Agricultural Economics Research Review
Vol. 27 (Conference Number) 2014 pp 157-165
DOI: 10.5958/0974-0279.2014.00018.4

Development and Diffusion of Dryland Cereals in Semi-Arid Tropics of India — Role of Partnerships§

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Abstract

In any crop improvement program, public and private partnerships are vital for development of improved cultivars and their dissemination to the target niche locations. This paper has provided information on the diffusion of dryland cereals (particularly sorghum and pearl millet) in India and has highlighted the role of partnerships in sustaining the crop improvement as well as improved cultivars' adoption. Over the past two decades, the R&D in pearl millet and sorghum has become increasingly privatized, reflecting a general shift in India's agricultural research system from public sector dominated to private sector-driven seed development and distribution. The accomplishments of pearl millet and sorghum breeding are considered as the success stories in India, with a large number of high-yielding, disease-resistant hybrids and open-pollinated varieties very widely used by the Indian farmers. This was made possible because of strong partnerships and Consortium model introduced by ICRISAT. This kind of approaches lead to scientific innovations that create a vibrant and sustainable supply of new improved cultivars and their adaptation in the targeted regions very quickly.

Key words: Improved cultivars, crop improvement, adoptions, pearl millet, sorghum, partnerships, dryland cereals, semi-arid tropics

JEL Classification: Q13, Q15, Q10

Introduction

The importance of crop genetic improvement research is demonstrated well by the green revolution in terms of a rapid increase in food production in Asia. Such increases in productivity gains contributed to a decline in poverty not only through increases in farmers' income, but also through a decline in prices of foodgrains. The success of crop genetic improvement research in several parts of the world leading to the development of improved varieties of several food crops, has been well documented (Evenson and Gollin, 2003; Bantilan *et al.,* 2014). But, despite progress made through crop varietal development in the past, poverty is still concentrated in South Asia, which is a home for around 571 million or one-third of the world's poor of about 1.29 billion in 2011 (World Bank, 2012). Substantial potential exists for further reduction in poverty through crop genetic improvement by increasing or stabilizing the yield of major food crops, particularly the dryland crops in South Asia. This varietal change by itself may not lift a large number of people out of poverty, but a greater dynamism in this area can go a long way towards moving poor people closer to that threshold.

Keeping this in view, ICRISAT under the umbrella of TRIVSA (Tracking Improved Varieties in South Asia) project envisioned in 2011-12 to study the successes and failures of crop improvement

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§ The paper draws heavily from TRIVSA Project supported by BMGF

investments and find the impact of those investments on poverty alleviation and achieving food and nutritional security. The current knowledge on diffusion, adoption and impact of improved crop varieties of dryland cereals in South Asia, especially in India is not complete. Although the adoption of improved varieties of dryland cereals has been reported to be substantial, very little statistically valid information on the extent of adoption at national and sub-national levels is available. This information is needed to strengthen the research system that continues to produce improved varieties with characteristics of high demand.

In any crop improvement program, public and private partnerships are vital for development of improved cultivars and their dissemination to the target niches/locations. Research collaborations and partnerships among and within the national, regional and international programs are the best means of meeting the diverse needs and exchange of knowledge. Partnerships are crucial for developing countries like India where the resources for crop genetic improvement are limited. Recognizing the power of cooperation, ICRISAT has been proactive in developing partnerships with public sector institutions, private sector organizations, non-governmental organizations (NGOs) and other stakeholders. These partnerships could be formal or informal and involve scientists and extension staff in public and private sector organizations, farmers and NGOs. Nevertheless, very few of these partnerships have been rated as highly successful in India. But, dryland cereals crop improvement and their dissemination in SAT of India is one of the success stories.

The objective of this research paper is to provide information on the diffusion of dryland cereals (particularly sorghum and pearl millet) in India and to highlight the role of partnerships in sustaining the crop improvement as well as improved cultivars' adoption.

