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Development and Diffusion of Sorghum Improved Cultivars In India: Impact on Growth and Stability in Yield

D Kumara Charyulu, Cynthia Bantilan, A Rajalaxmi, BVS Reddy, ST Borikar, A Ashok Kumar, NP Singh and D Moses Shyam

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Acronyms

AICSIP	All-India Coordinated Sorghum Improvement Project
CSH	Coordinated sorghum hybrid
CV	Coefficient of variation
DSR	Directorate of Sorghum Research
EE	expert elicitation survey
ESA	East and Southern Africa
FAO	Food and Agriculture Organization
FTE	full time equivalent
GCA	gross cropped area
GMR	grain mold resistance
HPRC	Hybrid Parents Research Consortium
HYV	high-yielding varieties
ICAR	Indian Council of Agriculture Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
NAGS	National Active Germplasm site
NARES	National Agriculture Research and Extension systems
NBPGR	National Bureau of Plant Genetic Resources
NRCS	National Research Centre for Sorghum
NSC	National Seeds Corporations
SAT	Semi-arid tropics
SAU	State Agricultural Universities
SFR	Shoot fly resistance
SRR	Seed replacement rate
SSA	Sub-Saharan Africa
WCA	West and Central Africa

1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the major staple foods for the poorest and most food-insecure people across the semi-arid tropics of the world. *Sorghum bicolor* ssp. *Verticilliflorum* is believed to be the progenitor of cultivated sorghum (Harlan, 1972). It is cultivated in wide geographic areas in Africa, Asia, Americas and the Pacific regions. While it is the fifth most important cereal crop in the world after wheat, maize, rice and barley, in India, sorghum is the fourth largest cereal crop after rice, wheat and pearl millet and the second major food crop in Africa after maize. Sorghum is often a recommended option for farmers operating in harsh environments where other crops do poorly, as it can be grown with limited rainfall (400-500 mm) and often without or with limited application of fertilizers and other inputs. In India, sorghum is grown in both rainy (2.6 million ha) and postrainy (3.5 million ha) seasons. An estimated 2 million ha is under forage sorghum, grown in the summer season. Nearly 30-40% of the rainy season sorghum is grown as the sole crop while the rest is cultivated as an intercrop with pulses and oilseeds in India. On the other hand, 90% of postrainy season sorghum is grown as a sole crop, which is most preferred for food purposes.

Sorghum is grown for a variety of uses like food, feed, forage and fuel. It is also used in the beer, alcohol, starch, sugar, bread and biscuit manufacturing industries. Sorghum is one of the cheapest sources of energy, protein, vitamins and minerals (Ashok Kumar et al. 2012 and 2013). Above all, it is a climate resilient crop that can adapt quickly to climate change conditions.

During the last three decades (1980-2010), cropped area under sorghum decreased by 0.34% and production decreased by 0.51%. However, development and adoption of improved cultivars and improved management practices have increased the productivity levels significantly despite the tumbling acreage of sorghum across the globe in the recent past. In 2010-11, sorghum was grown in 110 countries, covering an area of approximately 40.5 million ha with grain production of 55.65 million t and an average productivity of 1.3 t ha^{-1} (FAO website: http://www.fao.org). Sorghum produced in India (7.38 million ha) constituted about 18.21% share of total global area, followed by Sudan at 5.61 million ha (13.85%), Nigeria at 4.7 million ha (11.6%), Niger at 3.3 million ha (8.14%) and USA at 1.94 million ha (4.79%) during 2010-11. The lion's share of global sorghum production is contributed by USA (15.7%) followed by India (12.58%), Mexico (12.47%) and Nigeria (8.59%). The productivity in developed countries (USA and Mexico) is about five times higher than the productivity in developing countries like India and Pakistan. The world highest productivity levels were observed in USA (4520 kg ha^{-1}) while the productivity in India is about 949 kg ha^{-1}.

Objectives of the study

India has one of the largest sorghum research networks in the world for developing improved products and technologies. Considering the importance of the crop, we made an attempt to understand the development and diffusion of sorghum improved cultivars in India over the last five decades. The Indian Council of Agricultural Research (ICAR), which includes the Directorate of Sorghum Research (DSR), Hyderabad and the All-India Coordinated Sorghum Improvement Project (AICSIP), has been working for sorghum improvement in diverse agroecological zones of India since the early 1960s. Similarly, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), an International Agricultural Research Centre established at Patancheru, Hyderabad, Andhra Pradesh has also chosen sorghum as one of its five mandate crops and has been conducting research for its development since 1972. In partnership with NARS, ICRISAT is playing a catalytic role in conserving, maintaining and distributing sorghum germplasm as well as developing hybrids and parental lines/ open-pollinated varieties (OPVs) in Asia (especially in India) and Sub-Saharan Africa (SSA). Another key stakeholder for rapid development of sorghum hybrids in India is a group of about 35 private seed companies that have been very active since the late 1980s. A comprehensive and systematic study of the development and diffusion of sorghum improved cultivars in the major states of India would provide interesting insights about the history of the improvement of this crop. Current knowledge about the spread and impact of sorghum improved crop varieties in the country is incomplete. Very little statistically valid information is available on the extent of adoption at national and subnational levels. Keeping these issues in mind, the present study made an effort to understand the adoption of sorghum improved cultivars in the major states of India. The paper also discusses major preferred traits and constraints for technology adoption in these states.

2. Performance of sorghum in India and major states

India holds the first rank in terms of global sorghum area and ranks second in production (FAOSTAT 2012). In the early 1950s, sorghum was referred to as "great millet" because it was a major cereal staple occupying an area of more than 16 million ha. However, this decreased to 7.38 million ha by 2010-11 (5.82% of gross cropped area in India) and now contributes about 7.0 million t (2.86%) to India's total food production (Fig 1).

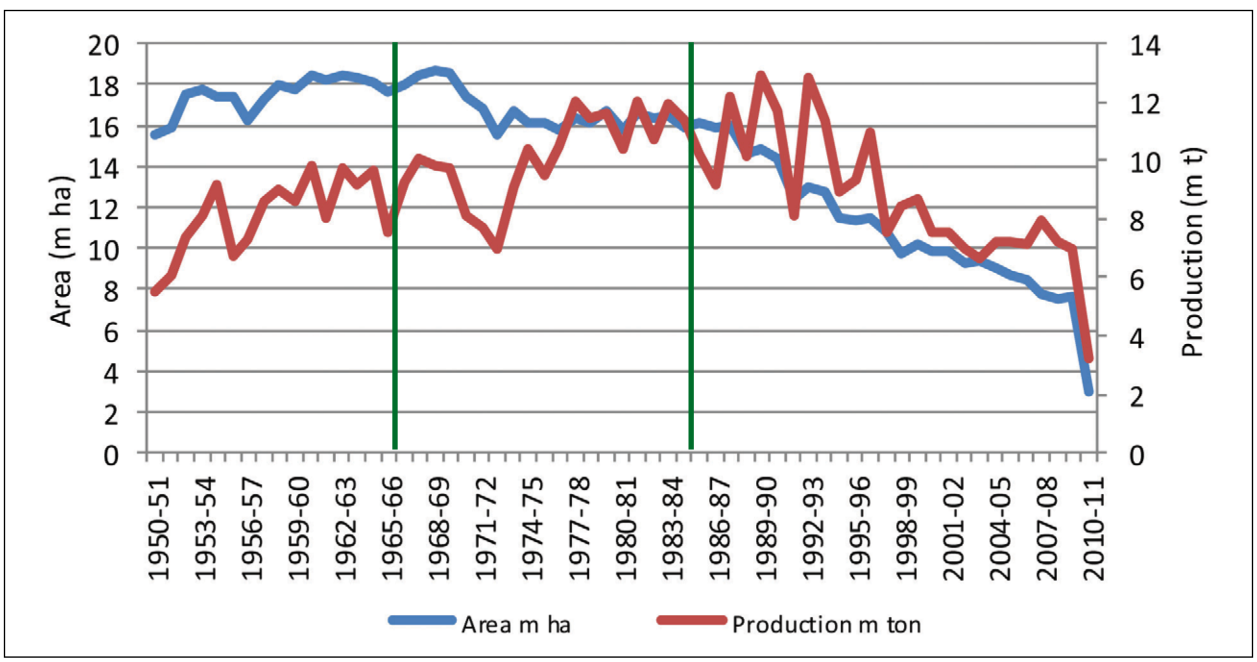

Figure 1. Sorghum area and production trends in different periods.

