followed by Haryana and Madhya Pradesh. The lowest adoption level was in Uttar Pradesh. The highest percentage increase in area under improved cultivars was observed in the case of Rajasthan followed by UP and Karnataka between 1996-98 and 2006-08.

Figure 21a & b depict the adoption pathways of pearl millet improved cultivars in the major study states in India. Gujarat exhibited a progressive pathway and reached its peak level of adoption in the early 1980s. It was followed by Maharashtra, Karnataka and Haryana, which attained significant momentum since the 1980s. Rajasthan, Madhya Pradesh and Uttar Pradesh have lagged behind with a slow rate of adoption. A deeper assessment is required to understand the differential adoption pathways of the pearl millet growing states.

Table 23. Diffusion of improved cultivars in major states (percentage of crop area).

State	1966-68	1976-78	1986-88	1996-98	2006-08
Rajasthan	1	10	27	29	52
Haryana	3	26	61	68	89
Maharashtra	7	14	65	90	98
Gujarat	7	70	87	87	95
Uttar Pradesh	1	3	12	27	35
Madhya Pradesh	1	16	35	67	60
Karnataka	2	27	57	79	95
All-India	3	19	41	50	67

Source: Department of Agriculture, Government of India.

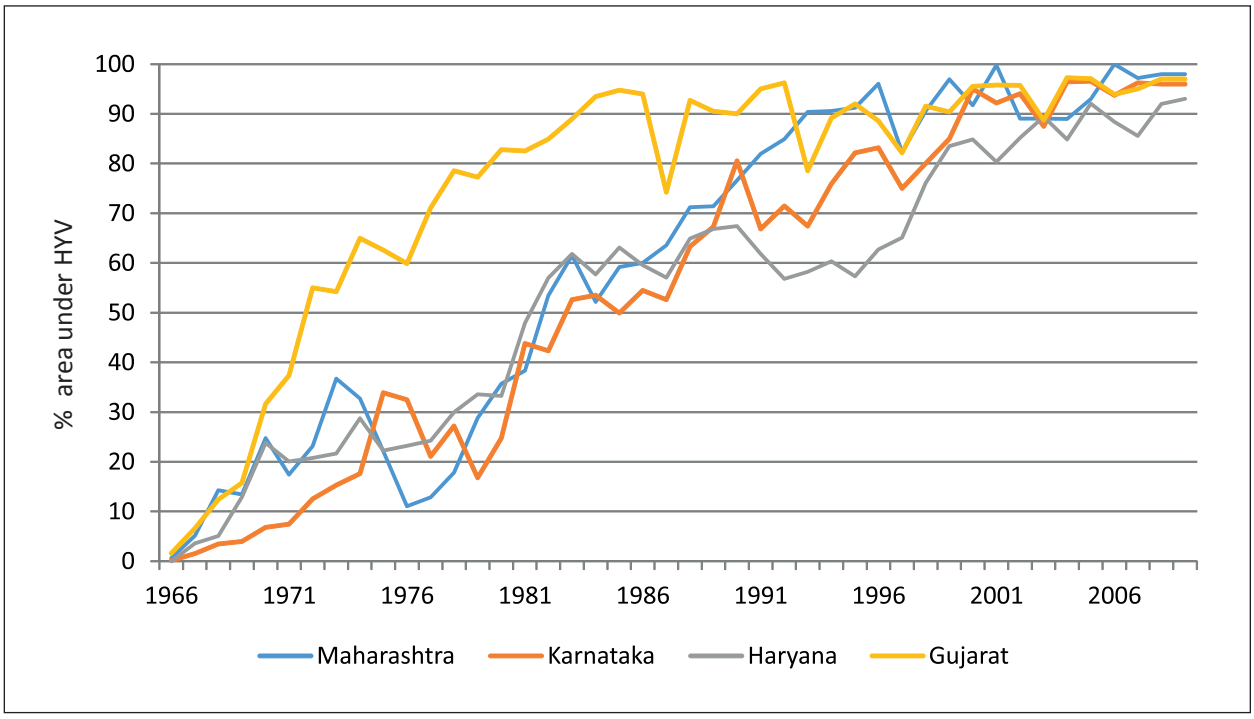


Figure 21a. Pattern of adoption of improved cultivars across four Indian states, 1966-2008.

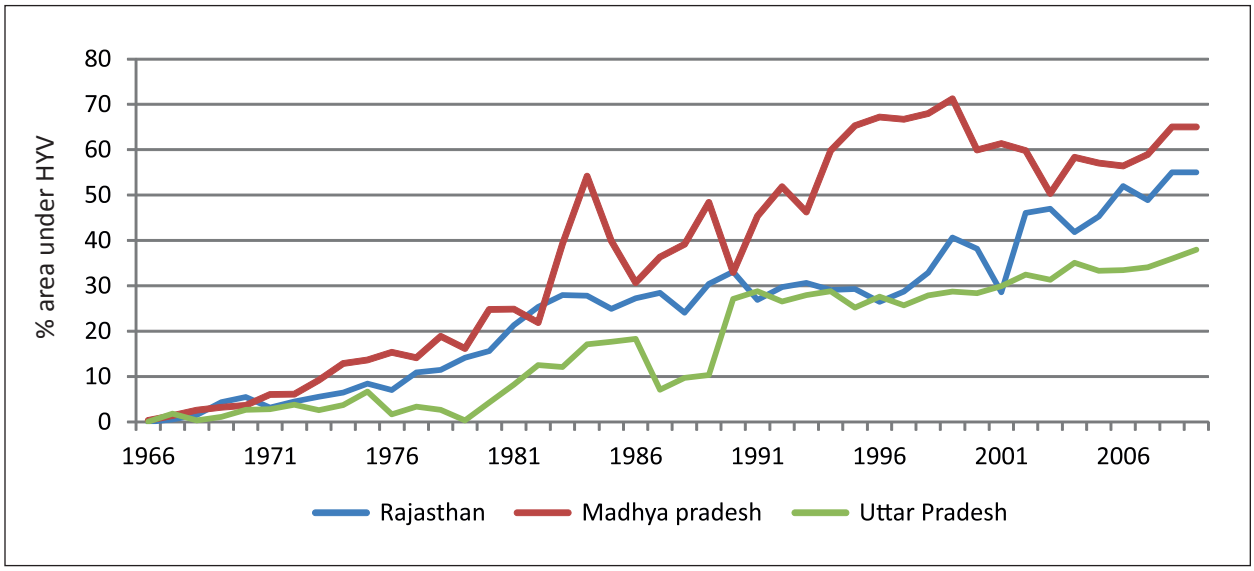


Figure 21b. Pattern of adoption of improved cultivars across three Indian states, 1966-2008.

Cultivar-specific Adoption Estimates in Major States

In this section, we summarize and discuss cultivar-specific adoption estimates for improved varieties and hybrids in the major pearl millet growing states in India. ICRISAT has studied pearl millet adoption patterns in collaboration with the Indian National Agricultural Research System (NARS), specifically with the All-India Coordinated Pearl Millet Improvement Program (AICPMIP), Jodhpur. A Tracking of Improved Varietal Adoption in South Asia (TRIVSA) team from ICRISAT visited all the major AICPMIP centers and conducted expert elicitations with key scientists. Based on their group knowledge and skills, information

was collected either at the regional or state level. This is one of the fastest methods of updating cultivar-specific adoption information. Information from secondary sources of data was also collected from the Department of Agriculture and the state seed corporations.

Overall, ICRISAT conducted two rounds of expert elicitations. The second round was organized through a workshop (see Annexure 3 for details) conducted at ICRISAT on 22nd December 2011 by involving state- and national-level experts. In general, the initial results are comparable with the secondary information collected from state agricultural departments. However, concerted efforts are on to collect similar information from private seed companies and distributors/dealers. National seed corporations (NSCs) and state agricultural universities (SAUs)/extension departments are some of the other avenues for validation of this information.

Expert elicitations were the fastest way of generating cultivar-specific varietal adoption information. This method has its advantages and disadvantages. The main advantages are that it is rapid, low-cost, less time-consuming and reliable provided the expert group has good knowledge and exposure to the crop. The major limitations arise from the group members having inadequate comprehension of farm-level adoption in that locality, or insufficient information about different cultivars, biased judgment and poor knowledge of the crop seed chains or seed channels, etc. Ultimately, the interest of the scientists who participate in the expert elicitation process is the key for its outcome. The cultivar-specific adoption estimates of five major states are summarized below:

Rajasthan

Despite being one of the major pearl millet producing states in India, Rajasthan has a relatively low adoption rate and lower productivity levels as well. Local cultivars dominate pearl millet cultivation in the state. The TRIVSA project elicitations concluded that the overall adoption rate in Rajasthan was around 52 per cent (Table 24). The major share of the pearl millet cropped area (nearly 48 per cent) in the state

Table 24. Adoption of improved cultivars in Rajasthan and Maharashtra, 2010-11.

Rajasthan			Maharashtra		
Cultivar	Year	% share	Cultivar	Year	% share
Pro-Agro 9444	2004	11.0	Pioneer (86-M-33)	2002	
HHB67 Improved	2005	10.2			
MH 169	1987	7.3	Pioneer (86-M-64)	2011	
JKBH 26	1997	4.4	Mahyco 2240	2010	
Ratan 666		3.6	Mahyco 2210	2010	
Bioseed 8494		3.5	Pro-Agro (XL-51)		
ICTP 8203	1988	3.2	Ajeet-35		80
Pioneer 86-M-52		3.1	Nath Seeds		
KBH 202		3.0	Ankur Seeds		
Pioneer 86-M-33		2.4	Ajeet 27		
Other hybrids	2004	0.3	MDBH-318		
			ICTP 8203	1988	
All MVs		52	All MVs		80

MV: Modern Variety

was under local landraces popular with different names. Popular hybrids too occupied by about 10-15% cropped area in the state. Pro-Agro 9444 (11%) and HHB 67 Improved (10.2%) are two prominent improved cultivars occupying significant areas in the state. The other improved cultivars preferred in Rajasthan are MH 169, JKBH 26, Ratan-666, Bioseed 8494, ICTP 8203, Pioneer 86-M-52, KBH 202, Pioneer 86-M-33, SagarLaxmi, Urmi 1111, Sujalam 68, Morixsori, Kisan 22, Nandi 55, Nandi 05, Nandi 32 and Gauri. These cultivars occupy around 31 per cent of the pearl millet area in the state. Cultivars having good fodder quality and dual-purpose (grain and fodder) varieties are highly preferred by farmers. Pro-Agro 9444 and HHB-67 Improved are the only two mega varieties (cultivars occupying more than 10% of the cropped area) in the state.

Maharashtra

The availability of a large number of hybrids/varieties in both public and private sectors resulted in large-scale adoption of improved cultivars in Maharashtra. This ultimately resulted in better yields compared to other local varieties. However, despite the large area under improved cultivars, production and productivity are still low in the state due to consecutive dry spells. Cultivation of pearl millet on lighter soils and poor management led to uneconomical yields in the state. The major improved cultivars grown in Maharashtra are Pioneer (86-M-33), Pioneer (86-M-64), Mahyco (MRB) 2240 and Mahyco (MRB) 2210, Pro-Agro (XL-51), Ajeet 35 and Ajeet 27, etc. (Table 24). All these improved cultivars together hold a share of around 80% of the area in Maharashtra. The experts were not able to provide the share of area under each cultivar due to insufficient knowledge and the dominance of private sector seed marketing.

Uttar Pradesh

In Uttar Pradesh, the adoption rate was relatively lower at 30% in 2010, primarily because the farmers' prefer to grow local cultivars than improved cultivars. Further, pearl millet is not considered as a priority crop in the state. The major varieties cultivated in Uttar Pradesh are Kaveri Super Boss, Pioneer 86-M-86, 86-M-52, 86-M-32, ICTP 8203, Raj 171, etc (Table 25).

Gujarat

Improved cultivars accounted for around 90-95% of the pearl millet area in Gujarat. The remaining 5-10 per cent was under local races with different local popular names, which are still preferred race for their good grain quality and taste. Adoption of improved cultivars started at a slow pace in the 1960s in Gujarat, and gained significant momentum from 1986 with the shift to improved cultivars like GHB 30, GHB 315, GHB 2 and GHB 3. This pushed the adoption rate to nearly 75-80% by the early 1980s. The other popular improved cultivars are GHB 558, GHB 568, Pioneer 86-M-86, MLBH 1012, Sagar Laxmi, Pro-Agro 9444, Ratan 666, Sujalam, Urvi 1111, Nandi 35, Nandi 55, DBI, Goha 126, Gopi and Prasanth 26 which altogether occupy nearly 95 per cent of the crop area in the state. However, experts failed to provide cultivar-specific adoption estimates in the state due to insufficient knowledge and the large varietal diversity existing in pearl millet.