Development Pattern of Improved Cultivars of Dryland Cereals

Sorghum[1]

Sorghum [*Sorghum bicolour (L.)*] is one of the main staple foods for the poor across the semi-arid tropics of world. In India, sorghum is grown in both rainy (2.6 million hectares) and post-rainy (3.5 M ha) seasons. An estimated 2 M ha is under forage sorghum grown in the summer season.

Table 1. Releases of sorghum cultivars by type in India
(No.)

Years/ Decades	National releases	State releases*	Total releases
1961-70	5	8	13
1971-80	13	35	48
1981-90	12	55	67
1991-00	13	58	71
2001-10	12	42	54
2011-2013	0	4	4
1960-2011	55	202	257

* including the notified parental lines

The decade-wise release of sorghum improved cultivars (including notified parental lines) by type (national and state) is summarized in Table 1. A total of 257 modern sorghum cultivars were released during 1960-2011. Nearly 79 per cent of the releases were from the states (including SAUs) and the remaining 21 per cent were from the national institutions. Across decades, the releases were highest during the 1990s (71), followed by 1980s (67) and early-21st century (54). The release pattern of national cultivars was almost consistent over the study period of 1970-2010, but, the state releases increased till the 1990s, and fell down during the past decade. The mean annual release rate of improved cultivars of sorghum in India is 5.24. The years of no release of improved cultivars were only three during the past fifty years in India. The standard deviation and coefficient of variation of releases were 4.70 and 89.98 per cent, respectively at all-India level for the study period.

The classification of sorghum improved cultivars based on the source of genetic material is summarized in Table 2. Among the 257 releases, nearly 91 per cent of cultivars generated through non-ICRISAT/public sector source of genetic material. The remaining around 9 per cent (24) improved cultivars were developed through either direct ICRISAT source germplasm or any of its intermediate materials. The ICRISAT also

[1] For more details, see Kumara Charyulu *et al*. (2014a)

Table 2. Classification of improved cultivars of sorghum based on source of genetic material in India

Released period	ICRISAT# source	Non-ICRISAT* source	Total**
1961-70	0	13	13
1971-80	1	47	48
1981-90	5	62	67
1991-00	16#	61	71
2001-10	14#	48	54
2011-2013	1	3	4
Total	37	234	257*

Notes: * including the notified parental lines #14 cultivars released by private seed companies also included ** Private releases (truthfully labeled) are not included in the total

Table 3. Releases of pearl millet cultivars by type in India

Year/Decade	National releases	State releases	Total
1931-40	5	1	6
1941-50	4	4	8
1951-60	5	0	5
1961-70	6	0	6
1971-80	21	3	24
1981-90	36	1	37
1991-00	41	12	53
2001-10	47	10	57
2011-2013	11	1	12
Total	176	32	208

supplied equally different forms of intermediate genetic materials to the members of hybrid parents' research consortium (HPRC) (nearly 35 seed companies) since 2001 in India. Fourteen new cultivars marketed (as truthfully labelled) by the private seed companies were counted under ICRISAT contribution, but were not added in the total releases because these have not been released officially till now.

Pearl Millet[2]

The pearl millet is the third most important cereal after rice and wheat in India. It is predominantly grown as a grain crop but is also valued for its stover and fodder. In spite of enormous and systematic pearl millet research in India since the 1960s, the cropped area under cultivation has witnessed a continuous reduction from 12.23 M ha to 9.61 Mha between 1966 and 2010 (GoI, 2013). Due to frequent outbreaks of downy mildew disease, changing food consumption habits, lower remuneration and poor demand for grain, farmers moved away from pearl millet cultivation to other commercial crops. However, despite decline in acreage, production of pearl millet has more than doubled, from 4.5 Mt to 10.36 Mt in the same period. This was made possible through the adoption of improved cultivars, which increased the productivity levels.