Source: Ministry of Agriculture, Government of India

Broadly, the sorghum area, production and productivity trends in India reveal three distinct time periods or phases: Phase I: Postindependence period (1947-1965); Phase II: Public-supported growth period (1965-85) and Phase III: Private sector driven growth period (1986 to present). Although the total area under sorghum was declining, the postindependence period witnessed a major increase in production due to increase in yields when compared to the initial years after independence. By the mid-1960s, new hybrids of sorghum were developed as part of the AICSIP. The Coordinated Sorghum Hybrid (CSH) series hybrids were particularly high-yielding and short duration hybrids that were successful at raising overall yields. In the last phase, Phase III, the production trend was reversed (Pray and Nagarajan 2009). Overall, the cropped area and production registered annual growth rates of around -2.9% and -1.9% respectively between 1980 and 2010.

This declining trend in area and production in the recent past can be attributed to certain specific factors. 1. Improved irrigation facilities that resulted in a shift to other commercial crops like groundnut, sunflower, soybean, pigeonpea, chickpea, maize, cotton and sugarcane. 2. The changing food habits (Basavaraj et al. 2011 and 2012; NSSO2004-05 Report), availability of fine cereals (rice and wheat) at affordable prices (subsidized through the public distribution system) and rising income levels, deterioration of grain quality due to grain mold, and biotic and abiotic factors affecting sorghum yields also played a crucial role. 3. Some of the government policies favoring the cultivation of commercial crops (cotton and sugarcane) through liberal loan facilities ruined the crop choices among farmers. This shift is of serious concern in terms of the cropping systems and the food and fodder security of the dryland regions of the country.

In India, sorghum is grown in two seasons: in the rainy season as a rainfed crop and in the postrainy season under residual soil moisture/limited-irrigated conditions. The sorghum story in India is further complicated by a major shift in production from the rainy to the postrainy season. The area shares between rainy season (62%) and postrainy season (38%) in the total cropped area in 1965-66 changed to 41.6% (rainy season) and 58.4% (postrainy season) by 2010-11. The reason for these shifts was poor quality of rainy season grains due to rains at the time of harvest, which was fetching lower prices in the market (Fig 2 and Table 1).

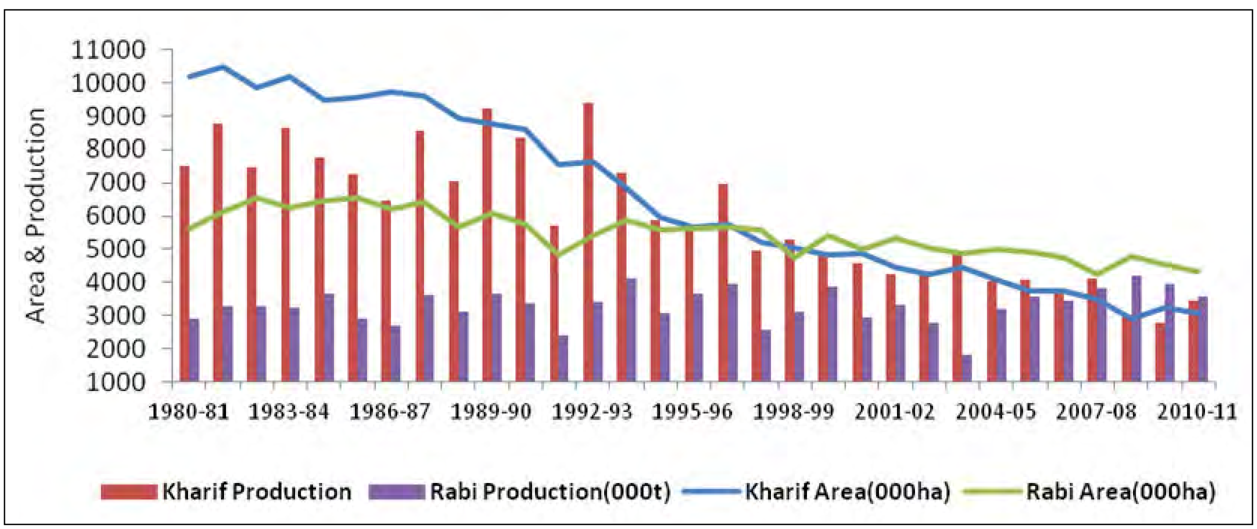

Figure 2. Performance of rainy season and postrainy season sorghum in India.

Table 1. Sorghum area and production growth rates (%).

	Rainy season		Postrainy season			
Period	Area	Production	Area	Production	Total area	Total production
1980-85	-1.72	0.52	3.09	4.42	0.06	1.67
1985-90	-2.52	5.80	-2.42	6.07	-2.48	5.88
1990-95	-7.99	-4.44	1.27	3.92	-4.05	-1.84
1995-00	-4.49	-5.85	-2.52	-1.23	-3.48	-3.96
2000-05	-3.38	-1.04	-0.89	-4.34	-2.08	-1.98
2005-10	-4.58	-5.33	-0.78	-1.22	1.01	2.2
1980-2010	-4.42	-3.38	-1.18	0.27	-2.89	-1.95

Source: Directorate of Economics and Statistics, Government of India, 2012

The season-wise growth rates in area and production during the period 1980-2010 shows that rainy season production has declined due to decline in area over this period (Table 1) despite successful crop improvement efforts by public and private sectors. On the other hand, yields have steadily increased to almost 1000 kg ha-^{1} due to adoption of improved cultivars (Pray and Nagarajan 2009). Even though there was a slight fall in postrainy season sorghum area, the production was stable over the study period. In fact, the postrainy season production growth rate was positive during 1980-2010. Overall trends indicate a steep decline in total sorghum area (-2.89%) and production (-1.95%) at the national level. Nevertheless, the technological advancement in sorghum has kept the sorghum production fairly stable regardless of decline in area planted.

In general, the average productivity levels are higher in rainy season when compared to the postrainy season. The main reasons for low productivity in the postrainy season include terminal moisture stress as the crop is grown on residual moisture, less use of recommended varieties, partial or less use of chemical fertilizers, high seed rate and narrow row spacing. However, the grain quality is far superior in the postrainy season as compared to the rainy season. Most of the rainy season production is used for industrial and poultry uses, while the majority of the postrainy season production is used for human consumption. In both the seasons, stover forms an important source of animal feed.

2.1 Sorghum performance across major states

In India, the main sorghum-producing states during 2010-11 were Maharashtra, which occupied 49% share in total production, followed by Karnataka (21%), Madhya Pradesh (9%), Rajasthan (7%), Andhra Pradesh (4%), Uttar Pradesh (3%) and Gujarat (2%). The lion's share of total cropped area belongs to Maharashtra (55%) followed by Karnataka (17%), Rajasthan (10%), Madhya Pradesh (6%) and Andhra Pradesh (3%). However, the highest productivity was noticed in Madhya Pradesh (1426 kg ha^{-1}) followed by Andhra Pradesh (1213 kg ha^{-1}), Karnataka (1180 kg ha^{-1}) and Gujarat (1112 kg ha^{-1}) during the same period.

Table 2. Sorghum performance in major producing states (Area – million ha; Production – million t and Yield – kg ha^{-1}).