Haryana

In Haryana, the real impact on productivity and production was witnessed with the development and adoption of high-yielding hybrids like HHB 50, HHB 60, HHB 67 Improved and varieties HC 10 and 20. Adoption of improved cultivars in Haryana is estimated at 85 per cent with the remaining area occupied by local landraces. The major cultivars identified by experts in Haryana were Pro-Agro 9444 (40%), HHB 67 Improved (30%) and HHB 197 (10%).

Table 25. Cultivar-specific adoption estimates in Gujarat, Haryana and Uttar Pradesh.

Gujarat			Uttar Pradesh		
Cultivar	Year	% share	Cultivar	Year	% share
GHB 558, GHB 568,			**Hybrids**		**20%**
Pioneer 86-M-86			Kaveri Super Boss		30
MLBH 1012			Pioneer 86-M 86		
SagarLaxmi			Pioneer 86-M-52		20
Pro-Agro9444	2004		Pioneer 86-M-32	2002	
Ratan 666			Pro-Agro 9443	2001	
Sujalam			Pro-Agro 9444	2004	15
Urvi 1111		95	Pro-Agro 9445		
Nandi 35			NPH40(Nirmal)		10
Nandi 55			JKBH 676	2009	5
DBI			Krishna 7201	2004	5
Goha 126			PB106,112,180	2001	5
Gopi			GHB558,557	2002	5
Prasanth 26			HHB146	2002	5
All MVs		95	**Varieties**		**10%**
Haryana			ICTP-8203	1988	50
Pro-Agro 9444	2004	40	Raj171	1992	20
HHB67 Improved	2005	30	Pusa 383	2001	15
HHB197	2008	10	JBV2	1998	5
Poineer86-M-86, JK hybrids, Nandi5 and Nandi32	1999	3	GICKV96752	2001	5
Others		2	Others		5
All MVs		85	All MVs		30%

MV: Modern Variety

Source: TRIVSA expert elicitation, 2012.

Table 26 summarizes the state-wide and all-Indiaadoption levels of pearl millet improved cultivars. About 68 per cent of total cropped area in the country was under improved cultivars. States like Gujarat, Maharashtra and Haryana are the forerunners in adoption while Uttar Pradesh and Rajasthan exhibited lower levels. There is a substantial scope for further enhancement of adoption in the country.

Pattern of Varietal Replacement

With the availability and adoption of high-yielding hybrids and varieties, pearl millet production has increased two-folds in a majority of the states. Table 27clearly reveals that the majority of the pearl millet cropped area across all states is under cultivars developed during the last one decade. We can observe the conspicuous dynamism in varietal replacement for almost every five-year span. This might be one of the reasons why private sector companies are investing more in pearl millet research and development.

Table 26. Summary of expert elicitations at the all-India level.

State	Pear millet (% area under MVs)
Rajasthan	52
Maharashtra	80
Gujarat	95
Uttar Pradesh	30
Haryana	85
All India	68
Evenson and Gollin estimate (2000)	65

Table 27. Pattern of pearl millet varietal replacement in India (% area under MV).

Period	Rajasthan	Maharashtra	Gujarat	Haryana	Uttar Pradesh
1981-90	10.50	0.00	0.00	0.00	8.00
1991-00	4.40	40.00	20.00	3.00	4.00
2001-10	21.50	40.00	75.00	80.00	7.00
Unknown	15.60	0.00	0.00	2.00	11.00
Total	52.00	80.00	95.00	85.00	30.00

Most Preferred Traits Across Different States

At the all-India level, adoption of pearl millet improved cultivars is hovering around 65-70%. However, it varies from state to state in the range of 30-95% depending on a wide range of constraints in technology adoption and policies. There is ample scope for further adoption of improved cultivars in India, particularly in Rajasthan and Uttar Pradesh. Cultivars/traits most preferred by farmers and consumers need to be developed and released for further enhancing the adoption in these niche locations. Understanding the farmer-preferred traits or market requirements is the need of the hour for better targeting of research and development. Information elicited from state experts is summarized in Table 28.

According to a study conducted by Ramasamy et al. (1999), higher grain yield followed by high fodder quantity were the most preferred traits in Tamil Nadu. Short duration, disease resistance, drought tolerance and good taste were some of the other priorities in choosing cultivars for adoption. Another study conducted in western Rajasthan (Kelley et al. 1995) revealed that straw yield and quality play a vital role in adoption of improved cultivars in low rainfall areas. More than 80 per cent of the respondents in surveys said that traditional cultivars yielded more straw of a better quality than improved cultivars in these regions.

Table 28. Preferred traits in pearl millet improved cultivars.

Preferred traits	Rajasthan	Maharashtra	UP	Gujarat	Haryana
Yield and biomass	√	√	√	√	√
Good fodder quality	√		√		√
Uniformity of grain size and color		√	√	√	√
Lodging resistant			√	√	√
Panicle length			√		√
Early-medium maturity	√	√		√	
Blast and downy mildew resistance		√		√	
Good grain size and compactness of the panicles		√		√	
Drought tolerance	√				

Source: Experts elicitation survey, ICRISAT, Dec 2011.

8. Major Constraints to Adoption of Improved Cultivars and Influences of Various Policies

High-yielding hybrids and OPVs have been widely accepted and adopted by farmers across the major pearl millet growing states. Despite the development of a large number of improved cultivars (208 cultivars between 1931 and 2011), the overall rate of adoption is still only 65-70 per cent. Differential adoption patterns/trends were observed across the major pearl millet growing states in India due to either specific constraints or skewed policy influences. Several factors might have played a significant role in influencing these diverse adoption pathways. A better understanding of these factors would help in further enhancing adoption in the targeted states. Ultimately, the entire exercise paves the way for better assessment of constraints and identifying factors and policies hindering the adoption process. The expert elicitations on pearlmillet conducted at ICRISAT helped us in summarizing them state wise:

Rajasthan

- Nonavailability of preferred improved and quality seeds, especially for the arid zone
- Lack of proper seed production and marketing channels
- Lower remuneration for produce/grain
- Lack of temperature-sensitive cultivars for the summer season
- Lack of awareness about improved cultivars

Gujarat

- Absence of suitable hybrids for the summer season
- Need for temperature-tolerant and rust-resistant cultivars for the postrainy (rabi) season
- Seed setting problems in the postrainy (rabi) season due to lower temperature
- Lack of awareness about recommended input usage and other practices

Haryana

- Shortage and lack of timely availability of improved seeds
- Nonavailability of quality seeds
- Lack of adherence to the recommended package of practices
- Lack of a minimum support price for grain and frequent rejection of produce by the government due to discoloration issues

Uttar Pradesh

- Lack of technical knowledge/awareness
- Lack of timely availability of high-yielding, disease-resistant cultivars
- Lack of dual-purpose high-yielding cultivars
- Nonavailability of short-duration (70-75 days) improved cultivars
- Suitable cultivars for delayed planting dates (after 25thJuly)
- Heavy weed infestation in the initial stages of crop growth
- Lack of suitable cultivars for summer-season pearl millet cultivation

Maharashtra

- Lack of balanced use of fertilizers and other inputs
- Less plant population due to frequent dry spells during the crop season
- Suitable improved cultivars/hybrids for lighter soil types (except ICTP 8203)
- Labor scarcity and shortage problems

Recommendations for Enhancing Adoption Rates

- Strengthening of public and private sector partnerships for effective seed production, multiplication and distribution, particularly in western Rajasthan (A_1 Zone)
- Creating awareness about benefits of improved cultivars through mass communication systems as well as Front Line Demonstrations (FLDs)
- Value addition through innovative value chain strategies as well as linking farmers to markets to reap remunerative prices
- Nearly 50% of the country's total production is being diverted to industrial purposes. However, regular supply of grains (round the year) brings more stabilization in the market and also attracts good market investments.
- The country-level Seed Replacement Rate (SRR) has been increasing during the last decade. However, the current level of 63% is not satisfactory for a highly cross pollinated crop like pearl millet.
- Misutilization of subsidies on seeds, especially in Rajasthan and Haryana, for the last two years.
- The quality of public sector seeds is inferior when compared with private sector seeds of improved cultivars. This issue needs to be addressed seriously.
- All the stakeholders in crop improvement should equally focus on the development of improved cultivars across different environments. Development of suitable cultivars, especially hybrids, for Arid Zone (A_1) should be prioritized and addressed holistically.

9. Seed Production, Availability and Seed Replacement Rates

Seed constitutes the most important input in farming and plays a seminal role in effecting successful agriculture. The efficacy of the other agriculture inputs is contingent upon the quality of the seed. A sound seed production program aimed at providing the consumer-farmer with high quality seed of improved open-pollinated varieties (OPVs) and hybrids is essential to national agricultural development.

During the last four decades, rapid progress has been made in terms of seed production and processing by using high-yielding seed parents, adoption of improved methods of seed production and modernization of seed processing and packaging practices, etc. In general, around 70% of the total seed production in India comes from the private sector and the remaining from the public sector (AICPMIP 2011). Approximately 20000-22000 tons of quality seed is required annually.

In general, the project coordinator of AICPMIP allots the breeder seed production of OPVs, and parental lines of hybrids to different originating centers and monitors the production program. The breeder seed produced is then passed on to the indenting agencies to enable them to use it in foundation seed production. The private sector is also involved in the large-scale seed production of public-bred hybrids as well as their own proprietary hybrids. The multiplication and distribution of certified seed of public hybrids like Pusa 23, HHB 67, HHB 67 Improved, HHB 197 and the OPV ICTP 8203 by the private sector is one example of mutually contributing toward the common goal of farmers' benefit. The private sector also produces a large quantity of truthfully labeled seed, which need not be certified by the seed certification agencies. The quantity of such seed produced and marketed by the private sector is yet to be assessed. In the case of pearl millet, hybrid and OPV seed production technology has been fine tuned, documented and disseminated well through various reports. The seed production is undertaken through a seed village concept for long-term sustainability of the system and better quality.

Data on pearl millet breeder seed production (BSP) in India from 2002 to 2010 are summarized in Table 29. In almost all these years, the actual breeder seed production in the country was much higher than the actual requirement except in 2009-10. The exception may be because of a severe drought in the seed producing locations. AICPMIP, which is the organization responsible for providing enough breeder seed, is meeting its requirements. But, the seed of both private and public-bred hybrids are not available to farmers in sufficient quantities.

Seed Multiplication Ratios (SMRs)

The seed multiplication ratio is nothing but the number of seeds to be produced from a single seed when it is sown and harvested. According to the expert group on seeds (1989), the seed multiplication ratio for pearl millet is around 1:200.

Seed Replacement Rate (SRR)

The seed replacement rate is the percentage of area sown with certified/quality seeds other than the farm-saved seed.

Table 29. Pearl millet seed production in India.

Year	No. of cultivars	Breeder Seed Production (BSP) required (Qtl)	BSP Actual (Qtl)	Excess/deficit (Qtl)
2002-03	40	12.62	70.05	57.43
2003-04	35	11.65	39.12	27.47
2004-05	51	13.17	31.00	17.83
2005-06	46	12.88	33.44	21.00
2006-07	46	20.00	38.00	18.00
2007-08	47	15.66	38.85	23.19
2008-09	44	16.2	35.91	19.71
2009-10	22	7.7	8.38	-0.68
2010-11	31	10.22	22.66	12.44

Source: Annual reports of AICPMIP.

Statewise Pearl Millet Seed Replacement Ratios

In India, the seed replacement rate (SRR) of pearl millet is gradually picking up due to the development and supply of niche-specific improved cultivars by NARS partners and ICRISAT. During the last decade, the SRR has improved from 45.92% in 2001 to 63%. This achievement was made possible by the intervention of the private and public sectors in seed production and distribution. The state-wise trend in the SRR over the years is presented in Table 30.