The decade-wise pattern of release of pearl millet improved cultivar by type (national or state) is summarized in Table 3. The systematic efforts on the development of pearl millet improved cultivars were started way back in 1930s in India. Between 1930 and 2011, the number of improved cultivar releases in India was 208, of which 176 cultivars were released through national release system and 32 were released at the state-level. The pattern of national releases was consistent with increasing trend over the study period, though gained significant momentum since 1970s. In contrast, a significant number of releases from the states started only after 1990s. The mean annual release rate at all-India level was 2.67 between 1934 and 2011. The years with zero release were 28, during this period. The estimated standard deviation and coefficient of variation was 3.04 and 113.8 per cent, respectively in the study period.

The total pearl millet improved cultivars were classified based on source of genetic material used for development (Table 4). It was observed that the kind and sources of genetic material have helped significantly in the development of improved cultivars of pearl millet in India over time. Among the total releases (208), ICRISAT released 80 improved cultivars in India by sharing either their germplasm or breeding materials with NARS and private seed companies between 1981 and 2011. The public sector breeding and crop improvement program in India released around 128 cultivars. The contribution of ICRISAT is quite evident in India, particularly since 1980s. The NARS research program for pearl millet crop improvement is more effective and consistent since the 1970s.

[2] For more details, see Kumara Charyulu *et al*. (2014b)

Table 4. Classification of pearl millet improved cultivars based on source of genetic material

Released period	ICRISAT source	Non-ICRISAT source
1931-40	0	6
1941-50	0	8
1951-60	0	5
1961-70	0	6
1971-80	0	24
1981-90	14	23
1991-00	35	18
2001-10	28	29
2011-2013	3	9
Total	80	128

Adoption of Improved Cultivars

Sorghum

The ICRISAT along with NARS partners and private seed companies has assessed the cultivar-specific adoption in major sorghum-growing states under TRIVSA project. A series of expert elicitations were conducted at various levels for obtaining the reliable adoption estimates at the state-level. The details of state-wise cultivar-specific adoption estimates of sorghum are summarized in Table 5. Across states, Maharashtra and Karnataka have exhibited the ceiling levels of adoption rate in the rainy season sorghum, followed by Madhya Pradesh, Andhra Pradesh and Rajasthan. In all the states, the improved cultivars are dominated by hybrids (nearly 70%) and open-pollinated varieties (30%). India also has a very peculiar case of post-rainy season sorghum cultivation in the world. Currently, the post-rainy crop production is much stable in India and has received higher attention from the consumers because of its good grain quality than of *kharif* sorghum. But, more than 70 per cent of the post-rainy season sorghum area is still under the local cultivars. In India, the sorghum crop improvement research during the past fifty years has been skewed towards development of rainy season crop, while very little emphasis was given to post-rainy season crop. However, this trend has changed for the past one decade and the adoption of new improved cultivars is slowly

Table 5. Cultivar specific adoption estimates of sorghum across the major states[#] in India

Andhra Pradesh		Maharashtra		Karnataka		Madhya Pradesh		Rajasthan	
Cultivar	%	Cultivar	%	Cultivar	%	Cultivar	%	Cultivar	%
Rainy (*kharif*) season (% area)									
SPV-462 (PSV-1)	20	CSH-9	40	CSH-14	40	CSH-15	13.9	CSV-15	10.9
CSV-15	2.5	CSH-14	30	DSV-2	18	CSH-18	12.3	JKSH-592	4.4
CSV-20	2.5	CSH-16		DSV-16	15	Ajeet 997	10.7	SSG-593	2.9
NTJ-2	2.5	MLSH-296		CSV-16	15	Pradhan	10.0	CSV-10	2.4
NTJ-4	2.5	MAHABEEJ-7-7A	10	Others	2	CSH-14	8.9	KJH-6363	2.2
Others	10	CSV-15		All modern varieties	90	GK-4010	6.5	Others	12.2
All modern varieties	40	PVK-801	20			CSH-16	5.8	All modern varieties	35
		Others				Others	8.9		
		All modern varieties	100			All modern varieties	77		
Post-rainy (*rabi*) season (% area)									
C-43	10	Parbhanimoti	3	DSV-4	20				
CSH-9	10	PhuleVasudha	5	DSV-5					
Others	20	RSLG-262	3	CSV-216R					
All modern	50	PhuleYashoda	3	CSV-22					
varieties		Phule Chitra	3	BJV-44					
		CSV-18	3	All modern	20				
		All modern varieties	20	varieties					

[#] Cultivars released after 1970 were only considered in the estimation.