	1966-1968			1976-1978			1986-88			1996-1998			2008-2010		
State	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield
Andhra Pradesh	2.57	1.24	483	2.21	1.31	587	1.51	0.87	568	0.80	0.56	695	0.30	0.39	1304
Gujarat	1.31	0.35	264	1.03	0.57	553	0.73	0.27	354	0.29	0.25	862	0.15	0.17	1119
Karnataka	2.82	1.49	527	2.00	1.62	808	2.40	1.71	710	1.92	1.60	833	1.33	1.49	1129
Maharashtra	6.25	3.35	535	6.53	4.90	750	6.39	4.44	691	5.32	4.83	908	4.10	3.53	862
Rajasthan	1.08	0.32	294	0.79	0.32	408	1.01	0.34	334	0.57	0.24	410	0.67	0.31	474
Madhya Pradesh	2.43	1.75	725	1.91	1.34	700	1.88	1.56	835	0.84	0.75	894	0.45	0.58	1295

Source: Directorate of Economics and Statistics, Government of India

The details of sorghum performance in major producing states are summarized in Table 2. The area under Maharashtra declined from 6.25 million ha in 1966-68 to 4.10 million. ha by 2008-10. However, the production was stable and productivity increased significantly (61%) during the same period. Karnataka exhibited similar trends in area and production while the productivity improved drastically by 114% from 527 kg ha^{-1} to 1129 kg ha^{-1} in the same study period.

Andhra Pradesh lost both considerable area and production but mean yields have increased substantially by 170%. Gujarat followed a similar path to Andhra Pradesh during the study period. Rajasthan also lost considerable sorghum area between 1966 and 2010. In Madhya Pradesh, the cropped area declined significantly to 20% and production to one third between 1966 and 2010, but the productivity registered a substantial improvement from 725 to 1295 kg ha^{-1}.

The details of state-wise growth rates in sorghum area, production and productivity are presented in Table 3**.** Almost all the states exhibited negative growth in area between 1970 and 2010. The highest negative growth rate was observed in Gujarat, followed by Andhra Pradesh and Madhya Pradesh. Similarly, the decline in production was also highest for Gujarat (-3.51%) followed by Andhra Pradesh (-2.99%) and Madhya Pradesh (-2.96%). A positive production growth rate was observed only in Maharashtra for the entire period (1970-2010). Interestingly, the productivity growth rates were positive among all states, with Gujarat leading, followed by Andhra Pradesh. However, during the last decade (2001-10) studied, the productivity growth rate was highest for Karnataka followed by Madhya Pradesh, Rajasthan, Andhra Pradesh, Gujarat and Maharashtra, in that order.

Table 3. Growth rates in area, production and productivity by state.						
State	Item	1971-80	1981-90	1991-00	2001-10	1970-10
Andhra Pradesh	Area	-2.65	-6.46	-5.27	-9.84	-5.55
	Prod	1.13	-6.96	-4.19	-7.04	-2.99
	Yield	3.88	-0.53	1.15	3.13	2.57
Gujarat	Area	-1.53	-2.52	-10.41	-2.55	-6.27
	Prod	7.27	-6.17	-5.02	0.16	-3.51
	Yield	8.94	-3.75	6.02	2.74	2.94
Karnataka	Area	-1.96	0.24	-1.96	-4.03	-1.01
	Prod	-0.10	-2.06	-1.83	3.54	-0.44
	Yield	1.90	-2.29	0.13	7.88	0.58
Maharashtra	Area	1.97	-0.52	-1.66	-2.37	-1.05
	Prod	14.16	2.58	-1.68	-0.22	0.67
	Yield	11.95	3.11	-0.02	2.20	1.73
Rajasthan	Area	-1.27	-0.35	-2.60	1.68	-1.37
	Prod	-1.68	-0.61	-4.17	5.31	-1.13
	Yield	-0.41	-0.26	-1.61	3.77	0.26
Madhya Pradesh	Area	0.46	-2.41	-8.85	-5.52	-4.31
	Prod	-0.09	-0.45	-9.87	-1.71	-2.96
	Yield	-0.55	2.02	-1.11	4.13	1.41

Source: Directorate of Economics and Statistics, Government of India

2.2 Inter-state shifts in sorghum areas

Figure 3 depicts the state-wise shifts in sorghum cropped area shares between 1966-68 and 2008-10. A lone state, Maharashtra, increased the sorghum cropped area share significantly (by nearly 20%) during the study period, while Karnataka and Rajasthan improved their shares in sorghum cropped area only marginally. On the other hand, Andhra Pradesh lost a significant share (nearly 10%) in total area under sorghum. States like Gujarat and Madhya Pradesh also equally lost their shares (around 5-6%) in the gross sorghum cropped area in India.

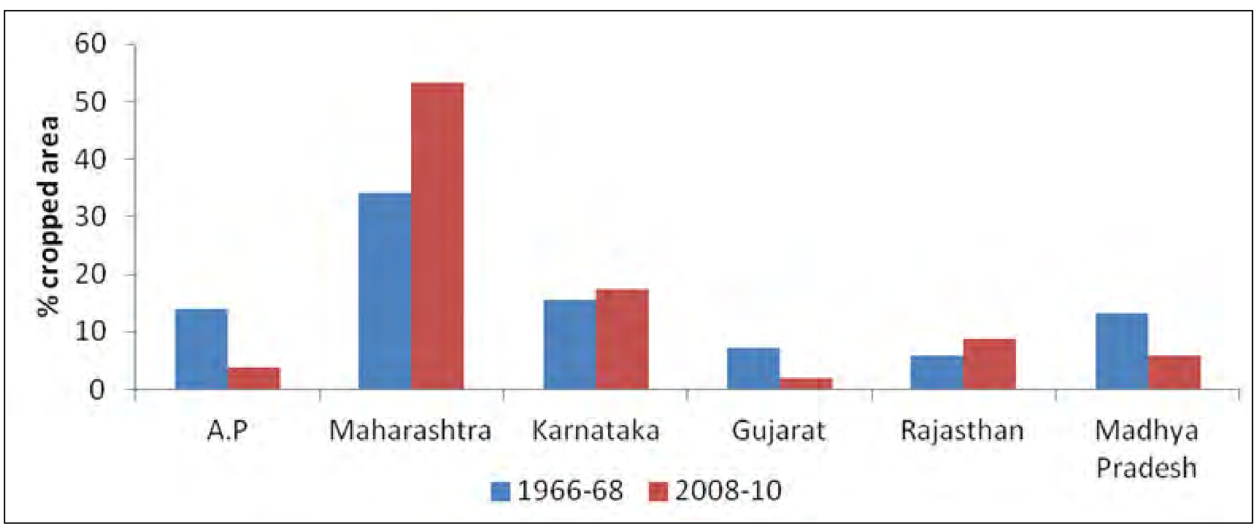

Figure 3. State-wise shifts in sorghum cropped area (%).

The details of inter-state shifts in sorghum cropped area across major states between1966-68 and 2008-10 are summarized in Table 4. The shares of rainy season and postrainy season in the total area significantly changed in Maharashtra, Karnataka and Gujarat, while the changes were negligible in the rest of the states. Among the seven states, area under sorghum was dominated by the postrainy season in Maharashtra and Karnataka whereas in Gujarat, Rajasthan, Madhya Pradesh and Tamil Nadu it was higher under the rainy season crop. Andhra Pradesh exhibited almost equal shares in both the time periods. In general, the productivity levels were higher during the rainy season (except in Tamil Nadu).

Table 4. Performance of sorghum in major growing states.

	Area shares in 1966-68		Area shares in 2008-10			
State	Rainy season	Postrainy season	Rainy season	Postrainy season	Crop nature	Productivity nature
Andhra Pradesh	0.47	0.53	0.45	0.55	Both rainy season and postrainy season	Rainy season productivity == Postrainy season productivity
Maharashtra	0.43	0.57	0.24	0.76	Postrainy season dominant	Rainy season productivity > Postrainy season productivity
Karnataka	0.43	0.57	0.18	0.82	Postrainy season dominant	Rainy season productivity > Postrainy season productivity
Gujarat	0.87	0.13	0.67	0.33	Rainy season dominant	Rainy season productivity > Postrainy season productivity
Rajasthan	1.00	0.00	1.00	0.00	Rainy season only	N.A
Madhya Pradesh	0.99	0.01	1.00	0.00	Rainy season dominant	Rainy season productivity == Postrainy season productivity
Tamil Nadu	0.73	0.27	0.75	0.25	Rainy season dominant	Rainy season productivity < Postrainy season productivity

2.3 District-wise distribution of sorghum cropped area

The district-wise spatial distribution of sorghum cropped area was studied for the rainy season (Fig 4) and postrainy season (Fig 5) between 1980-82 and 2005-07. During the 1980s, high concentrated sorghum (rainy season) areas were prominently present in Maharashtra followed by Madhya Pradesh, Rajasthan, Andhra Pradesh and Karnataka (Fig 4). But these area concentrations conspicuously disappeared by 2005-07 in the major sorghum-growing states. Sorghum is now highly localized in a few selected districts (area more than 100,000 ha) of Maharashtra followed by Madhya Pradesh and Rajasthan. Similarly, the postrainy sorghum area was predominant in Maharashtra followed by Karnataka and Andhra Pradesh (Fig 5) during 1980-82. The postrainy season concentrated districts (area more than 100,000 ha) are more or less stable in Maharashtra and Karnataka, but they disappeared totally in Andhra Pradesh. These shifts in sorghum cropped area are clearly evident even at the district level in the major sorghum-growing states of India.