In Rajasthan, pearl millet is one of the major crops during the rainy season. However, the SRR is low at 56% in the state. Nearly half of the cropped area is under local landraces as they have better taste and roti-making quality. Overall, enhancement of the SRR is the need of the hour in the state. Due to the availability of good quality seeds, Maharashtra has a high SRR of 92%. However, despite the high adoption rate and SRR, average yields in this state are very low due to prolonged dry spells, cultivation of the crop on marginal and poor soils and the prevalence of subsistence farming.

In Uttar Pradesh, the SRR hasincreased significantly from 14% to 77% during the last decade. However, the extent of adoption of improved cultivars was rather low. The peculiar case of Uttar Pradesh needs to be investigated. Development of attractive and stable markets for the sale of end products determines and influences the farmers' decision in adopting new technologies. In Haryana, the SRR is stable at around 66 per cent. All the southern states exhibited very low level of adoption due to severe competition from other commercial crops.

10. Impact of Technology and Unit Cost Reductions

In general, the impacts of crop improvement research can be perceived in terms of yield gain, reduction in the unit production cost, technology spillover and improvement in yield stability. For any crop, it can be difficult to interpret yield levels and changes in yield as measures of the research impact. This is particularly true for crops such as pearl millet which are customarily grown with few inputs on poor quality land. Even small changes in the quantities of inputs used or the quality of the land planted to pearl millet can have large effects on crop yields. However, the area under pearl millet has been declining since the 1980s while productivity gains were observed in all the major growing states due to the increased adoption of improved cultivars. Nevertheless, the impact of improved cultivars on yield gains and yield stability needs to be assessed deeply for better understanding. Similarly, the effect on reduction in the unit cost of production in major states needs to be estimated.

Table 30. Statewise pearl millet seed replacement rates (%).

State	2001	2002	2003	2004	2005	2006	2007	2008
Karnataka	26	21	22	23	27	29	28	29
Andhra Pradesh	44	87	32	44	62	67	85	46
Maharashtra	72	74	74	75	74	75	74	92
Rajasthan	33	59	35	31	45	46	42	56
Uttar Pradesh	14	18	36	42	50	52	58	78
Haryana	64	36	59	-	-	57	60	66
Gujarat	-	-	-	-	-	-	-	-
India	46	48	51	45	55	55	48	63

Source: Directorate of Economics and Statistics.

The increase in crop productivity during the period 1971-2010 is summarized in Table 31. Significantly improved yield levels were observed during 2007-10 compared to 1971-74 in all the selected states. In general, the highest yield levels were found in Haryana (1749 kg ha^{-1}) and Uttar Pradesh (1608 kg ha^{-1}). Over a period of four decades, yield levels increased by nearly 216% from 228 kg/ha to 721 kg ha^{-1} in Rajasthan. In Haryana, yields increased by 221% to 1749 kg/ha, and by more than 100% in Uttar Pradesh, Gujarat and Maharashtra. This success happened only through increased adoption of improved varieties. However, in Rajasthan the relative yield levels are very low due to cultivation of age-old cultivars and climatic reasons.

The impact of pearl millet hybrids on productivity across the major pearl millet growing states is summarized in Table 32. In general, most of the pearl millet hybrids (both public and private) penetrated well in India since the early 1990s. For a deeper understanding of the changes in area, production and productivity, the analysis period was divided into two i.e., Pre-hybrid phase (1955-66) and Post-hybrid phase (2001-10). Except Rajasthan, all other states showed declining trend in pearl millet cropped area between pre- and post-HYV period. But, production and productivity increased significantly during the same period in all study states. Tamil Nadu, Haryana, Uttar Pradesh and Gujarat showed the most promising trends when compared with other states. Overall, the comparison clearly demonstrates the potential of hybrid technology relative to OPVs in the country.

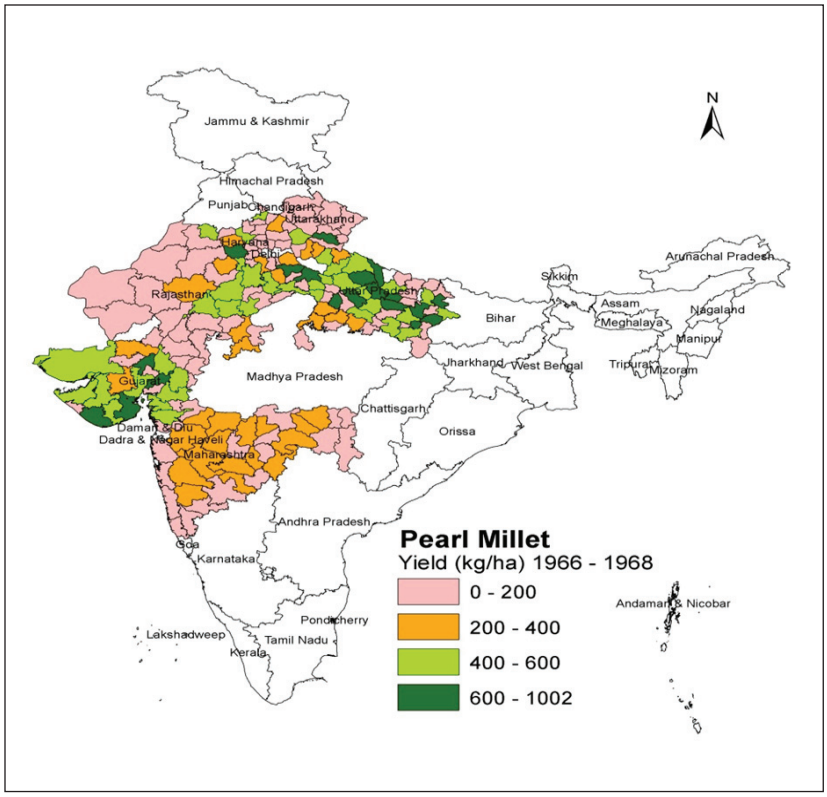
Table 31. Impact of improved pearl millet cultivars on productivity in India, 1971-2010.

	Average yield (kg ha^{-1})					Yield gain (%) compared to 1971-74			
State	1971-74	1981-84	1991-94	2001-04	2007-10	1981-84	1991-94	2001-04	2007-10
Gujarat	634	1027	926	1243	1317	62	46	96	108
Haryana	545	631	913	1309	1749	16	68	140	221
Rajasthan	228	327	387	690	721	43	70	203	216
Maharashtra	251	397	676	686	867	58	169	173	245
Uttar Pradesh	614	835	1100	1309	1608	36	79	113	162

Table 32. Impact of high-yielding varieties (HYVs) of pearl millet on area, production and productivity in India.

	Area (million ha)		Production (million t)		Productivity(kg ha^{-1})	
State	Pre-HYV*	Post-HYV	Pre-HYV	Post-HYV	Pre-HYV	Post-HYV
Rajasthan	4.13	4.95	0.87	3.55	188	690
Maharashtra	1.73	1.29	0.47	0.97	270	767
Gujarat	1.57	0.89	0.58	1.11	370	1250
Uttar Pradesh	1.07	0.86	0.57	1.25	534	1456
Haryana	0.78	0.59	0.25	0.91	315	1503
Karnataka	0.62	0.34	0.31	0.23	505	670
Andhra Pradesh	0.51	0.08	0.29	0.08	593	1010
Tamil Nadu	0.51	0.08	0.12	0.10	234	1312
Madhya Pradesh	0.19	0.17	0.11	0.24	597	1382
India	11.32	9.27	3.67	8.28	324	884

*Pre-HYV phase: 1955-66; post-HYV phase: 2001-10.
Source: AICPMIP, Jodhpur, Rajasthan, 2010.



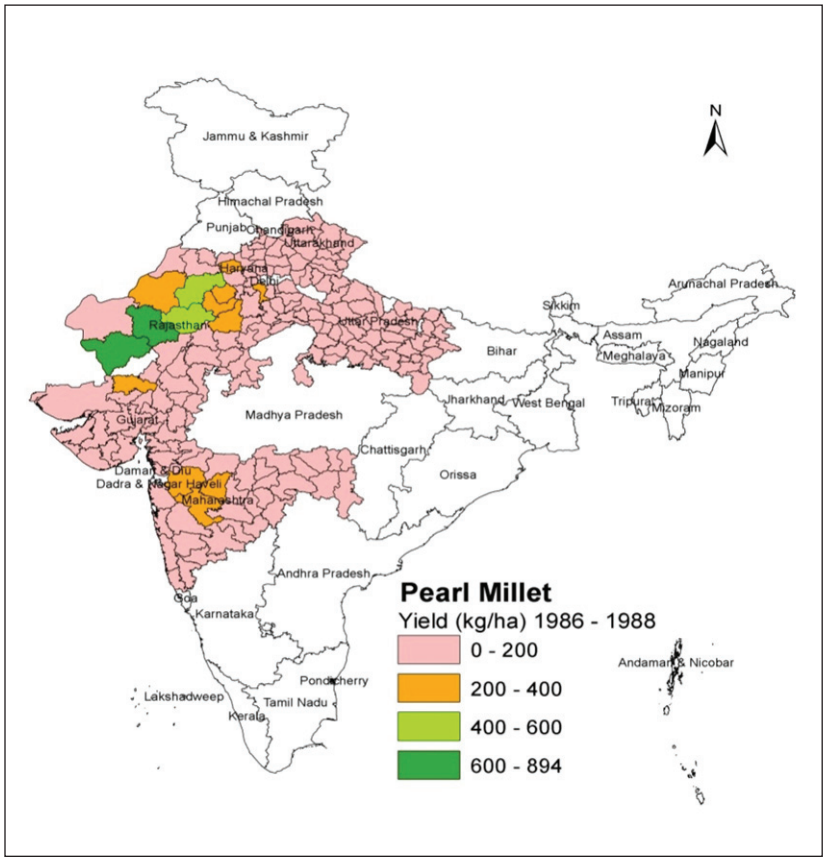
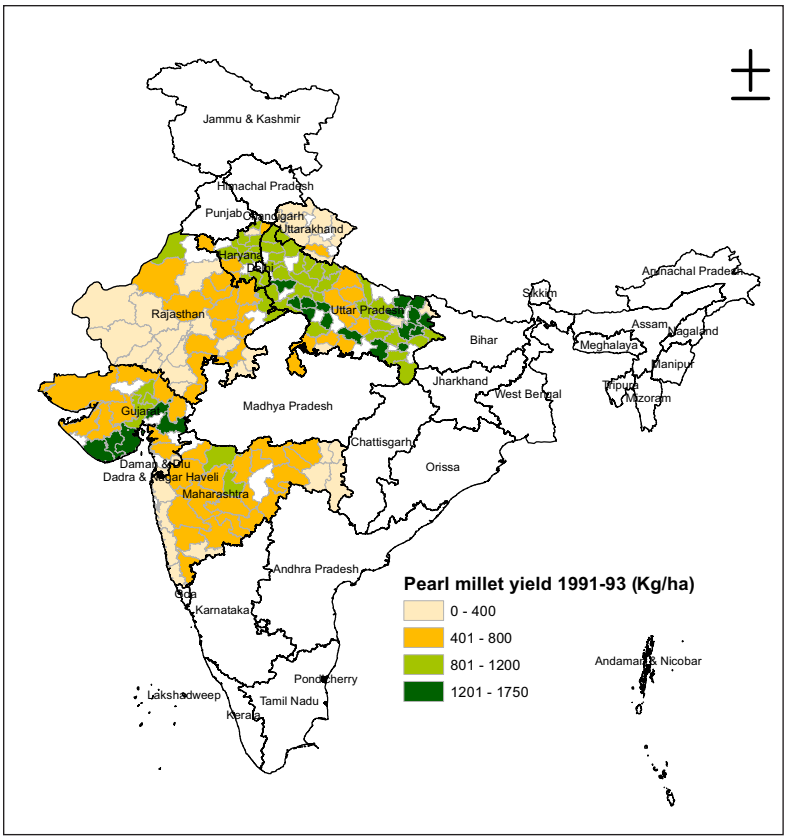


Figure 22. Spatial distribution of pearl millet productivity across major states from 1966-68 to 1986-88.