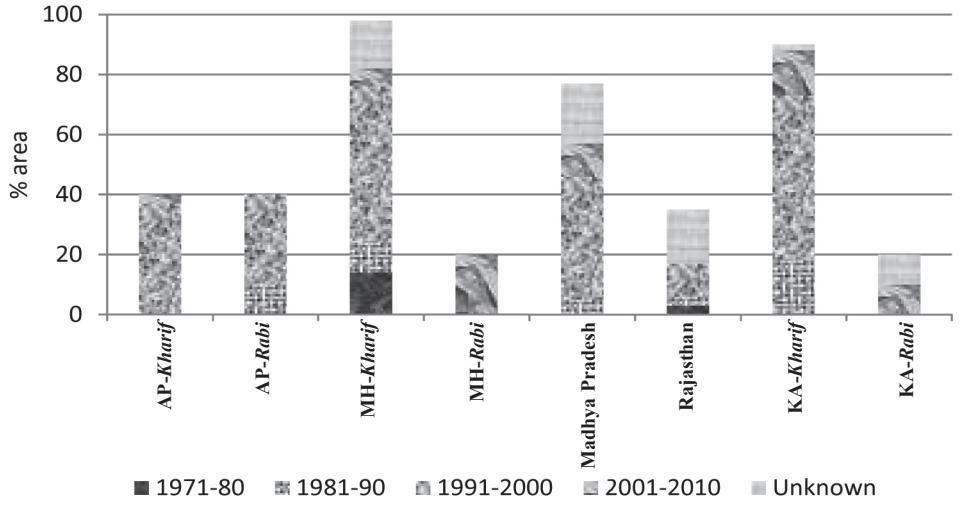

Figure 1. Pattern of varietal replacement in sorghum across major states in India
AP: Andhra Pradesh; MH: Maharashtra; KA: Karnataka

replacing the dominant land races like 'Maldhandi'. Overall, a rich varietal diversity was observed among improved cultivars across the studied states and seasons.

Along with public sector research, private sector seed companies have also been significant players in sorghum crop improvement in India since 1980s. Some of their products have been officially released, but they also market many other improved cultivars as truthfully labelled which are not officially notified and released. However, the aggregated weighted adoption rate for all India was estimated at 82 per cent for rainy season sorghum, while it was assessed at 21 per cent for post-rainy season sorghum. The baseline survey conducted in 1999 (Evenson and Gollin, 2003) has estimated it to be at 69 per cent at the all-India level. Although adoption has slightly improved, huge potential still exists for enhancing it, especially in the states like Rajasthan and Andhra Pradesh.

The pattern of varietal replacement in sorghum by their age (from release year till adoption) across the studied states has been presented in Figure 1. All the five major states under study covered with the highest sorghum cropped area by cultivars released during 1991-2000. The extent of share of cropped area occupied by releases between 2001 and 2010 was rather low. Some of the sorghum cropped area in Madhya Pradesh and Rajasthan is also covered by unknown cultivars mainly from either private seed companies or local land races. This data clearly visualized that the present popular sorghum cultivars in different states were released at least 15 years ago. Overall, the average sorghum varietal turn-over velocity was found 10-15 years in India.