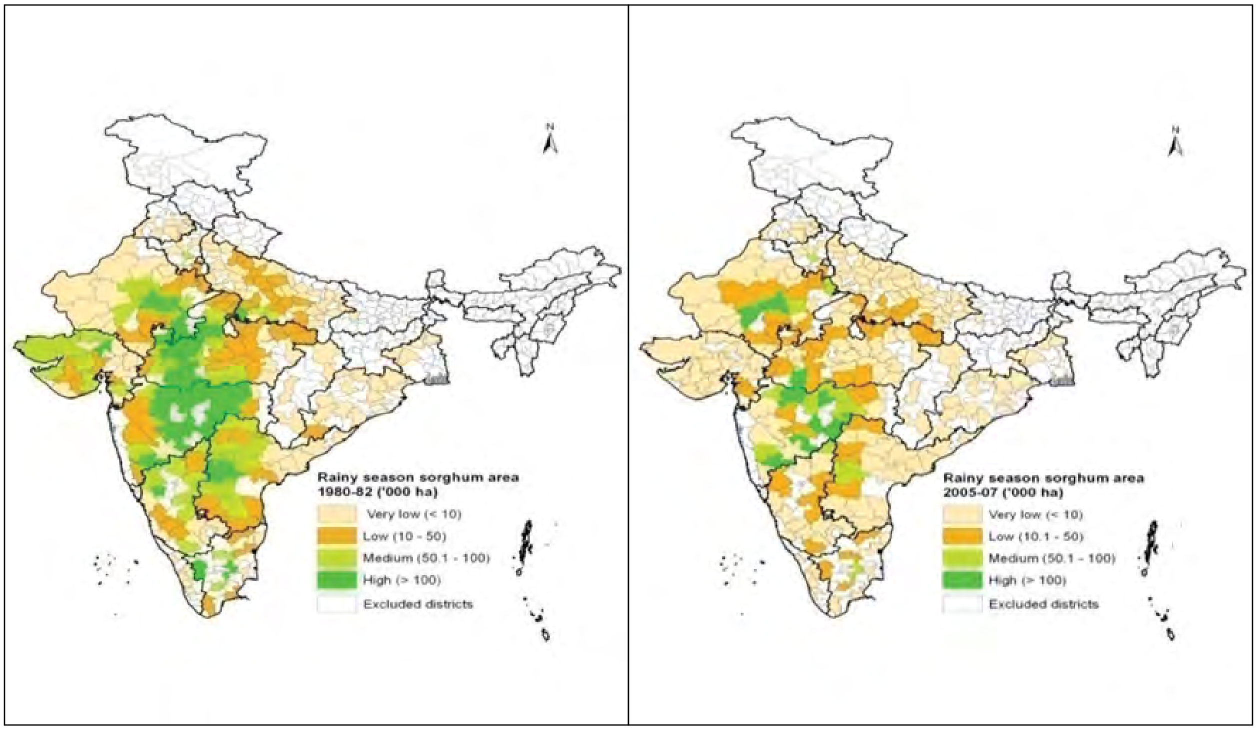

Figure 4. Spatial distribution of rainy season sorghum area in India by district.

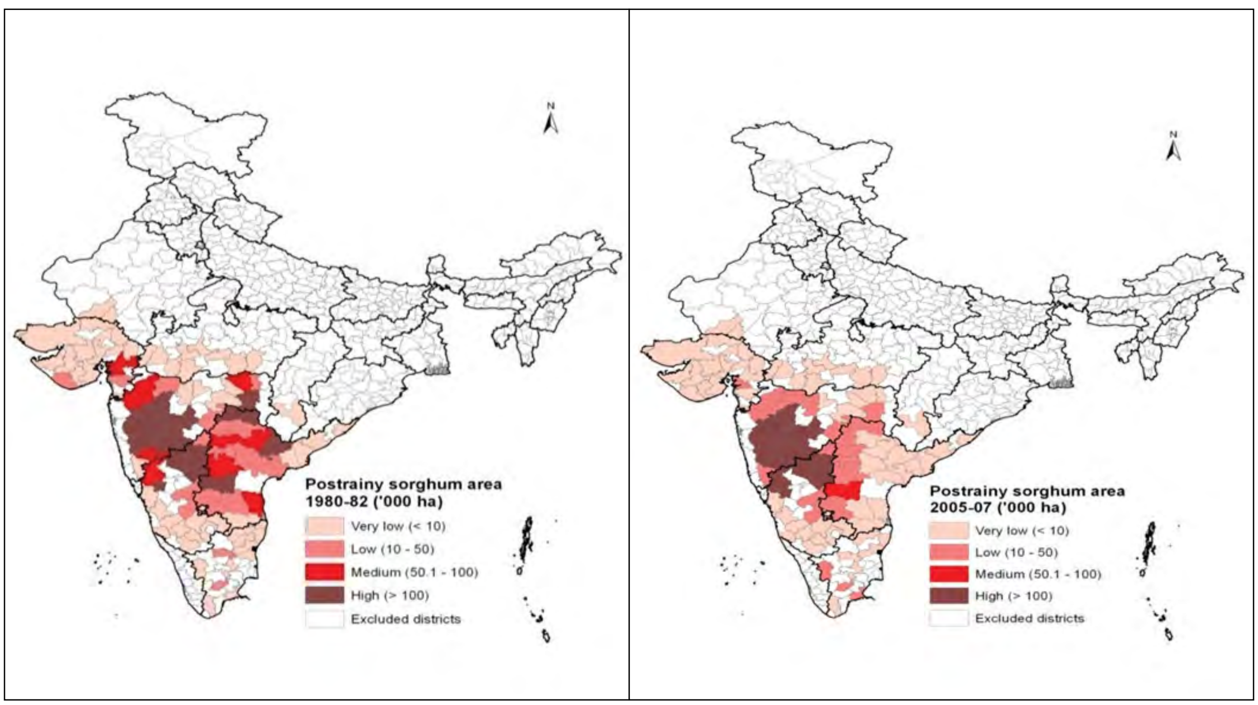

Figure 5. Spatial distribution of postrainy season sorghum area in India by district.

2.4 Utilization pattern of sorghum in India

In the last two decades the nature and utilization of sorghum grain has undergone a change from being a staple food to industrial uses such as livestock and poultry feed, potable alcohol, starch and ethanol production (Kleih et al. 2000). In addition, new value added/processed food products for human consumption are emerging such as popped sorghum, *papad, porridge*, *rava* and as an ingredient for Indian dishes like *dosa* and *khichdi* which, though in the nascent stage, are likely to be significant avenues for diversifying utilization of sorghum. In India, consumption is more or less analogous to the production trend. However, the consumption of the grain as a whole is declining with the falling production figures with an annual negative growth rate of around -2.06% (Fig 6).