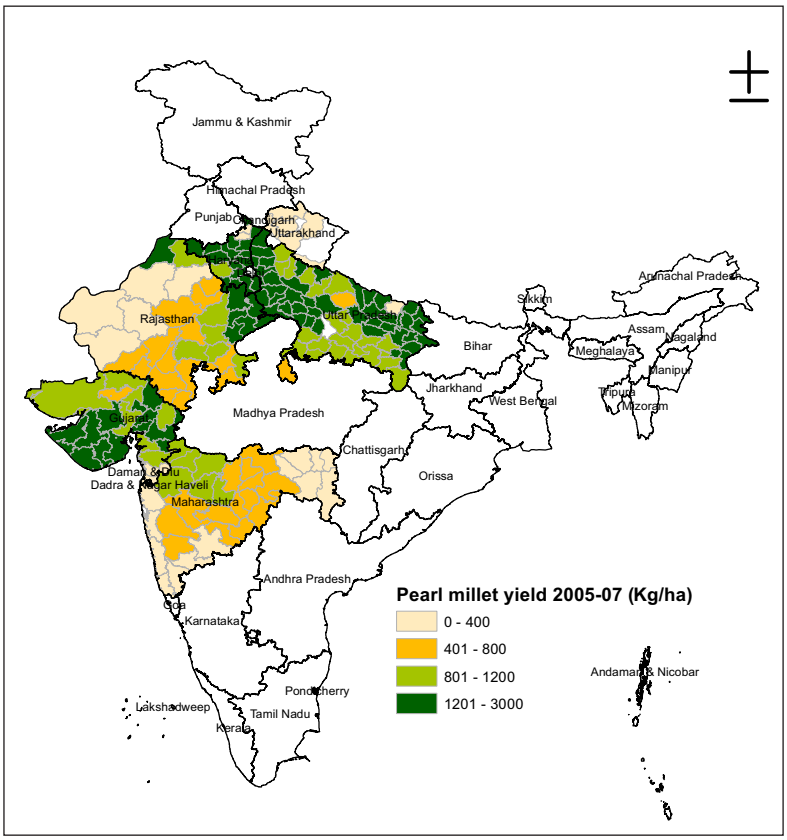


Figure 23. Spatial distribution of pearl millet productivity across major states from 1991-93 to 2005-07.

Successes Stories of Important Pearl Millet Improved Cultivars

- *'BJ 104' was the most widely grown pearl millet hybrid in India until it became susceptible to downy mildew (DM) in 1984-85. Residual variability for resistance was found in both parental lines, 5141 B (maintainer of 5141 A) and J 104, and through four generations of pedigree selection under intense disease pressure in the DM nursery, two lines, IC-MA841 (from 5141 B) and ICMP 84814 (from J 104), were selected resulting in a reconstituted DM resistant hybrid ('ICMH 84814') which was equal in yield to the original 'BJ 104'. The reconstituted hybrid, though phenotypically similar, can be distinguished from "BJ 104" being slightly taller, flowers later, has heavier heads, and 1000-seed weight, but tillers less.*
- *In 1982, an ICRISAT-bred downy mildew-resistant open-pollinated variety WC-C75 produced grain and stover yields equal to the best available hybrid at that time (BJ 104) and was released in India in 1982 (Andrews et al. 1985). This variety provided a timely alternative to the susceptible BJ104, and to low-yielding local landraces. The rapid multiplication of WC-C75 and its adoption by farmers helped to prevent a decline in pearl millet production in the country. At the peak of its adoption during the late 1980s, it was cultivated on about 1.2 million ha (Rai et al. 2006).*
- *In 1990, CCS Haryana Agricultural University (CCSHAU) released the hybrid pearl millet HHB 67, the earliest maturing pearl millet hybrid (62–65 days from sowing to harvest) anywhere to date. This was rapidly adopted by farmers in northwestern India. This type of single cross hybrids were vulnerable to downy mildew (DM) epidemics and created a 30% production loss in the country. With proactive role of ICRISAT HHB 67 Improved developed which was a DM resistant and high yielding hybrid. By 2011, HHB 67 Improved had spread to 875,000 ha, with Rajasthan accounting for 768,000 ha (16% of the state's total pearl millet area) and Haryana accounting for 107,000 ha (21% of the state's pearl millet area).*
- *On the hybrids front, an ICRISAT downy mildew-resistant hybrid, ICMH 451 (also known as MH 179) was released in 1986. It yielded more than all the other varieties and hybrids released earlier, and its seed production was relatively easy and profitable. The release of improved pearl millet cultivars in India has increased exponentially over time. NARS breeding programs grew stronger in India, and ICRISAT parents (rather than finished material) grew more in importance over time (Bantilan and Deb 2002).*
- *ICTP 8203 is a landmark OPV cultivar that was developed at ICRISAT, Patancheru with an average grain yield of 1.6 t ha^{-1}. It was released in Maharashtra and Andhra Pradesh in 1988 (Rai et al. 1990). At the peak of its adoption in 1992, this variety was grown on 0.6-0.7 million ha in Maharashtra alone (Bantilan et al. 1998). It sustained for a longer period despite stiff competition from several hybrids released during the past 20 years. This is due to its early maturity, drought tolerance, large grain size and dark graycolor and excellent adaptation to low-fertility light soils. It has also been adopted well in parts of Rajasthan and Uttar Pradesh apart from the targeted two states.*
- *The hybrid JKBH 26, developed by JK Agri Genetics, is based on an A-line that has no other hybrid in the market. This hybrid has been in cultivation since 1996, retaining its initial high level of downy mildew resistance. The hybrid was adopted by an increasing number of farmers for its high grain and stover yield as well as its high level of downy mildew resistance. It reached a peak adoption level of more than 400,000 ha in 2005.*
- *The hybrid Pro-Agro9444 was developed by Proagro Seed Company (now Bayer Bio Science). It was also highly valued for its high grain and stover yield, good stover quality (farmers' perception), and downy mildew resistance. This hybrid is also highly tolerant to temperatures as high as 45°C during flowering time. The adoption of this hybrid rapidly increased from 60,000 ha in 2001 to more than 400,000 ha in 2006 (Mula et al. 2007).*

Figures 22 and 23 summarizes the spatial distribution of pearl millet productivityin major growing states during 1966-68 to 1986-88 (period-1) and 1991-93 to 2005-07 (period-2) respectively. The high (>600 kg ha^{-1}) productivity districts were conspicuously observed in Gujarat and Uttar Pradesh during 1966-68. But, they were almost disappeared by end of period-1. However, the average productivity levels were significantly improved among study states between period-1 and 2. By early 1990s, the high productivity districts were again spotted in Gujarat and Uttar Pradesh states. Their spread was significantly increased in Gujarat, Uttar Pradesh, Haryana and Rajasthan states by 2005-07.

Data and Research Methodology

The study used data collected from two main sources: 1) District-level secondary data published in the stateseason and crop reports and state statistical abstracts; and 2) cost of cultivation data published by the Ministry of Agriculture and Cooperation, Government of India. District-level yield data for 1966-2007 covering 226 pearl millet growing districts in nine states – Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu and Uttar Pradesh –were used to estimate yield and stability gains due to the adoption of improved cultivars (Table 33). All these districts together accounted for about 99.64% of the total pearl millet area and 99.67% of pearl millet production in India (2005-07). However, districts with a negligible area (<500 ha) were discarded from further analysis. Some 91 districts were removed from the data analysis due to low cropped area and nonavailability of data, etc.

Table 33. Selection of study districts in major pearl millet growing states of India.

State	No. of pearl millet growing districts	No. of districts considered in the study	Discarded districts
Andhra Pradesh	20	15	West Godavari, Krishna, Hyderabad, Khammam, Karimnagar
Gujarat	18	16	Bulsar, Dangs
Haryana	7	7	-
Karnataka	19	9	Bangalore, Kolar, Tumkur, Mandya, Hassan, Chickmagalur, Shimoga, DakshinaKannada, UttaraKannada, Coorg
Madhya Pradesh	43	11	Durg, Bastar, Raipur, Bilaspur, Raigarh, Surguja, Jabalpur, Balaghat, Chhindwara, Narsinghpur, Seoni, Mandla, Sagar, Damoh, Tikamgarh, Chhatarpur, Panna, Sidhi, Satna, Shahdol, Gunna, Indore, Ratlam, Ujjain, Mandsaur, Sehore, Raisen, Vidisha, Betul, Rajgarh, Shajapur, Hoshangabad
Maharashtra	26	15	Bombay, Thane, Raigad, Ratnagiri, Kolhapur, Nanded, Amravati, Wardha, Nagpur, Bhandara, Chandrapur
Rajasthan	26	22	Basawara, Chittorgarh, Dungarpur, Jhalawar
Tamil Nadu	13	9	Thanjavur, Nilgiris, Kanyakumari,Chennai
Uttar Pradesh	54	31	Saharanpur, Muzaffarnagar, Pilibhit, Bijnor, Jhansi, Hamirpur, Gorakhpur, Deoria, Basti, Azamgarh, Kheri, Faizabad, Gonda,Bahraich, Sultanpur, Nainital, Almorah, Pithoragarh, Chamoli, Uttar Kashi, TehriGarhwal, Garhwal, Dehradun.
All India	226	135	-

Table 34 analyzes the average yield and relative variability in yield of pearl millet in different states during the last four decades, in three phases. The highest productivity was observed in Uttar Pradesh followed by Haryana, Madhya Pradesh and Gujarat during 1994-2007. Almost all the states witnessed an increase in productivity during all the three periods and a corresponding decrease in the coefficient of variation by the third period compared to the 1966-79 period (P-1) except in Karnataka. This was made possible by the adoption of modern varieties and management practices. Relatively low productivity and a higher coefficient of variation was observed in the case of Rajasthan followed by Karnataka during the last period. A higher preference for local cultivars and limited adoption of improved cultivars were the crucial factors responsible for this. Upon comparing P-3 with P-2, the coefficient of variance declined in almost all the states except Karnataka and Madhya Pradesh. Significant productivity gains and relative reduction in yield variation were observed in states like Maharashtra, Gujarat and Haryana due to increased adoption of improved cultivars. Overall, yields were enhanced by almost 81 per cent at the all-India level between 1966-79 and 1994-2007.

If we examine the long-term trends in average yields and relative variability among different study states (Table 35), we find that mean yields were the highest in Uttar Pradesh followed by Gujarat and Madhya Pradesh over the last four decades. But the coefficient of variation was the lowest in Karnataka

Table 34. Mean productivity and stability of pearl millet across major states of India.

	1966-79 (P-1)		1980-93 (P-2)		1994-07 (P-3)		Change (P-3 over P-2)	
State	Yield (kg ha^{-1})	CV (%)	Yield (kg ha^{-1})	CV (%)	Yield (kg ha^{-1})	CV (%)	Yield (%)	CV (%)
Gujarat	723.5	29.05	875.2	28.04	1160.8	17.18	32.64	-38.72
Karnataka	420.4	25.09	491.3	19.34	613.2	26.33	24.83	36.17
Madhya Pradesh	596.3	28.45	688.0	19.22	1160.4	20.82	68.66	8.32
Maharashtra	319.0	24.20	481.3	37.73	708.9	16.04	47.29	-57.48
Rajasthan	248.4	48.85	299.7	49.32	561.8	42.98	87.45	-12.86
Uttar Pradesh	617.6	21.38	930.3	17.69	1328.8	11.50	42.84	-34.99
Haryana	516.7	36.53	649.4	40.35	1255.3	25.48	93.31	-36.85
All India	439.2	22.30	523.5	25.82	796.5	19.82	52.15	-23.25

Table 35. Long-term average yields and relative variability in pearl millet, 1966-2007.

State	Average Yield (kg ha^{-1})	CV (%)
Gujarat	919.87	30.63
Karnataka	508.31	28.61
Madhya Pradesh	826.46	36.91
Maharashtra	504.46	40.91
Uttar Pradesh	958.93	34.32
Rajasthan	374.97	58.86
Haryana	814.56	50.48
All India	593.67	33.82

and Gujarat. High rates of adoption coupled with a favorable environment may explain the decrease in variation in state average yields over the period. High variability in yields was observed in Rajasthan followed by Haryana and Maharashtra. Rajasthan has a relatively lower adoption rate and more erratic climatic conditions when compared with the other two states. But the low stability in average yields in Maharashtra and Haryana needs to be probed further.

Table 36 reveals the association between yield and yield instability in different pearl millet growing districts between 1986-95 and 1996-2007. Overall, only 22 out of the 135 sample districts exhibited

Table 36. Association (%) between pearl millet yield and yield instability in different districts between 1986-95 and 1996-2007.