Pearl Millet

Similar efforts were also made in case of pearl millet crop under TRIVSA project. The state-wise cultivar specific adoption estimates of improve cultivars is presented in Table 6.The first round of expert elicitations were conducted by visiting the major AICPMIP centres while the second round elicitations facilitated through a special workshop organized at ICRISAT. The fore-runners in adoption of improved cultivars in the country are Gujarat, Haryana and Maharashtra, while Rajasthan and Uttar Pradesh lag much behind. But, due to high varietal diversity and dominance of the private sector, the experts could not guess the cultivar-specific adoption information in case of Gujarat and Maharashtra. Pro-agro 9444 and HHB-67-improved are the dominant (mega) varieties in both Rajasthan and Haryana. Except a few public institutions bred cultivars (ICTP 8203, HHB-67 improved, HHB 197and GHB 558, etc.), all other major cultivars across the states belonged to the private seed companies. The aggregated weighted adoption at country level was estimated at 67 per cent. The baseline survey conducted in 1999 (Evenson and Gollin, 2003) assessed the adoption rate at 65 per cent for all India. This clearly indicates that ample scope still exists for the promotion

Table 6. State-wise cultivar specific adoption estimates[$] of pearl millet in India

Rajasthan		Maharashtra		Gujarat		Uttar Pradesh		Haryana	
Cultivar	%	Cultivar	%	Cultivar	%	Cultivar	%	Cultivar	%
Pro-Agro 9444	11	Pioneer (86-M-32)	80	GHB 558/568	95	Kaveri Super Boss	6	Pro-Agro 9444	40
HHB-67- improved	10	Pioneer (86-M-64)		Pioneer 86-M-86		ICTP-8203	5	HHB-67 Improved	30
MH 169	7	Mahyco 2240		MLBH 1012		Pioneer hybrids	4	HHB-197	10
JKBH 26	4	Mahyco 2210		Sagarlaxmi		Others	15	Others	5
Others	20	Pro-Agro (XL-51)		Pro Agro-9444		All modern varieties	30	All modern varieties	85
All modern varieties	52	Others		Ratan 666					
		All modern varieties	80	Others					
				All modern varieties	95				

[$]Cultivars released after 1970 were only considered in the estimation.

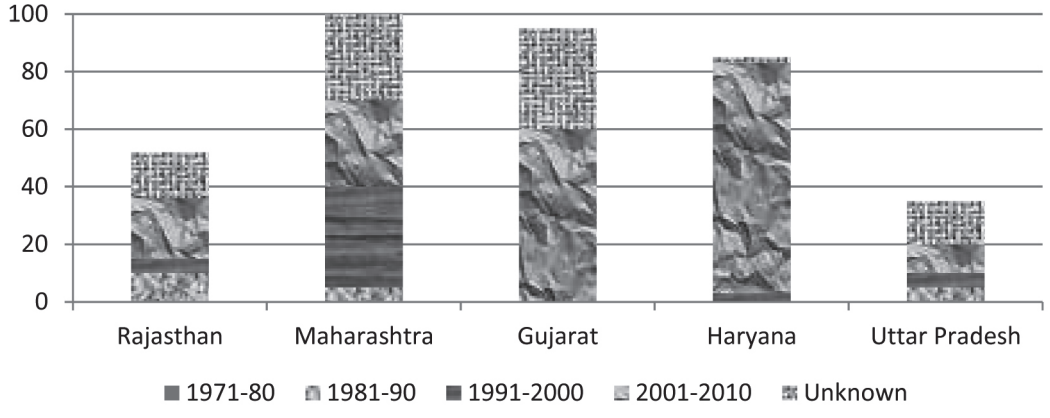

Figure 2. Velocity of varietal turnover in pearl millet across major states in India

of improved cultivars in India, especially in Rajasthan and Uttar Pradesh.

The details about velocity of varietal turnover in pearl millet in major growing states of India are depicted in Figure 2. Except Uttar Pradesh, all other four states had a significant area under pearl millet cultivar releases between 2001 and 2010. It is even much conspicuous in Gujarat and Haryana. The next major chunk of pearl millet cropped area was occupied by either some unknown cultivars released by the private sector companies or by cultivation of some land races. These results clearly concludes that the varietal turnover velocity in pearl millet was much faster, i.e. 6-8 years. A highly competitive private-sector and the need for new sources for developing downy mildew resistance are the two forces that drive the rapid replacement of improved pearl millet cultivars by farmers in the country.