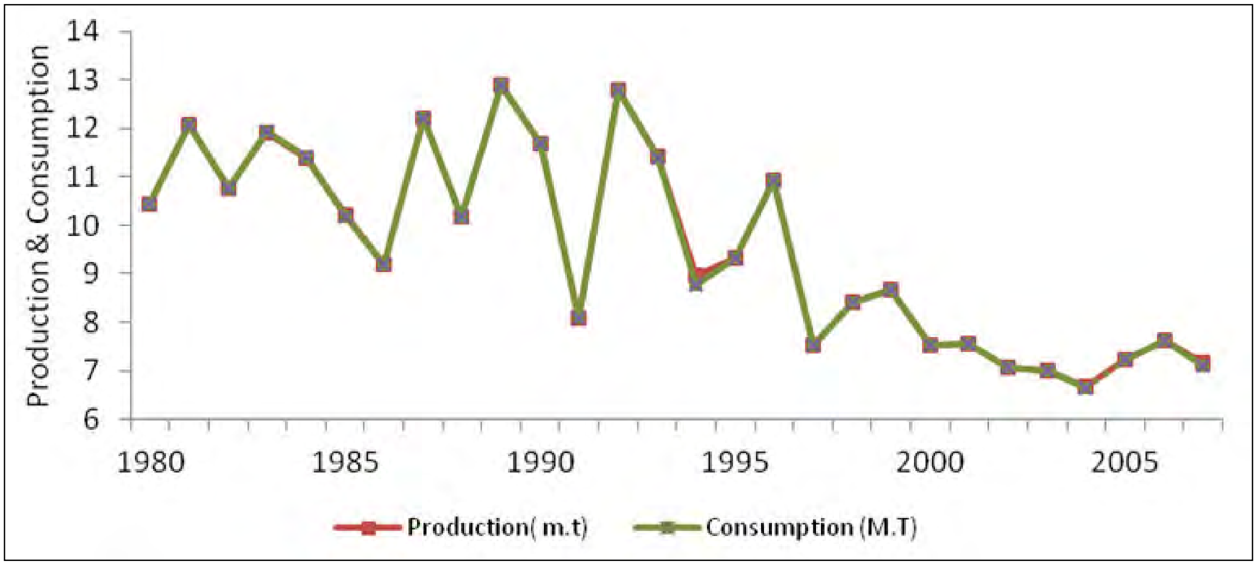

Figure 6. Sorghum production and consumption in India.

Source: CRP 3.6 Dryland Cereals Proposal, ICRISAT dated August 16, 2012

A study conducted by Ramesh Chand (2007) between 1972–73 and 2004–05 reveals that the annual per capita consumption of sorghum at all-India level has declined sharply by 68% (from 8.5 to 2.7 kg) in urban areas and by 70% (19.1 to 5.2 kg) in rural areas. This decline in per capita consumption of sorghum both in rural and urban areas at the all-India level is due to several factors but the most important ones are increase in per capita income, growing urbanization and changing tastes and preferences

Despite the decline in per capita consumption, sorghum grain is an important staple for the low and middle income consumers. The low income consumers (about 30% of the population in rural and urban areas each) account for 35% sorghum consumption in rural areas and 49% in urban areas of India. Their per capita consumption is also the highest among the three (low, middle and high) income groups. The share of high-income consumers is low both in rural and particularly in urban India (NSSO Report, 2004-05). Finally, the demand for sorghum is expected to be enhanced by increasing use in the poultry (especially layer feed) and animal feed sector along with human consumption due to increased health consciousness.

The study conducted by Basavaraj et al. (2011 and 2012) concluded that the three major sorghum-producing states (Maharashtra, Andhra Pradesh, Karnataka) still have a per capita consumption at 60% of the total production. The traditional sorghum consuming belt of Maharashtra has the highest per capita annual consumption of 54 kg in rural area and 34 kg in urban areas. But in Karnataka, the per capita consumption is around 50 kg in rural areas and 33 kg in urban areas. The major factors attributed for higher consumption of sorghum are cultural practices, eating habits of these regions and prevailing climatic and soil conditions.

The study of change in consumption pattern across different income groups both in rural and urban areas showed an inverse relationship with increasing income. Low income groups in rural areas in all the three states consume larger quantities of sorghum compared to middle and high income groups. A similar but more significant difference in consumption between low and middle income groups was observed in urban areas. Urban consumers in Karnataka consume almost twice the quantity of sorghum compared to consumers in urban Maharashtra for all income groups. This is because of the availability/penetration of a wide range of ready-to-eat sorghum products to the urban population. Apart from this, purchasing power determines consumption habits as the postrainy season harvest is priced 1.5 to 2 times higher than the rainy season crop due to its superior quality (Parthasarathy Rao et al. 2010). Most of the sorghum consumed by humans comes from postrainy season sorghum (nearly 90% of the total production) and the remaining 10% goes to the processing sector (Dayakar Rao et al. 2010). In general, the surplus production from the major sorghum-producing states available is from the rainy season crop after meeting the 40-45% consumption demand. This left over surplus production from rainy season is normally diverted to industrial uses.

Keeping in view the potential benefits of sorghum, research efforts should be focused more on release of varieties to cater to the demand for feed, fodder and the processing sector so that it may result in better value-added products and meet the demand of the growing urban and rural population. Enhancing the productivity of the postrainy season crop may bring down the real prices in the long run and make it affordable for the rural poor.

3. Research organization and history of crop improvement

3.1 Organization of national sorghum research in India

Indian public sector agricultural research agencies have been breeding improved sorghum varieties since the early part of the twentieth century. The development of hybrid sorghum in India started in the early 1960s, with the establishment of hybrid breeding programs at a number of agriculture research centers: IARI (Indian Agricultural Research Institute) and the State Agricultural Universities (SAUs) in Maharashtra, Haryana, Karnataka, and Andhra Pradesh. The DSR (formerly National Research Centre for Sorghum) was also established in 1987 by ICAR.