	Types of Association			
State	**AA:** Increase in yield with decrease in variability	**AB:** Increase in yield with increase in variability	**BA:** Decrease in yield with decrease in variability	**BB:** Decrease in yield with increase in variability
Andhra Pradesh (15*)	6.67	20.00	40.00	33.33
Gujarat (16)	37.50	6.25	43.75	12.50
Haryana (7)	14.29	28.57	57.14	0.00
Karnataka(9)	11.11	44.44	33.33	11.11
Madhya Pradesh (11)	36.36	27.27	9.09	27.27
Maharashtra (15)	0.00	0.00	86.67	13.33
Rajasthan (22)	18.18	9.09	54.55	18.18
Tamil Nadu (9)	11.11	11.11	44.44	33.33
Uttar Pradesh (31)	12.90	9.68	64.52	12.90
Overall (135)	16.30 (22)	14.07 (19)	51.85 (70)	17.78 (24)

* Figures in parentheses indicate no. of districts.

Table 37. Instability in yield of pearl millet in different districts, 1966-2007.

	Instability in yield (CV%)			
State	<=25%	26-50%	51-75%	>75%
Andhra Pradesh (15*)	13.33	60.00	20.00	6.67
Gujarat (16)	6.25	75.00	18.75	0.00
Haryana(7)	0.00	42.86	57.14	0.00
Karnataka (9)	11.11	66.67	22.22	0.00
Madhya Pradesh (11)	9.09	81.82	0.00	9.09
Maharashtra(15)	0.00	80.00	20.00	0.00
Rajasthan (22)	0.00	13.64	40.91	45.45
Tamil Nadu (9)	22.22	66.67	11.11	0.00
Uttar Pradesh (31)	3.23	83.87	12.90	0.00
All India (135)	5.93 (8)	63.70 (86)	21.48 (29)	8.89 (12)

*Figures in the parentheses indicates no. of districts.

an increase in yield with a decrease in variability. Around 19 sample districts showed increased yield associated with an increase in variability during the study period. Nearly 94 districts revealed a decrease in yield growth between these periods. Among these 94 districts, nearly 74.46 per cent of the districts displayed a decrease in yield along with variability while the remaining showed an increase in variability. On the whole, nearly 31.85 per cent of the study districts expressed an increase in variability in yields between two these periods. More in-depth analysis is required to further probe the root cause of variability in yields in these districts.

Table 38. Distribution of districts based on percentage of area under improved cultivars.

	Percentage of total pearl millet area under improved cultivars			
State	<=25 %	26-50%	51-75%	76-100%
1977-79				
Andhra Pradesh (15)	5	6	4	0
Gujarat (16)	0	1	6	9
Haryana (7)	3	3	1	0
Karnataka (9)	6	1	1	1
Madhya Pradesh (11)	10	1	0	0
Maharashtra (15)	12	1	1	1
Rajasthan (22)	15	7	0	0
Tamil Nadu (9)	1	3	2	3
Uttar Pradesh (31)	31	0	0	0
All India (135)	83	23	15	14
1991-93				
Andhra Pradesh (15)	2	0	5	8
Gujarat (16)	1	0	4	11
Haryana (7)	0	0	6	1
Karnataka (9)	3	0	3	3
Madhya Pradesh (11)	6	3	1	1
Maharashtra (15)	0	0	5	10
Rajasthan (22)	13	2	2	5
Tamil Nadu (9)	1	1	3	4
Uttar Pradesh (31)	23	8	0	0
All India(135)	49	14	29	43
2005-2007				
Andhra Pradesh (15)	4	2	4	5
Gujarat (16)	1	1	3	11
Haryana (7)	0	0	1	6
Karnataka (9)	0	2	1	6
Madhya Pradesh (11)	5	4	1	1
Maharashtra (15)	0	0	0	15
Rajasthan (22)	10	1	1	10
Tamil Nadu (9)	0	0	1	8
Uttar Pradesh (31)	21	10	0	0
All India (135)	41	20	12	62

Table 37 summarizes the analysis of long-term instability in pearl millet yields in different districts during 1966-2007. Eighty-six study districts showed yield variability between 26% and 50%. Only 8 displayed less than 25% variability, and 41 districts exhibited high variability (>50%). In general, the majority (64%) of the pearl millet growing districts and states exhibiting moderate levels of instability in yields over the four decades. This might be because of erratic climatic situations prevailing in the pearl millet growing locations and periodic outbreak of downy mildew in these places. Based on these results, we cannot conclude that adoption of improved cultivars alone will reduce yield variability in these districts.

Table 38 furnishes the distribution of the sample districts based on the proportion of area under improved cultivars during 1977-79 and 2005-07. Available secondary sources of information (mostly from the Department of Agriculture) were used for classifying the sample districts over period of time. The data clearly reveal that area under improved pearl millet cultivars increased significantly during the study period. The number of districts with a greater than 50% adoption rate increased from 29 in 1977-79 to 74 in 2005-07. Similarly, the number of districts with a less than 50 per cent adoption rate decreased drastically from 106 to 61 during the same time. However, nearly 41 districts still showed adoption rates less than 25 per cent. These districts were mainly concentrated in Uttar Pradesh, Rajasthan and Madhya Pradesh. The districts with higher adoption rates were situated mostly in Haryana, Gujarat, Maharashtra, Rajasthan and Tamil Nadu. Rajasthan exhibited a peculiar characteristic of adoption with nearly 50 per cent of the sample districts having an adoption rate of less than 25 per cent while the remaining districts showed more than 75 per cent adoption.

Determinants of Interdistrict Differences in Pearl Millet Yield

A regression equation was fitted to examine the determinants of interdistrict (N=90) differences in pearl millet yield for the period 2005-08 (triennium average) (Table 39). The mean district level yields were regressed against the respective pearl millet cropped area, area under improved cultivars and with state-level dummies. For further understanding variability across the study states, four state-level dummy variables were added in the equation. The OLS method of multiple-regression equation was fitted for secondary data. The empirical form of the equation was as follows:

$$Y_d = a + b_1 a + b_2 a_H + b_3 d_R + b_4 d_H + b_5 d_M + b_6 d_{UP}$$

Table 39. Determinants of interdistrict differences in pearl millet yields.

Variables	Coefficient	Std. Error	t value	Sig.
(Constant)	449.4	324.2	1.4	0.169
Pearl millet area	-0.9	0.3	-2.7	0.008*
% area under MV	1.4	0.5	2.5	0.013*
D-Rajasthan	502.6	124.4	4.0	0.000*
D-Haryana	-408.3	154.4	-2.6	0.010*
D-Maharashtra	750.7	123.2	6.1	0.000*
D-Uttar Pradesh	64.2	107.2	0.6	0.551
R-square	0.516			
N#	90			

N=90 study districts D: Dummies for each state

* Significant at 1 per cent level.

Table 40. Determinants of variability in pearl millet yields.

Variables	Coefficients	Std. Error	t	Sig.
(Constant)	79.38	10.42	7.62	3.7E-11*
SMV	-0.04	0.01	-6.52	5.2E-09*
Yield	-0.01	0.03	-0.48	6.3E-01
D-Rajasthan	-10.71	4.96	-2.16	3.4E-02*
D-Haryana	-9.86	5.11	-1.93	5.7E-02
D-Maharashtra	17.80	5.13	3.47	8.4E-04*
D-Uttar Pradesh	6.24	3.82	1.64	1.1E-01
R –square	0.667			
N#	90			

N=90 study districts D: Dummies for each state
* Significant at one per cent level.

The R-square value of the regression equation fit was 0.516. The district-wise cropped area under pearl millet exhibited negative and significant relation with pearl millet yield among the sample study districts. This may be true that with expansion of the cropped area in any district would lead to higher variation in crop yields. This might be due to climatic variability and increase in the probability of obtaining lower levels of yields per hectare. In general, this is an anticipated trend in a rainfed agriculture situation. The percentage of cropped area covered with improved cultivars showed a positive and significant relationship with district level yields. This clearly lends support to our argument that the adoption of improved cultivars not only increases yields but also reduces variability among them. Among the four state-level dummies, Rajasthan, Haryana and Maharashtra displayed significant differences in yield levels when compared with Gujarat.

Determinants of Variability in Pearl Millet Yields

Another regression equation was fitted to analyze the determinants of variability in pearl millet district level long-term mean yields from 1966-2007 (Table 40). For this purpose, the variability (coefficient of variation) for each study district was assessed for five major states. The coefficient of variation was taken as a dependent variable in the regression equation. It was regressed against the mean district yields, mean cropped area covered under improved cultivars and state-level dummies for understanding variability. A total of 90 observations from five states (Gujarat, Rajasthan, Maharashtra, Uttar Pradesh and Haryana) were fitted within the following form:

$$Y_{CV} = a + b_1 d_{Ym} + b_2 a_{Hm} + b_3 d_R + b_4 d_H + b_5 d_M + b_6 d_{UP}$$

The explanatory power of the equation was moderate at 0.667. The proportion of area under improved cultivars exhibited a negative and significant relationship with variability in the district yields. This clearly indicates that increased adoption of improved cultivars leads to reduced coefficient of variation in the mean district yield levels. Increases in the average productivity levels in the sample districts are to some extent minimizing the variability and increasing the stability in district yields. But this relation was not statistically significant in the case of pearl millet. This might be one of the reasons why most of the study districts displayed variability between 25% and 50%. The cultivation of pearl millet in typically harsh environments may be another cause for high variability in productivity. States like Rajasthan and Maharashtra exhibited significant deviations in variability from Gujarat. However, the deviations in Haryana and Uttar Pradesh were significant at 10 per cent only.

Impact on Unit Cost of Production

Irrespective of the crop, an unconventional measure of productivity gains after intervention with improved technology is the reduction in the unit cost of production. An analysis of the cost of production data is carried out to study the fluctuations in the unit cost of production over a period of time. Thus data was collected from the Commission on Agriculture Costs and Prices (CACP) annual reports in major

Table 41. Impact on the unit cost of production (₹ per quintal at 1993 real prices).

Year	Gujarat	Haryana	Maharashtra	Rajasthan	Uttar Pradesh
1986-87	2.9	3.6	NA	2.6	2.7
1994-95	2.7	2.3	3.5	2.4	NA
1996-97	NA	3.8	3.8	3.1	3.1
1997-98	NA	3.3	4.6	2.8	2.4
1999-2000	4.2	4.9	4.4	3.8	3.3
2000-01	3.8	3.9	3.8	3.5	2.6
2001-02	3.2	3.2	4.3	2.1	3.0
2002-03	3.8	5.0	3.9	3.6	4.2
2003-04	3.1	3.5	4.5	2.0	2.8
2004-05	3.2	3.9	3.7	2.8	2.7
2005-06	3.2	4.7	3.8	3.3	3.3
2006-07	3.1	3.5	3.8	3.0	2.7
2007-08	2.9	3.2	3.6	2.7	2.6
2008-09	2.9	3.6	5.0	3.2	3.4
1996-98 avg	NA	3.5	4.2	3.0	2.7
2007-09 avg	2.9	3.4	4.3	2.9	3.0
% change	NA	-2.19	2.05	-1.66	10.07

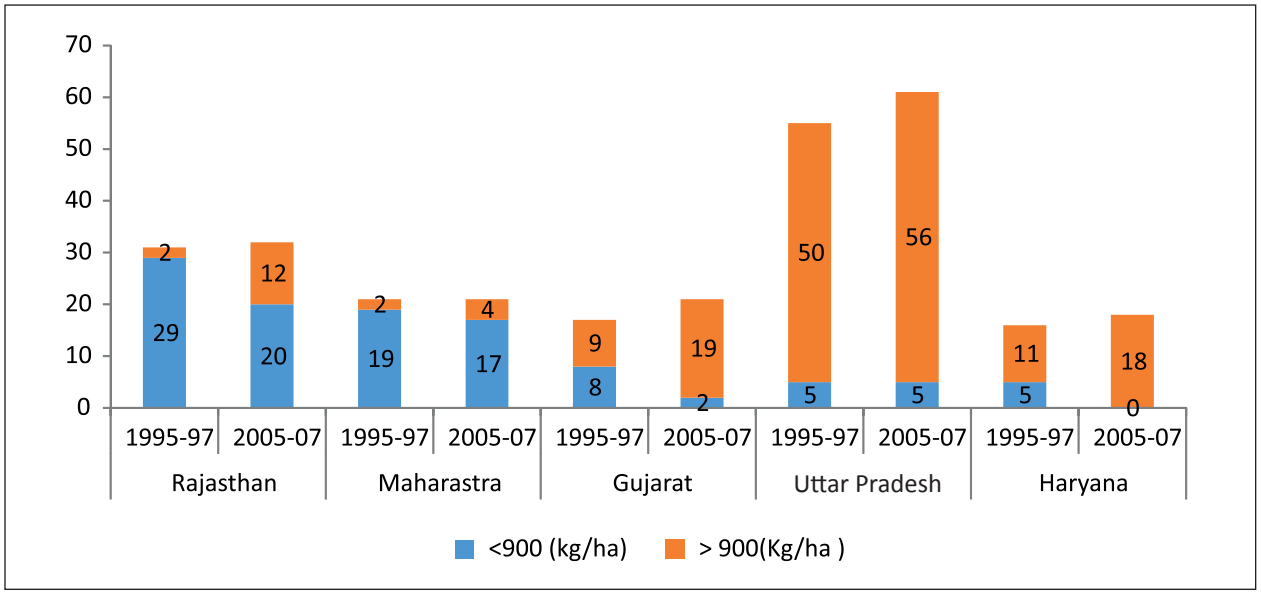


Figure 24. District-level yield performance of pearl millet.
Source: DLD database,ICRISAT.

pearl millet growing states for the period of 1986-87 to 2008-09. States like Haryana and Rajasthan showed a marginal decline in the unit cost of production per quintal while the same slightly increased in case of Maharashtra and Uttar Pradesh at 1993 real prices (Table 41). This was made possible due to the development of CMS-based hybrids and their adoption at the field level. The main reasons attributed for these lower productivity levels are erratic and unfavorable weather conditions, low levels of adoption of improved cultivars and the inefficient seed production system in India.