Role of Partnerships in Technology Development and Dissemination

The spread of modern varieties and hybrids of pearl millet and sorghum that started in the mid-1960s had a significant impact on small farmers' welfare in India. The success of these improved cultivars resulted from three types of interventions by the Indian government: (1) Increased investments in crop improvement during the 1970s, (2) Development of efficient seed systems, with gradual inclusion of the private sector in the 1980s, and (3) Liberalization of Indian seed industry in the late -1990s. These innovations of new hybrid technology have not been limited to the green revolution crops; but also had a significant impacts on the productivity of small farm households and dryland crops, such as pearl millet and sorghum in India (Pray and Nagarajan, 2009).

The deregulation of seed sector in 1971, relaxed the restrictions on seed imports and also allowed the entry of private firms. The new seed policy enacted in 1988 spurred enormous growth in the private sector seed supplies in India. Another key seed policy instrument enhanced the participation of private firms: varieties could be multiplied and sold to the farmers without going through the regular certification process, by selling their hybrids or varieties as "truthfully labeled" (TFL) seed (Pray and Nagarajan, 2009).

The public sector research on pearl millet and sorghum advanced more rapidly than for other hybrids after the establishment of ICRISAT in 1972. The public sector research also provided the basis for success of private research and development. Pray and Ramaswami (2001) sought to measure the impact of these efforts to liberalize India's seed sector by comparing 1987 with 1995. They provided evidence to show that liberalization has increased the competitiveness in the seed sector and suggested that Indian farmers would be the ultimate beneficiaries of these policy changes. Finally, all the above initiatives coupled with strong cooperation between public and private sector research organizations paved the way for successful dryland cereal crop improvement and their adoption in India.

The Consortium Model[3]

The poor farmers need access to better seed, and hybrid seed is becoming more popular as farmers are able to enhance yields and profits from growing hybrids. The Hybrid Parents Research Consortia (HPRC) is an initiative of ICRISAT that was formed with the basic objective of increasing the accessibility of poor farmers to better hybrids by poor farmers through effective public-private partnerships.

The partnership between ICRISAT and public & private sector seed companies has evolved over time. In the early years, ICRISAT played a nurturing role to the fledgling industry through informal networks. As the private seed industry grew, it started to develop a significant research capability of its own. Recent years have witnessed remarkable growth in private sector investment in crop improvement research and development, especially in crops that provide hybrid cultivar options.

[3] For more details, please refer to Gowda *et al*. (2006)

The recognition of the private sector as a valuable research and development (R&D) partner led to the formation of the Sorghum and Pearl Millet Hybrid Parents Research Consortia in 2000. ICRISAT has been providing genetically improved diverse breeding lines and hybrid parents to partners in both public research institutions and private sector seed companies globally. Using the improved hybrid parents, public institutions and private sector seed companies have developed and marketed several hybrids during the past two decades. These hybrids have enabled farmers to realize higher yields, enhanced incomes and improved livelihoods (Belum *et al*., 2005; Gowda *et al*., 2006; Mula *et al*., 2007).

The first phase of the Consortia (for sorghum and pearl millet) was initiated in the year 2000 with 9 members, which grew three-fold by 2008. The second phase was operative during 2004-08, and the third phase started operating from 2009. The growth of membership in the Consortia, from 9 in 2000 to >50 in 2014, demonstrates how companies value the benefits of partnership with ICRISAT, which include access to improved breeding material and diversified hybrid parents (Belum *et al*., 2005; Mula *et al*., 2007). Similarly, the public & private seed companies have also played a significant role in taking the improved cultivars to farmers' door steps. The efforts of both public and private sectors have resulted in the development of complete varietal diversity in both these crops as well as have enhanced adoption rates in the major targeted locations. Except one or two major states, all dryland cereals cultivating states have reached their ceiling level of adoption. However, the varietal turnover velocities are still higher in case of sorghum than in pearl millet.