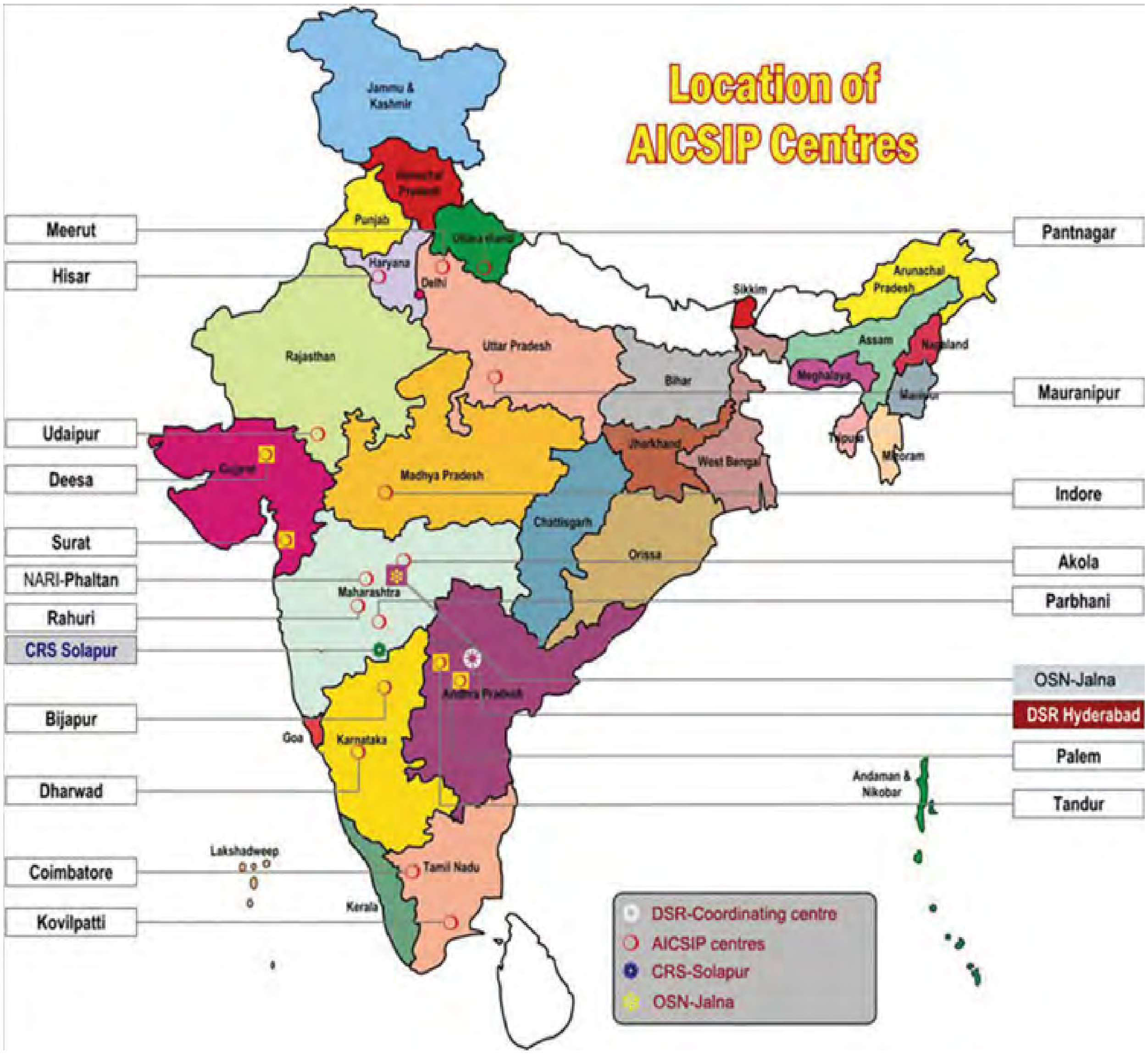

Figure 7. Location of AICSIP centers in India.

Source: AICSIP, Rajendranagar, Hyderabad

The DSR is the nodal agency in the country dealing with all aspects of sorghum research and development (R&D) including coordination and consultancy. The Directorate works closely with many other sister institutions of ICAR, SAUs and national and international agencies such as ICRISAT and other institutions both in the public and private sector. The DSR is also mandated with organizing and coordinating sorghum research at the all-India level through AICSIP, a network of 16 centers located in the states that have major sorghum-growing areas (Fig 7).

The center-wise thrust in sorghum crop improvement is summarized in Table 5. Through its network centers located across the country in diverse geographical zones; ICAR has so far developed 26 hybrids (CSH 1 to CSH 26) and 29 varieties between 1964 and 2010 (Appendix 1). However, India is the unique center of origin for the postrainy season varieties of sorghum in the world (DSR Annual Report 2011).

Table 5. Center-wise major thrust(s) in sorghum crop improvement.				
State	Center	SAU Name	Major constraint dealt with	Major product types
Tamil Nadu	Coimbatore	TNAU	Diseases, drought	Dual purpose and forage
	Kovalpatti	TNAU	Insects, esp. of panicle	Dual purpose and sweet and forage
Karnataka	Dharwad	UAS	Insects, foliar diseases, mold	Hybrids and varieties, dual purpose
	Bijapur	UAS	Shoot fly, charcoal rot, drought	Postrainy season hybrids and varieties
Andhra Pradesh	Palem	ANGRAU	Insects, mold	Dual purpose, forage
	Tandur	ANGRAU	Postrainy season adaptation	Varieties
	Warangal	DSR	Borer, storage pests	Forage
Maharashtra	Parbhani	MAU	Mold, shoot fly, borer, shoot bug	Hybrid and varieties, sweet stalk
	Rahuri	MPKV	Shoot fly, charcoal rot, food quality	Hybrid, variety, sweet sorghum, forage
	Akola	PDKV	Shoot fly, borer, mold	Hybrids and varieties
Gujarat	Surat	NAU	Shoot fly, borer, panicle pests and mold	Dual purpose, forage
	Deesa	SDAU	Shoot fly, borer, foliar diseases	Forage single-and multi-cut
Madhya Pradesh	Indore	JNKVV	Shoot fly, borer, leaf diseases	Hybrids and varieties
Rajasthan	Udaipur	MPUAT	Shoot fly, borer, leaf diseases	Dual-purpose varieties, single-cut forage
Uttar Pradesh	Mauranipur	CAUAT	Shoot fly, borer, leaf diseases	Dual purpose varieties, single-cut forage
Haryana	Hisar	CCSHAU	Stem borer	Forage, single-and multi-cut
Uttarakhand	Pantnagar	GBPUAT	Borer, leaf diseases	Forage, single-and multi-cut

Source: AICSIP, Rajendranagar, Hyderabad

3.2 Crop improvement strategies

3.2.1 Sorghum improvement strategies, 1960-2010[1]

At the national level, DSR and AICSIP work together for sorghum crop improvement. Broadly, the mandate of DSR in India is to conduct basic and strategic research leading to technology development for increased productivity of sorghum and its diversified utilization, to promote profitability from sorghum-based cropping systems and to serve as the national repository of sorghum germplasm. The DSR also puts emphasis on sorghum market development and export promotion and very closely coordinates with AICSIP program to conduct multilocational trials at the national level to develop superior varieties and hybrids, and to evolve appropriate crop management practices. In India, along with ICRISAT, DSR is the one of the National Active Germplasm Sites (NAGS) working actively in the area of collection, conservation, characterization, evaluation and documentation of sorghum genetic resources in cooperation with the National Bureau of Plant Genetic Resources (NBPGR). These germplasms have contributed significantly to crop improvement in terms of yield, resistances and utilization/ quality traits (House 1995). As on February 2011, DSR had collected and conserved a total of 23,612 germplasm accessions, in which 1,280 accessions are identified as duplicate samples (Elangovan et al. 2009).

3.2.2. Improvement in local landraces

Natural selection, domestication and selections in populations of landrace crosses between 1930-1960 have resulted in the development of varieties highly local in their adaptation. Notable among these varieties are the Co (Coimbatore) series in Tamil Nadu, the Nandyal, Anakapalle and Guntur series of Andhra Pradesh, the PJ (Parbhani) rainy and postrainy season selections, Saoner, Ramkel, Aispuri, Maldandi and Dagadi selections of Maharashtra, the Fulgar, Nandyal, Hagari and Yanigar varieties of Karnataka, the BudhPerio, Sundhia and Chasatio of Gujarat, the Gwalior and Indore selections of Madhya Pradesh and RS selections of Rajasthan. In India, the popular rainy season types developed through pure line selection include PJ4K,PJ16K, Vidisha 60-1, Aispuri, BP 53 and Coimbatore selection. Pure line selection M 35-1 from Maldandi locals is a landmark achievement and highly popular even today. These locals are generally tall and late maturing, flower after cessation of rainfall, and they are photoperiod sensitive and characterized by local adoption and low harvest index. These varieties were mostly grown without fertilizers resulting in limited (400-500 kg ha^{-1}) yield increase (10-15%) over landraces, yields of which were mostly affected in years of drought (Rao 1971). The age old association and the local preferences for taste of respective local varieties are reasons for their continued cultivation in spite of their erratic behavior and low yields. In addition to this, there are special varieties for popping, parching, roasting etc. which are also maintained by the farmers.

3.2.3. Exploitation of heterosis

As a result of germplasm introductions from USA (kafir, milo, durra, caudatum), the discovery of workable cytoplasmic-genetic male sterility and efforts under hybrid project (Rao 1972) initiated by the ICAR during 1962, four commercial hybrids CSH 1 (1964), CSH 2 (1965), CSH 3 (1970), CSH 4 (1973) and improved variety Swarna (1968) were released for general cultivation

[1] The authors are highly thankful to ST Borikar, SP Mehtre and SP Deshpande for their inputs in this section of the report.

in the rainy season. These achievements marked a genetic breakthrough due to exploitation of heterosis and suitable combination of height and maturity genes. These dwarf and early-maturing (100 days) cultivars gave linear response to nitrogen application and the yield was three times that of local improved varieties. The response of new cultivars to increased plant populations was well demonstrated. Release of early maturing dwarf hybrids triggered the cultivar-input-management- interactions and resulted in quantum jumps in productivity. These early maturing hybrids also opened new vistas for the development of new sequential cropping patterns suited to rainfed situations. The growing period of the hybrids generally coincided with the length of the rainy season and their performance was consistently superior over varying environments. The superiority of the hybrids was more pronounced when the yields of the locals tended to be low under moisture stress and other unfavorable growing conditions. In general, the hybrids yielded 60-100% more grain than the existing improved varieties even under light soil and low rainfall conditions (Rao 1971). When the recommended inputs were applied, hybrid yield was elevated to 2500 kg ha^{-1} under stress conditions and to the order of 5000 kg ha^{-1} under normal growing conditions. This classical work practically realized a "Hybrid Revolution" in major rainy season sorghum-growing states of India and it is one of the success stories in the history of agricultural research in India.