District-level Yield Gaps

District-level data from five major states were used for analyzing the yield gaps across the sample districts and states. The total number of districts among these five states was 200, out of which only 140 and 153 pearl millet growing districts were chosen for the 1995-97 and 2005-07 triennium periods respectively. In India, the average pearl millet yield ranges from 900-950 kg ha^{-1}. This was considered as a benchmark for identification of district-level yield gaps. Figure 24 summarizes the distribution of pearl millet sample districts between two time periods. Nearly 60 per cent of the study districts had less than 900 kg ha^{-1} yield levels while the remaining obtained more than that during 1995-97. The number of districts cultivating pearl millet increased to 153 by 2005-07. About 109 districts (71.2%) out of the 153 attained an average yield level of more than 900 kg ha^{-1} during 2005-07.

Productivity improvement in the sample districts was significant in Rajasthan, Gujarat and Haryana when compared to Maharashtra and Uttar Pradesh. The major factors responsible for the lower yield levels in these states are the absence of input application (fertilizers), poor management of the crop and cultivation of age-old cultivars on marginal lands. However, a huge potential still exists in India in Rajasthan and Maharashtra states.

Front Line Demonstrations (FLD)

Despite extensive pearl millet research and dissemination activities during the last five decades, a huge gap exists between the potential and actual yield realized by farmers**.** To analyze and understand the yield gaps in major pearl millet producing states, we collected and compiled Field Level Demonstrations (trials data) from AICPMIP annual reports. This information was compared with the respective state average yields (SAY) and the findings are summarized in Table 42.

The largest yield gap over farmers' practice was noticed in Uttar Pradesh (116%) followed by Karnataka (46%) and Tamil Nadu (45%) with the least gap in Haryana (11%) whereas, Maharashtra had the highest yield gap of 171% over the state average yield followed by Uttar Pradesh (139%), Karnataka (119%). The lowest differences were observed in Gujarat (16%) and Haryana (34%) states. The FLD data of Gujarat pertained to the summer season, wherein pearl millet is grown with assured irrigation and high input management leading to low yield gaps.

The yield gap analysis clearly indicated the adequate scope for productivity improvement in pearl millet. The crop has almost gone out of cultivation in Punjab where wheat-rice cultivation is now completely depleting both soil and water resources. However, the crop has good yield potential of 5,000 kg ha^{-1} in the state, particularly in arid areas. Under climate change scenarios in the country, cultivation of pearl millet needs to be encouraged with robust policy support from the government.

Table 42. Performance of FLDs among major pearl millet growing states.

State	Plot	Year wise yield (kg ha^{-1})					
		2000-01	**01-02**	**04-05**	**05-06**	**09-10**	**Mean**
Gujarat (Summer)	FLD	2457	2883	2651	1350	2202	2309
	Control	1352	2508	1601	950	1914	1665
	SAY	2144	1926	2000	1861	-	1983
				% Yield gap over		Control	39
						SAY	16
Haryana (Kharif)	FLD	1273	1819	-	2420	2500	2003
	Control	1165	1545	-	2000	2000	1803
	SAY	1607	1316	1147	1649	1769	1498
				% Yield gap over		Control	11
						SAY	34
Karnataka (Kharif)	FLD	1213	1420	-	-	-	1317
	Control	986	822	-	-	-	904
	SAY	600	602	-	-	-	601
				% Yield gap over		Control	46
						SAY	119
Madhya Pradesh (Kharif)	FLD	1480	2108	-	2060	2015	1916
	Control	1187	1683	-	1660	1570	1525
	SAY	1403	1368	-	1365	849	1246
				% Yield gap over		Control	26
						SAY	54
Maharashtra (Kharif)	FLD	1588	1819	-	2330	2174	1978
	Control	1487	1545	-	1980	1871	1721
	SAY	676	736	-	729	779	730
				% Yield gap over		Control	15
						SAY	171
Rajasthan (Kharif)	FLD	1459	1338	-	1350	1779	1482
	Control	1071	1062	-	950	1433	1129
	SAY	1136	658	-	701	394	722
				% Yield gap over		Control	31
						SAY	105
Tamil Nadu (Kharif)	FLD	1956	1966	2385	-	2128	2109
	Control	1263	847	1964	-	1737	1453
	SAY	1085	1274	1158	-	1477	1249
				% Yield gap over		Control	45
						SAY	69
Uttar Pradesh (Kharif)	FLD	3056	-	-	-	-	3056
	Control	1418	-	-	-	-	1418
	SAY	1276	-	-	-	-	1276
				% Yield gap over		Control	116
						SAY	139

SAY: State Average Yield

Source: Status Paper on Millets, Department of Agriculture and Cooperation, Jaipur, 2010.

11. Synthesis for Future Pearl Millet Research and Crop Development Priorities

Six decades of tireless research efforts by national and international agricultural research institutes and the private sector in India resulted in the development of myriad cultivars (hybrids and OPVs), strong hybrid production technology, and modern molecular tools. The outbreeding nature of pearl millet and its evolution under diverse and challenging agroclimatic conditions hold great prospects for continuing genetic gains and higher profit levels. But there still exists scope for further acceleration in yield, and there is a need to bridge the existing gap between potential yield and actual yield at the farmer level. However, the greatest challenge is in sustaining the current yield levels in the face of diverse biotic and abiotic stresses.

Another research area that deserves more focus in pearl millet is forage hybrid breeding, which is a potential option to bridge the existing gap between aggregate demand and supply of dry stover in the feed industry. Changing food habits, rising income levels and increasing demand for animal products may further enhance the demand for forage crops (Dikshit and Birthal 2010). Pearl millet has been recognized as a good fodder crop due to its high biomass yield potential, fewer disease and pest problems, high fodder quality and water use efficiency (Rai et al. 2005). Pearl millet also makes an excellent genomic resource for the isolation of the candidate genes responsible for tolerance to climatic and edaphic stresses and their deployment in other crops using genetic transformation tools generates huge prospects. The other avenues of research identified are leaf blast resistance and also targeted breeding for smut resistance as there is a serious threat to pearl millet productivity from these biotic constraints.

A_1 CMS sources have been exploited heavily for hybrid parent development in recent past. However, dependency on single cytoplasm can make the pearl millet hybrid seed industry vulnerable to disease and insect-pest epidemics. So, there is a need to promote A_4 and A_5 CMS sources for hybrid parent development to provide insurance against any risk associated with the use of a single CMS source. A_4 and A_5 CMS sources are providing the greatest opportunities for breeding genetically diverse and stable A-lines than A_1 sources (Rai et al. 2012). Further, the nutri-cereal (rather than coarse-grain cereal) nature of pearl millet would open-up new opportunities in food processing and alternative food uses and beverages.

References

AICPMIP (All-India Coordinated Pearl Millet Improvement Project). 2009. Annual report. Mandor, Rajasthan, India: All-India Coordinated Pearl Millet Improvement Project, Indian Council of Agricultural Research.

Andrews DJ, Rai KN and **Singh SD.** 1985. A single dominant gene for rust resistance in pearl millet. Crop Science 25:565-566.

Bantilan MCS and **Deb UK.** 2002. Grey to green revolution in India: role of public-private-international partnership in research and development. Paper presented at the BAEA-IAAE conference on 'Public-Private Sector Partnership for Promoting Rural Development,' Dhaka, October 2–4.

Bantilan MCS, Subba Rao KV, Rai KN and **Singh SD.** 1998. Research on high-yielding pearl millet–Background for an impact study in India. Pages 52-61 *in* Assessing joint research impacts: proceedings of an International Workshop on Joint Impact Assessment of NARS/ICRISAT Technologies for the Semi-Arid Tropics, 2-4 Dec 1996, ICRISAT, Patancheru, India (Bantilan MCS and Joshi PK, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Bidinger FR and **Parthasarathy Rao P.** 1990. Genetic and cultural improvement in the production of pearl millet. Pages 194–206 *in* Proceedings International Congress of Plant Physiology Vol. I. (Sinha SK, Sane PV, Bhargava SC and Agarwal RK, eds.). New Delhi, India: Society for Plant Physiology and Biochemistry.

CWC (Central Water Commission). 2003. Statistical report. New Delhi, India: Department of Statistics, Ministry of Agriculture, Government of India.

Dikshit AK and **Birthal PS.** 2010. India's livestock feed demand: estimates and projections. Agricultural Economics Research Review 23:15–28.

FAOSTAT database 2012. (www.fao.org).

Gowda CLL, Reddy BVS and **Rai KN**. 2003. ICRISAT strengthens ties with private seed companies. Asian Seed and Planting Materials 10 (4): 16-17.

Gupta SK, Bhattacharjee R, Rai KN and **Suresh Kumar M.** 2011. Characterization of ICRISAT-bred restorer parents of pearl millet. Journal of SAT Agricultural Research 9.

J**oshi PK, Pal S, Birthal PS** and **Bantilan MCS** (eds) 2005. Impact of Agricultural Research: Post-Green Revolution evidence from India, NCAP, New Delhi, 324 pp.

Kelley TG, Parthasarathy Rao P, Weltzien R and **Purohit ML.** 1995. Adoption of improved cultivars of pearl millet in an arid environment: Straw yield and quality considerations in western Rajasthan. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh *and* Central Arid Zone Research Institute (CAZRI), Jodhpur, Rajasthan, India.

Mula RP, Rai KN, Kulkarni VN and **Singh AK.** 2007. Public-private partnership and impact of ICRISAT's pearl millet hybrid parents research. Journal of SAT Agriculture Research 5(1), Pp:1-5. (ejournal.icrisat.org)

Parthasarathy Rao P, Basavaraj G and **Ahmad W.** 2011. Regional analysis of household consumption of pearl millet in major pearl millet producing and consuming states in India. Working Paper series no. 29. RP-MIP, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.

Parthasarathy Rao P, Birthal PS, Reddy BVS, Rai KN and **Ramesh S.** 2006. Diagnostics of sorghum and pearl millet grain-based nutrition. International Sorghum and Pearl Millet Newsletter 47:93-96.

Pray CE and **Nagarajan L.** 2009. Pearl millet and sorghum improvement in India. IFPRI Discussion Paper 00919, Nov 2009, Washington D.C., USA.

Pray CE, Ribeiro S,Mueller RAE and **Parthasarathy Rao P.** 1988. Private research and public benefits: the private seed industry and sorghum and pearl millet in India. Research Paper-P-398-0282-1-89. New Brunswick, NJ, USA: Department of Agricultural Economics, Rutgers University.

Pray CE, Ribeiro S, Mueller RAE and **Parthasarathy Rao P.** 1991. Private research and public benefit: the private seed industry for sorghum and pearl millet in India. Research Policy 20:315-324.