Economic Impacts

Among the more than 50 commercial sorghum hybrids present in the market, about 30 (mostly from the private sector) are based on ICRISAT-bred parental lines, or on proprietary parental lines developed from the ICRISAT-bred improved germplasm. Similarly, about 60 per cent of India's 9 Million ha under pearl millet is planted with at least 84 hybrids, of which at least 60 (mostly from the private sector seed companies) are based on ICRISAT-bred parental lines

Box 1. Exemplars for Power of Partnerships in India

- An ICRISAT-PS partnership sorghum hybrid, JKSH 22, known for its high grain yield potential, large grain and earliness (5–10 days compared to the most popular hybrid CSH 9) showed remarkable adoption covering 210,000 ha in 2002 (about 0.5% of the total rainy season sorghum area) (Belum *et al*., 2005).
- The adoption of another ICRISAT-PS partnership high yield potential hybrid, VJH 540, increased from 650 ha in 1997 to 1,42,000 ha in 2003 in rainy season in major sorghum growing areas in India, as evidenced from the increased seed sales of this hybrid from 6.5 t in 1997 to 1420 t in 2003 (Belum *et al*., 2005).
- Apart from these, several other private sector hybrids, such as MLSH 296, GK 4009 and GK 4013, are widely adopted in India. High rate of adoption of ICRISAT-based hybrids is due to large grain, higher grain and fodder productivity (Gowda *et al*., 2003).
- The pearl millet hybrid JKBH 26, developed by JK Agri Genetics, is based on an A-line on which no other organization from the private sector or from the Indian national program has any hybrid in the market. This hybrid has been under cultivation since 1996, retaining its initial high level of downy mildew resistance. This hybrid was adopted by increasing number of farmers for its high grain and stover yield, and high level of downy mildew resistance. It reached the highest adoption level of more than 400,000 ha in 2005
- Another pearl millet hybrid 9444, developed by Proagro Seed Company (now Bayer BioScience), is also highly valued for its high grain and stover yield, and 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.

or on proprietary parental lines developed from ICRISAT-bred improved germplasm (see Box 1). According to Pray and Ribeiro (1990), the social internal rates of returns to private pearl millet and sorghum research were at least 50 per cent. However, Evenson and Gollin (2003) have shown that the benefits of crop improvement benefits were less pronounced for millets and sorghum than for rice and wheat in India; nevertheless the progress in these crops has been significant.

Over the past two decades, the R&D in pearl millet and sorghum has become increasingly privatized, reflecting a general shift in India's agricultural research system from public sector-dominated to private sector-driven seed development and distribution. The accomplishments of pearl millet and sorghum breeding are considered as the success stories in India, with a large number of high-yielding, disease-resistant hybrids and open-pollinated varieties very widely used by the Indian farmers. This was made possible because of strong partnerships and Consortium model introduced by ICRISAT. This kind of approaches lead to scientific innovations that create a vibrant and sustainable supply of new improved cultivars and their adaptation in the targeted regions very quickly.

Conclusions and policy implications

In this context, it is to be recognized, as pointed out by Spielman and Von Grebmer (2005) that public-private partnership happens because of common interests of the parties involved. Variability in the incentives do exist, but it is not a constraint because partners agree on mutually acceptable framework that brings order in the system, and makes it more efficient by harnessing the complementary strengths and avoiding unnecessary duplications. These kind of models needs to be invented and sustained for reaching the technological benefits to farmers' in India without any research and adoption lag. Public institutions and public donor agencies should formulate and emulate 'Consortia models' for enhancing the crop improvement research benefits in the country.

Acknowledgements

This study was carried out as a part of 'Tracking Improved Varieties in South Asia' (TRIVSA) project supported by Bill and Melinda Gates Foundation (BMGF). The authors are highly thankful to AICRP on sorghum and pearl millet scientists for their cooperation and support during the implementation of

the project. They are also thankful to the anonymous reviewers for critical comments and suggestions on this paper.

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