3.2.4. Establishment of AICSIP

The Indian Council of Agricultural Research (ICAR) has two units for conducting research in India. One is the DSR, which deals with mainly basic and strategic research issues. The AICSIP, established at Hyderabad in 1970, is a nationwide network for cooperative, interdisciplinary and inter-institutional research linking ICAR institutes (DSR Hyderabad) with the 18 centers in SAUs to focus attention on R & D related to sorghum. The AICSIP was established with the mission of enhancing the productivity and profitability of sorghum on a sustainable a basis, and to popularize sorghum based technologies to benefit farmers. The AICSIP has succeeded in joint evaluation of new technologies to arrive at a collective recommendation which is generally more valued, respected and implemented for sustainable crop production in the country (Tonapi et al. 2011). Establishment of the All-India Coordinated Research Project can be considered as a valuable success story and other developing nations can take guidelines from these achievements.

Development and release of hybrids was primarily based on exotic breeding material (CK 60 A/B, IS 84, IS 3691). This change in the pedigree initially brought some problems of grain quality and, and increased incidence of insect pests particularly shoot fly. Hybrids CSH 2 and CSH 3 had problems in seed production due to dwarf nature of pollen parent (R-line IS 3691) than respective seed parent (A-line).

3.2.5. Hybrids with improved grain quality

Hybridization between exotic (dwarf, early) and Indian (tall, late) sorghums resulted in products with high yields. Heterosis for panicle characters and recovery of desirable segregates was generally more in the crosses involving parents of similar panicle morphology. In general, longer panicle (more primary branches in a panicle) was a desirable trait for rainy season hybrids whereas panicle breadth (more secondary and tertiary branches) was more desirable under the postrainy season. The desirable plant type was based on the ‘genetic engineering ‘of height and maturity genes. The tall Indian varieties possess the dominant alleles for yield and plant height whereas the dwarf exotic lines have alleles for earliness. In general, yield potential of genotype is better with medium maturity and medium plant height. Subsequently efforts were directed to breed cultivars with medium maturity (110-115 days), medium plant height (160-200 cm) with better grain quality and tolerance to grain mold.

Since the chalky white grains of kafir place a limitation on grain quality, efforts were directed to develop new male sterile lines with Indian varieties. At Coimbatore new male sterile like 2219 A (Rainy-shalu) and 2077 A (3677B x IS 2046 from Senegal) were developed by identifying maintainer lines (B) from Indian breeding material and backcrossing to milo (A) cytoplasm line to substitute the nucleus (direct method). The restorer CS 3541, developed from IS 3675 (kafir durra from USA) x IS 3541 (Ethiopian ZeraZera), contributed to yield improvement and grain mold tolerance. These lines were used for developing CSH 5 (2077 A x CS 3541) in 1975 and CSH 6 (2219 A x CS 3541) in 1977.

The Maharashtra researchers at Nagpur and Parbhani took an “indirect” method of developing new male sterile lines. They first crossed tall Indian varieties to Kafir B, identified sterility maintainers in F 2/F 3 by test cross and carried through several generations of backcrossing till a stable sterile (A) was developed. This method involving kafir x Indian crosses helped to develop male sterile lines (A / B) with better grain quality and varied combinations of height and maturity genes. The male sterile line 1036 A, based on PJ 7 R, was used in CSH 4 (1036 A x Swarna) in 1973. Several new sterile based on PJ 4 K, PJ 8 K, PJ 16 K, PJ 1R, PJ 15 R and M35-1 were developed. Male sterile line 36 A developed from CK 60 B x PJ 8 K was used in CSH 7 and CSH 8 R in 1977. All these efforts helped to develop new hybrids with improved grain quality (Rao 2006).

Sorghum hybrids based on temperate material showed increased incidence of shoot fly under late plantings. The advantages of planting sorghum hybrids with the onset of the monsoon for achieving higher yields and for avoidance of shoot fly incidence was demonstrated and quickly adopted. Similarly, cultivation of early hybrids and late flowering locals in the same area during initial years of hybrid spread resulted in extended periods of flowering conductive to rapid multiplication of sorghum midge, causing damage to late locals. A judicious policy of en-block coverage of hybrids contained midge. In fact, it may be said that the incidence of midges promoted hybrids and discouraged and eliminated late flowering locals. These are typical examples of management changes consequent to a genotype change leading to pest avoidance.

Another example of a transitional problem in the process is grain deterioration. Traditional cultivars normally maturing in December have clean grains. The reduction in duration to minimize climate vulnerability caused them to mature during mid or late October, which has low probability of occurrence of rains. The farmers’ reaction to early (100 days) maturing hybrid CSH 1 was good in dry and low rainfall years. Such hybrids are more suited to areas where soils are light to medium and rainfall is less and withdraws early by about two weeks.

New early maturing hybrid CSH 6 (1977) was quickly accepted in low rainfall areas due to better grain quality and grain mold tolerance contributed by the male parent. The breeding program involving temperate-tropical crosses gave desirable restorers (CS 3541) rather than exotic (IS 84) lines. Similarly hybrid CSH 5 (1975) not only reduced the problem of grain deterioration but also opened the doors to sequence cropping in areas of assured rainfall. A sequence crop (safflower, chickpea or mustard) in the postrainy season following sorghum in rainy season was found to be possible in those areas which receive rainfall above 700 mm and have medium to deep black soils. Intercropping sorghum with pigeonpea or soybean (2:1, 3:3) is recommended and widely accepted. While such intercropping systems are advantageous in area of low rainfall, multiple cropping is more profitable in high rainfall areas with moisture retentive soils. These sustainable agronomic changes were possible due to availability of early (100-110 days) maturing hybrids with acceptable grain quality. Ratooning hybrid sorghum (CSH 5) was followed in Jalgaon district of Maharashtra.

3.2.6. Early maturing hybrids and yield stability

Any crop improvement strategy for rainfed lands should provide for assured yields even when unfavorable conditions are encountered. The yields of hybrids were significantly better against near total failure of late locals in widespread drought year like 1972. Such situations were frequently observed in many areas with below normal rainfall. Sorghum hybrids had good coverage in major sorghum-growing states like Maharashtra and Karnataka. CSH 5 reflected a marked increase in yields over CSH 1, but was of a slightly longer duration (110 days). This hybrid was preferred in assured rainfall areas due to higher yield potential and less infestation by grain molds. CSH 1 and CSH 6 (95-100 days maturity) continued to be preferred in low rainfall and risky situations (Rao 1971).

3.2.7. Improvement through exotic x Indian crosses

Subsequent efforts to breed new male sterile line from exotic (American IS 3922) x Indian (Karad local from Maharashtra) crosses led to the development of 296 A, which marked a major breakthrough in the development of seed parents which yielded highly heterotic hybrids. The hybrid CSH 9 (296 A x CS 3541) was released during 1983, reflecting another yield advancement over CSH 5. This hybrid became very popular and remained widely cultivated over longer periods. Virtually many public and private sector hybrids have 296 A and CS 3541 or their variants in some form in their pedigree (Rao 2006). The hybrids CSH 10 (296 A x SB 1085) and CSH 11 (296 A x MR 750) showed marginal superiority in grain yield. During the 1990s, most of the hybrids tested in All-India trials were based on MS 296 A with various restorers. The fodder yield of CSH 13 was significantly increased (40%) over existing hybrids. Early maturing hybrid CSH 14 (AKMS 14 A x AKR 150) developed from Akola involved new parents and almost replaced CSH 1 and CSH 6.

3.2.8. Genetic diversification of seed parents

The need for diversification of female parents was felt in view of seed production problems (temperature sensitive 296 A) and stagnating yield levels. With continued efforts to pyramid genes for productivity, grain quality and resistance to biotic and abiotic stresses, new parental lines were developed. Another high-yielding hybrid CSH 16 (27 A x C 43) released in 1997 showed further improvement in grain yield and mold tolerance. The seed parent is developed from multiple crosses involving IS 3687, IS 3922 and 2219 B. This new male sterile (27 A/B) line has long panicle with round grains. The male parent C 43 was an improved version with added genes for grain mold tolerance from Ethiopian line IS 23549.