Radhakrishna R. 2005. Food and nutrition security of the poor. Economic and Political Weekly 18:1817-1821.

Rai KN.1990. Development of high-yielding dwarf composites of pearl millet. Crop Improvement 17 (2): 96-103.

Rai KN, Gupta SK, Bhattacharjee R, Kulkarni VN, Singh AK and **Rao AS.** 2009. Morphological characteristics of ICRISAT-bred pearl millet hybrid seed parents. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi Arid Tropics.

Rai KN, Kulkarni VN, Thakur RP, Haussmann BIG and **Mgonja MA.**2006. Pearl millet hybrid parents research: approaches and achievements. Pages 11–73 *in* Hybrid parents research at ICRISAT (Gowda CLL, Rai KN, Reddy BVS and Saxena KB, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Rai KN, Reddy BVS and **Dakheel AJ.** 2005. Forage potential of sorghum and pearl millet adapted to drylands. Pages 243–251 *in* Sustainable development and management of drylands in the twenty-first century. Proceedings of the Seventh International Conference on the Development of Drylands, 14–17 September 2003, Tehran, Iran (El-Beltagy A and Saxena MC, eds.). Aleppo, Syria: International Center for Agricultural Research in the Dry Areas.

Rai KN, Yadav OP, Gupta SK, Mahala RS and **Gupta SK.** 2012 Emerging research priorities in pearl millet. Journal of SAT Agricultural Research, Vol:10 Pp:1-5.

Ramaswamy C, Bantilan MCS, Elongovan S and **Asokan M**. 1999. Perceptions and adoption decisions of farmers in cultivation of improved pearl millet cultivars – a study in Tamil Nadu. Indian Journal of Agricultural Economics 54 (2), 139-154.

Upadhyaya HD, Pundir RPS, Dwivedi SL and **Gowda CLL.** 2009.Mini core collection for efficient utilization of plant genetic resources in crop improvement programs. Information Bulletin no.78. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 52 pp. ISBN 978-92-9066-519-9. Order code IBE 078.

Yadav OP, Rai KN, Rajpurohit BS, Hash CT, Mahala RS, Gupta SK, Shetty HS, Bishnoi HR, Rathore MS,Kumar A,Sehgal S and **Raghvani KL.** 2012. Twenty-five years of pearl millet improvement in All-India Coordinated Pearl Millet Improvement Project, Jodhpur, ICAR, New Delhi, India. 122 pp.

Yadav OP, Manga VK and **Gupta GK.** 1993. Influence of A1 cytoplasmic substitution on the downy mildew incidence of pearl millet. Theoretical and Applied Genetics 87:558-560.

CGIAR Final Proposal on Dryland Cereals, submitted to CGIAR Consortium, 1st August 2012, ICRISAT, Patancheru, Hyderabad - 502324.

Status paper on millets. 2010. Directorate of Millets Development, Ministry of Agriculture, Department of Agriculture & Cooperation, Jaipur, ICAR, New Delhi, India.

Annexures

Annexure 1

Central releases of pearl millet cultivars in India

S.no	Type	Release name	Pedigree/source	Release year	Notification year	Released by
1	Variety	N 28-15-1	A selection from local bajra	1934	1934	-
2	Variety	Kopar Gaon local	A local variety	1934	1934	-
3	Variety	Avsari	A local variety	1934	1934	-
4	Variety	Co1 (Whip Cumbu)	Selection from a Bombay cultivar	1939	1939	AICPMIP, TNAU, Coimbatore
5	Variety	Co2	Selection from Bombay cultivars	1940	1940	AICPMIP, TNAU, Coimbatore
6	Variety	A-1/3		1942	S.O.361(E) 30.06.73	-
7	Variety	Jakharana	Mass selection from local landraces of Jakharana village in Alwar district	1950	1950	-
8	Variety	T-55		1952	S.O.361(E) 30.06.73	-
9	Variety	Co-4	Selected from Bombay cultivars	1953	1953	-
10	Variety	RSJ	A pure line selection from local variety	1956	1956	-
11	Variety	RSK	A pure line selection from local variety	1956	1956	-
12	Variety	S-530	A derivative of Indian and Africa sources	1965	S.O.361(E) and 786 30.06.73 and 02.02.76	-
13	Variety	Pusa Moti		1969	S.O.361(E) 30.06.73	IARI, New Delhi
14	Variety	Vijay	A composite (23 D2B X 3b) Senegal selection	1975	S.O.440 21.08.75	-
15	Variety	Nagarjuna	A composite developed from 20 elite lines of African and Indian origin	1976	S.O.13(E) 19.12.78	LAM, Andhra Pradesh
16	Variety	Visaka	Vijayanagaram composite	1976	S.O.13(E) 19.12.78	Andhra Pradesh
17	Variety	Balaji	Perumallapalla bajra composite of Senegal type	1976	S.O.13(E) 19.12.78	-
18	Variety	K-2	A selection from S35 inbred	1977	1977	-
19	Variety	HS-1 (synthetic)	A synthetic variety developed from 15 inbreds having good general combining ability	1978	S.O.13(E) 19.12.78	AICPMIP, CCSHAU, Hisar

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Central releases of pearl millet cultivars in India.

S.no	Type	Release name	Pedigree/source	Release year	Notification year	Released by
20	Variety	PSB -8	A composite variety developed by chain crossing among 60 early and medium tall growing inbred lines	1980	S.O.19(E)14.01.82	AICPMIP, Ludhiana
21	Variety	AMP-2		1981		AICPMIP, RRS, NARP, Aurangabad
22	Variety	Co- 5 (KullanCumbu)	Selection from kullancumbu cultivars	1983	S.O. 2(E) 03.01.83	AICPMIP, TNAU, Coimbatore
23	Variety	Co-6	African selection from cultivar MS 7625	1983	S.O.257(E) 26.11.86	AICPMIP, TNAU, Coimbatore
24	Variety	RCB-2	20 inbreds of diverse genetic origin	1985	S.O.832(E) 18.11.85	AICPMIP, Durgapur, Jaipur
25	Variety	Giant Bajra	Australian bajra X local bajra	1985	295(E) 09.04.85	Rahuri, Maharashtra
26	Variety	PCB-15	Developed by intermating half-sib progenies of elite genotypes in the breeding nursery	1985	S.O.258(E) 14.05.86	AICPMIP, PAU, Ludhiana
27	Variety	Sangam	Developed by selection in F_2 and F_3 segregated material received from ICRISAT	1986	S.O.258(E) 14.05.86	AICPMIP, MPKV, Rahuri
28	Variety	Co-7	Composite developed by cross of (Co-6 X BK560)X PT1921	1986	S.O. 887(E) 26.11.86	AICPMIP, TNAU, Coimbatore
29	Variety	PusaSafed	Composite variety consisting of 9 homozygous lines from India and Africa	1989	S.O.280(E)	IARI, New Delhi
30	Variety	Raj Bajra Chari-2	Random mating among 20 crosses of four inbred from West Africa by full sib selection method	1990	S.O.386(E) 15.05.90	Jobner, Rajasthan
31	Variety	Co-8	-	1993	615(E) 17.08.93	Coimbatore
32	Variety	Pusa Bajra-266	A composite obtained by mixing nine lines	1997	S.O.360(E) 1997	IARI, New Delhi
33	Variety	Pusa Composite 334	Composites obtained by mixing 3 lines, highly resistant for downey mildew and elite inbred	1999	S.O.360(E) 26.10.1999	IARI, New Delhi

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Central releases of pearl millet cultivars in India.

S.no	Type	Release name	Pedigree/source	Release year	Notification year	Released by
34	Variety	Pusa Composite-383	A composite developed by mixing a large number of open-pollinated bulk from Indian collections	2001	S.O.1134(E) 2001	IARI, New Delhi
35	Variety	Avika Bajra Chari	Forage variety	2009	2187(E) 27.08.09	
36	Variety	Pusa composite -612	-	2010	S.O.733(E) 01.04.2010	IARI, New Delhi
37	Variety	MP489	-	2011		
38	Hybrid	X-1	PT 348 X PT 350	1950	1950	AICPMIP, TNAU, Coimbatore
39	Hybrid	X-2	PT411 X PT422	1950	1950	AICPMIP, TNAU, Coimbatore
40	Hybrid	X- 3	PT826/7 X PT829/8	1957	1957	AICPMIP, TNAU , Coimbatore
41	Hybrid	HB- 1	Tift 23A XBil3 B	1965	S.O.4045 & S.O.716 (1969-70)Denotified in 1978	AICPMIP PAU Ludhiana
42	Hybrid	HB -2	Tift 23 A X J88	1966	S.O.4045(E) 1969	AICMIP, MRS, Jamnagar
43	Hybrid	HB -4	Tift 23A X K560	1968	S.O.4045 &716(E) 1969 & 1970	AICPMIP, Kanpur
44	Hybrid	HB -3	Tift 23A XJ 104	1968	S.O.4045 &5505, 1969 &1971	AICPMIP, MRS, Jamnagar
45	Hybrid	HB -5	Tift 23 A X K 559	1972		AICPMIP, Kanpur
46	Hybrid	NHB -4	5071A X K560-230	1975		IARI, New Delhi
47	Hybrid	NHB-3	5071A X J104	1975		IARI, New Delhi
48	Hybrid	GHB-1399	126 D2A X JI399	1975		AICPMIP, MRS, Jamnagar
49	Hybrid	PHB-14	PB111A X PIB 228	1975	S.O.786 (02-02-1976)	AICPMIP, PAU, Ludhiana
50	Hybrid	PHB-10	PB111A X PIB 155	1975	S.O.786 (1976) De notified on 1997	AICPMIP, PAU, Ludhiana
51	Hybrid	NHB-5	5071A X K559-85	1975	S.O.786(E) 02-02-1976	IARI, New Delhi
52	Hybrid	CJ-104	5054A X J-104	1977	S.O.13 (1978)	Gujarat
53	Hybrid	BK-560	5141A X K 560-230	1977	S.O.13 (1978)	IARI, New Delhi

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Central releases of pearl millet cultivars in India.

S.no	Type	Release name	Pedigree/source	Release year	Notification year	Released by
54	Hybrid	BD-111	5141A X D111	1977	S.O.470(E) 19-02-1980	IARI, New Delhi
55	Hybrid	BJ-104	5141 X J104	1977	S.O.13 & S.O.470 (1978/1980)	IARI, New Delhi
56	Hybrid	MBH-104	BMS1 X BPL-15	1978	S.O.13 (1978)	Mahyco, Jalna
57	Hybrid	x-4	5141 A X PT 1921	1980	S.O.19(E)14-01-1982	AICPMIP, TNAU, Coimbatore
58	Hybrid	KBH-1	Pb 111A X S444	1980	S.O.19(E) 1982	AICPMIP, TNAU, Coimbatore
59	Hybrid	GHB-27	5141A X J2002	1981	S.O.499(E) 1983	AICPMIP, MRS, Jamnagar
60	Hybrid	Pusa-763	5141A X D 763	1982	S.O. 371 (E) 29-05-1982	IARI, New Delhi
61	Hybrid	Pusa-46	5054A X M46	1982	S.O.2(E) 03-01-1983	IARI, New Delhi
62	Hybrid	MBH-110	MS 2 X Pollinator NO.2	1982	S.O.2(E) 03-01-1983	Mahyco, Jalna
63	Hybrid	X-5	PB111A X PT 1921	1983	S.O.295 (E) 09-04-1985	AICPMIP, TNAU , Coimbatore
64	Hybrid	PHB-47	PB111A XPIB 1234	1983	S.O.832(E) 18-11-1985	AICPMIP, PAU, Ludhiana
65	Hybrid	HHB-45	MS 5141A X H90/4	1984	S.O.540(E) 1985	AICPMIP, CCSHAU, Hissar Haryana
66	Hybrid	GHB-32	5141A X J1188	1985	1985	AICPMIP, MRS, Jamnagar
67	Hybrid	MBH-118	2A X Pollinator No.3	1985	S.O.295(E) 09-04-1985	Mahyco, Jalna
68	Hybrid	MBH-130	2A X Pollinator No.4	1986	S.O. 165(E) 1986	Mahyco, Jalna
69	Hybrid	GHB-30	5054A X J2002	1987	S.O.165(E) 1986	AICPMIP, MRS, Jamnagar
70	Hybrid	MBH-136	2 AX PL NO.6	1989	S.O.(E)280 (1989)	Mahyco, Jalna
71	Hybrid	MBH-149	4A X PL NO.13	1989		Mahyco, Jalna
72	Hybrid	MBH- 160	NMS-9 X PI 21	1993	1993 (13.01.93)	Mahyco, India
73	Hybrid	RHRBH -8609(Shardha)	RHRBH 1A X RHRBI 138	1994	S.O.638(E) 02.09.94	AICPMIP, MPKV, Rahuri
74	Hybrid	GHB- 15	5054A X J 108	1994	S.O.636(E) 02.09.94	AICPMIP, MRS, Jamnagar

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Central releases of pearl millet cultivars in India.

S.no	Type	Release name	Pedigree/source	Release year	Notification year	Released by
75	Hybrid	PABH -3	PAMS 1A X Zim-1	1995	-	AICPMIP, RRS, NARP, Aurangabad
76	Hybrid	GHB-316	405A X J2290	1997	S.O.662(E) 17.09.97	MMRS, GAU, Jamnagar
77	Hybrid	RHRBH -8924(Saburi)	RHRB 5A X RHBI 458	1997	S.O.360(E) 01.05.97	AICPMIP, MPKV, Rahuri
78	Hybrid	Proagro 1(FMH 3)	PSP 21 X PP 23	1998	S.O.401(E) 15.05.98	ProAgro, Hyderabad
79	Hybrid	7686 (XM-631)	PH 01 X PH 03	1998	S.O.401(E) 15.05.98	Pioneer, Hyderabad
80	Hybrid	Nandi-8	NMS 5A X NMP 23	1999	S.O.425 (E) 08.06.99	New Nandi, Ahmadabad
81	Hybrid	Pusa-415	576A X PPMI 301	1999	S.O.1050(E) 26.10.99	IARI, New Delhi
82	Hybrid	MLBH-504	36A X MI-67	1999	S.O.1050(E) 26.10.99	Mahendra Hybrid Seed Ltd., Jalna
83	Hybrid	7688	PH 03 X PH 05	2001	S.O.92(E) 02.02.01	Pioneer, Hyderabad
84	Hybrid	PB -106 (Proagro-9443)	PSP 41 X PP 6	2001	S.O.92(E) 02.02.01	ProAgro, Hyderabad
85	Hybrid	PB-112 (Proagro -9445)	PSP 35 X PP 1	2001	S.O.1134(E) 15.11.01	ProAgro, Hyderabad
86	Hybrid	Nandi-35	NMS 11A X NMP 42	2001	S.O.1134(E) 15.11.01	New Nandi, Ahmadabad
87	Hybrid	PB -172	PSP 35 X PP 27	2003	S.O.283(E) 12.03.03	ProAgro, Hyderabad
88	Hybrid	PB-180	PSP 41 X PP 29	2004	S.O. 161(E) 04.02.04	ProAgro, Hyderabad
89	Hybrid	GHB -719	ICMA 95222 X J 2454	2007	S.O. 122(E) 06.02.07	MRS, GAU, Junagadh
90	Hybrid	NMH -68 (Nandi-62)	ICMA 97444 X NMP 48	2007	S.O. 1703 (E) 05.10.07	New Nandi, Ahmadabad
91	Hybrid	B -2301(B -2301)	B 0009A X B 5103R	2007	S.O. 1703 (E) 05.10.07	Zuari Seeds Ltd, Bangalore
92	Hybrid	PB 727 (Proagro 9555)	PSP 51 X PP 38	2008	S.O.1108(E) 08.05.08	Bayer Bio Science, Hyderabad
93	Hybrid	JKBH-676	JKMS 20A x JKR 6136	2009	S.O.2187(E) 27.08.09	JK AgriGenetics Hyderabad

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Central releases of pearl millet cultivars in India.

S.no	Type	Release name	Pedigree/source	Release year	Notification year	Released by
94	Hybrid	B -2095	B 0009A X B 5220R	2009	S.O.449(E) 11.02.09	Zurari Seeds Ltd, Bangalore
95	Hybrid	Nandi-65	NMS 24A x NMP 75	2010	S.O.2136 (E) 31.08.10	New Nandi
96	Hybrid	Nandi-61	NMS 24A x NMP 64	2010	S.O.2136 (E) 31.08.10	New Nandi
97	Hybrid	RHRBH-9808	RHRB 13A x RHRBI 1314	2010	S.O.2136 (E) 31.08.10	AICPMIP, MPKV, Dhule
98	Hybrid	Nandi-64 (NMH-69)	NMS 2-11A x NMP 4-1	2010	S.O.211(E) 29.01.10	New Nandi
99	Hybrid	HHB-234	HMS -7A X H77/833-2-202	2011	2011	AICPMIP-HAU, Hissar
100	Hybrid	VBBH-3040	VBBA 310089 X VBBR330585	2011	2011	Vibha seeds, AP
101	Hybrid	86- M -66	M124 F x M118R	2011	2011	Pioneer, Hyderabad
102	Hybrid	MH-1609	MOO 1A/MOOR	2011	2011	Metahelix, Karnataka
103	Hybrid	MH-1610	MOO 2A/Moo4R	2011	2011	Metahelix, Karnataka
104	Hybrid	PAC-909	110057X130453	2011	2011	Advanta India Ltd. Secunderabad
105	Hybrid	86 M 53	M096F x M 119R	2011	2011	Pioneer Overseas Corp., Hyderabad
106	Hybrid	86 M 64(MSH 203)	M096F x M 117R	2011	2011	Pioneer Overseas Corp., Hyderabad

Annexure 2

State releases of pearl millet improved cultivars in India.

S.no	Type	Release name	Pedigree/source	Release year	Notification year	Released by
1	Variety	N 207		1940		
2	Variety	Co-3 (KoltapualiCumbu) (Napier hybrid	PT1697 X *Pennisetum perpureum*	1942	1942	AICPMIP, TNAU, Coimbatore
3	Variety	N-28-15-2		1950		
4	Variety	Babapuri		1950		
5	Variety	G-61/21		1950		
6	Variety	New Vijay	Improvement of Vijay variety by half sibling and mass selection	1975		LAM
7	Variety	Manupur		1978	S.O. 13 (19.12.78)	
8	Variety	Rajko		1978	S.O.13 (19.12.78)	
9	Variety	AnantaS (APS-1)		1997	S.O.662(E) 17.09.1997	AICPMIP, Anantapur,AP
10	Variety	HC 10 (Haryana Composite-10)	HP8601(MP209)	2000	S.O.425(E) 2000	AICPMIP, CCSHAU,Hissar
11	Variety	HC20 (HMP-9102)	S_1 progenies from gene pool	2002	S.O.283(E) 2002	AICPMIP, CCSHAU, Haryana
12	Variety	CoCu-9		2004	S.O.1177(E) 25.08.2005	AICPMIP, TNAU, Coimbatore
13	Variety	PPC-6 (Parbhani Sampada)		2005	S.O.122(E) 02.02.2005	AICPMIP, RRS, NARP,Parbhani
14	Variety	FBC 16 (forage variety)		2007	1178(E) 20.07.07	PAU, Ludhiana
15	Variety	PCB- 164	Bred from seven elite populations and 27 diverse inbred lines	2007	S.O.1178(E) 20.07.2007	AICPMIP, PAU, Ludhiana
16	Variety	Napier Grass Culture-4		2010	S.O.211(E) 29.01.10	
17	Variety	Napier Grass Culture-21		2010	S.O.211(E) 29.01.10	
18	Variety	BAIF BAJRA-1		2010	S.O.211(E) 29.01.10	
19	Hybrid	X-6	732A X PT 3095	1997	S.O.360(E) 01.05.97	AICPMIP, TNAU, Coimbatore
20	Hybrid	X-7	Pb 111A X PT 1890	1997	S.O.647(E) 09.09.97	AICPMIP, TNAU, Coimbatore
21	Hybrid	CoH(Cu)- 8	732 A X PT 4450	2001	S.O.1134(E) 15.11.01	AICPMIP, TNAU, Coimbatore
22	Hybrid	HHB -117	HMS 7 A X H77/29-2	2004	S.O. 161 (E) 4.02.04	AICPMIP, CCSHAU,Hisar

Annexure 3

List of participants (see picture below) of the TRIVSA Project Pearl Millet Workshop (22 Dec, 2011).

NARS	Private seed companies	ICRISAT
Dr OP Yadav, AICPMIP	Dr RS Mahala, Pioneer	Dr Oscar Riera-Lizarazu
Dr HP Yadav, HAU	Dr ML Swami, JK Seeds	Dr MCS Bantilan
Dr LD Sharma, Durgapura	Dr AK Jayalekha, Bayer Bio	Dr KN Rai
Dr KD Mungra, JAU	Mr SM Rafiq, Nuziveedu	Dr IS Khairwal
Dr NB Katare, RRS	Dr YogendraVerma, Metahelix	Dr G Harinarayana
Dr HT Patil, Dhule	Dr Milind Kulkarni, Nirmal Seeds	Dr SK Gupta
Dr BB Yadav, MPKV	Dr SK Gupta, J K Seeds	Dr Rakesh Srivastava
		Dr P Parthasarathy Rao
		Dr Uttam Kumar Deb
		Dr N Nagaraj
		Dr NP Singh
		Dr Kumara Charyulu
		Dr S Nedumaran
		Dr A Amarenderreddy
		Dr G Basavaraj
		Dr Lalmani Pandey
		Mrs A Raja Laxmi
		Mr Surajit Halder

About ICRISAT

ICRISAT
Science with a human face

International Crops Research Institute for the Semi-Arid Tropics

The **International Crops Research Institute for the Semi-Arid Tropics** (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, of whom 644 million are the poorest of the poor. ICRISAT innovations help the dryland poor move from poverty to prosperity by harnessing markets while managing risks – a strategy called Inclusive Market-Oriented Development (IMOD).

ICRISAT is headquartered in Patancheru, Telangana, India, with two regional hubs and six country offices in sub-Saharan Africa. It is a member of the CGIAR Consortium. CGIAR is a global research partnership for a food secure future.

About ICRISAT: **www.icrisat.org**

ICRISAT-India (Headquarters)
Patancheru 502 324
Telangana, India
Tel +91 40 30713071
Fax +91 40 30713074
icrisat@cgiar.org

ICRISAT-Liaison Office
CG Centers Block, NASC Complex,
Dev Prakash Shastri Marg, New Delhi 110 012, India
Tel +91 11 32472306 to 08
Fax +91 11 25841294

ICRISAT-Ethiopia
C/o ILRI Campus, PO Box 5689
Addis Ababa, Ethiopia
Tel: +251-11 617 2541
Fax: +251-11 646 1252/646 4645
icrisat-addis@cgiar.org

ICRISAT-Kenya (Regional hub ESA)
PO Box 39063, Nairobi, Kenya
Tel +254 20 7224550, Fax +254 20 7224001
icrisat-nairobi@cgiar.org

ICRISAT-Malawi
Chitedze Agricultural Research Station
PO Box 1096, Lilongwe, Malawi
Tel +265 1 707297, 071, 067, 057, Fax +265 1 707298
icrisat-malawi@cgiar.org

ICRISAT-Mali (Regional hub WCA)
BP 320, Bamako, Mali
Tel +223 20 709200, Fax +223 20 709201
icrisat-w-mali@cgiar.org

ICRISAT-Mozambique
C/o IIAM, Av. das FPLM No 2698
Caixa Postal 1906, Maputo, Mozambique
Tel +258 21 461657, Fax +258 21 461581
icrisatmoz@panintra.com

ICRISAT-Niger
BP 12404, Niamey, Niger (Via Paris)
Tel +227 20722529, 20722725
Fax +227 20734329
icrisatsc@cgiar.org

ICRISAT- Nigeria
PMB 3491
Sabo Bakin Zuwo Road, Tarauni, Kano, Nigeria
Tel: +234 7034889836; +234 8054320384,
+234 8033556795
icrisat-kano@cgiar.org

ICRISAT-Zimbabwe
Matopos Research Station
PO Box 776, Bulawayo, Zimbabwe
Tel +263 383 311 to 15, Fax +263 383 307
icrisatzw@cgiar.org

ICRISAT's scientific information: **http://EXPLORE*it*.icrisat.org**

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