Subsequent studies revealed the need to diversify the genetic base of both male (R) and female (A/B) parents. Hybrids CSH 17 (AKMS 14 A x RS 673) and CSH 18 (IM 9 A x Indore 12) were diversified for early maturity and higher fodder yield. The recently released hybrid CSH 25 (PMS 28 A x C 43) is based on a new male sterile line with diverse genetic base.

3.2.9. Breeding of varieties

With efforts on hybrid improvement program in full swing, the varietal improvement programs were also able to develop high-yielding varieties from AICSIP (CSV 1 to CSV 20). Many cultivars (51) were also released in various states. Some of these varieties are dual purpose types.
By and large, varieties encountered less acceptability among farmers. More preference was observed to dual-purpose varieties such as CSV 10, CSV 13, SPV 462 and CSV 15 in some restricted pockets. A major advantage of varieties over hybrids was their relatively better grain quality and multiple resistance or tolerance against major pests and diseases. The dual-purpose varieties CSV 15, CSV 20 and CSV 23 could establish higher grain and fodder yield potential than the hybrids released earlier. The high-yielding varieties also served as sources of R-parents in hybrid breeding. CSV 4 (CS 3541) was used as restorer of the three most popular hybrids, CSH 5, CSH 6 and CSH 9. Another variety which became popular, SPV 462 (from Coimbatore), was developed from multiple cross involving IS 2947, IS 3687 (both from USA), IS 1151 (Maharashtra) and BP 53 (Gujarat). Grain mold tolerant and hybrid plant type variety PVK 801 (Parbhani Sweta) is popular in Maharashtra. Some of the important state-level releases include GJ40, 41 (Gujarat), DSV 4, 5 (Karnataka), PSH 1, NTJ 3 (Andhra Pradesh), JJ 1041 (Madhya Pradesh), PVK 400, PVK 801 and Mahabeej 7 (Maharashtra).

3.2.10. Problems of rainy season sorghum

The economic advantage of the rainy season productivity increase was largely nullified most of the time by grain mold incidence. The reduced duration of the cultivars led to high vulnerability to grain mold during the rainy season. Building reasonable resistance against grain mold is difficult. These biological limitations seriously restrict the economic advantage of their high yield. The government policies on production, pricing, procurement and distribution of cereals have favored fine cereals and placed coarse grains such as sorghum at a disadvantage. The administered pricing of oil seeds, pulses and fiber crops also added an advantage to these crops over sorghum under rainfed conditions. With the advent of irrigation, some parts of rainy season sorghum area shifted farming to commercial crops. These factors caused limitations that seriously affected the profitability from the crop and its competitiveness over other dryland crops (Dayakar Rao et al. 2006).

3.2.11. Postrainy season sorghum improvement

Improvement of postrainy season sorghum did not receive as much emphasis and effort as the rainy season sorghum until the 1990s. Six hybrids and five varieties were hitherto centrally released for the postrainy season. In postrainy season sorghum, the fodder yield given is even more important than that in rainy season sorghum. From this point of view, a progressive success was achieved from the first postrainy season hybrid CSH 7R to the latest hybrid CSH 19R. Unlike the rainy season cultivars, higher levels of resistance against major pest (shoot fly) and disease (charcoal rot), stringent maturity duration to suit different receding soil moisture regimes and certain levels of thermo-insensitivity are essential in postrainy season cultivars for better adaptability. Grain quality is also as important as the grain yield. The quality benchmark is that of the popular landrace, Maldandi (M 35-1). In adaptability criteria such as shoot fly resistance (SFR) as well as the grain quality aspects, the varieties are superior to hybrids. The three postrainy season varieties released – CSV 8R, CSV 14R, CSV 18 (Parbhani Jyoti) and Swathi– were better received than the postrainy season hybrids such as CSH 7R and CSH 8R. The recently developed hybrids CSH 15R and CSH 19R are more productive, but their acceptability among farmers is not high as they do not want to invest in hybrid seeds during the postrainy season (dry season) without irrigation. Unlike the rainy season sorghum, biological and environment limitations posed hurdles in postrainy season sorghum productivity. Limitations in the maneuverability of postrainy season adapted genetic variability to gain yield heterosis, and high vulnerability of non-postrainy season adapted variability to biotic stresses are causing hurdles in the progress of postrainy season sorghum productivity. Some of the newly developed varieties could gain acceptability in certain deep soil pockets with assured soil moisture. (Tonapi et al. 2011).

3.2.12. Postrainy season sorghum improvement in Maharashtra

Postrainy season sorghum varieties are developed and released by the AICSIP centers. Among them varieties like Parbhani Moti (SPV 1411) and Parbhani Jyoti (CSV 18), Phule Vasudha, Phule Chitra, Phule Anuradha, Phule Revati and PKV Kranti are becoming popular. Large quantity of seed is multiplied by the universities and Maharashtra State Seeds Corporation. These varieties are tested in AICSIP trials and generally give 20-25% higher grain and 15-20% higher fodder yield than locals/M35-1. Farmers have accepted these varieties and there is huge demand for the seed produced by the universities.

ICRISAT, DSR, MPKV and MAU are working together under the BMGF-funded HOPE Dryland Cereals Project in Maharashtra with the focus on enhancing postrainy season sorghum productivity in farmers' fields. Hence, viable management methods to narrow the existing gap between the production potential of local and improved cultivars and their farm yield could become a short-term approach to increase postrainy season productivity. It appears that postrainy season sorghum may continue to enjoy increasing demand for its food and fodder. Thus, its area, particularly in Maharashtra and Northern Karnataka, may not decline substantially and will possibly stabilize between 4.5 and 5.0 million ha.

We have not fully succeeded in developing high-yielding postrainy season sorghum cultivars which could replace the low-yielding landraces. Unlike the rainy season sorghum which has wide variability and good heterotic expression and allows maneuverability in production management, postrainy season sorghum has narrow genetic variability, low heterotic expression and suffers environment-imposed harsh limitations under heterogenic production regimes. This disadvantage of postrainy season sorghum, as well as a consideration that a major breakthrough in sorghum production could be achieved through productivity improvement of rainy season sorghum which had occupied two-thirds of sorghum area at one time, relegated postrainy season sorghum improvement to a low priority (Tonapi et al. 2011).

Both high grain and fodder yield under receding moisture situation are essential requirements. The resistance to shoot fly, charcoal rot, drought and cold are important for adaptation in the postrainy season. Bold, round and lustrous grain and higher flour recovery add to consumer acceptability. Research on postrainy season sorghum to enhance productivity requires gene pools, breeding lines and parental lines with different adaptation niches from those of rainy season sorghum, higher dependence on the postrainy season adapted genetic variability, specific emphasis on grain quality and fodder yield, and development of high-yielding cultivars with maturity duration suited to different growing conditions defined by soil depth, water retention capability and nutrient use efficiency. Situation specific crop production management techniques may facilitate yield optimization under varied nutrient use soil moisture regimes. Possible development of genetically engineered cultivars with resistance to shoot fly may offer opportunity to advance postrainy season planting and avoid problems associated with terminal moisture stress and low temperature. Due to lack of a complete database on several aspects of postrainy season sorghum such as its genetic variability, limits to dry matter production and partitioning, yield components and those which are easily maneuverable for achieving quick yield improvement, gene pools effecting higher levels of heterotic expression, breeding behavior for grain quality, biotic and abiotic stresses, control and correction of low temperature induced seed set and production problems, nutrient-use efficiency among genotypes and under variable receding soil moisture regimes. The progress in postrainy season sorghum improvement is low, therefore it is important that a database is generated to strengthen the postrainy season sorghum research strategy. The immediate option, however, is improvement of postrainy season sorghum productivity with the available scientific understanding on breeding and production management. Due to high demand for postrainy season grain for food use and better profitability to the producer, this research demands high priority, additional manpower in relevant disciplines and expanded infrastructure commensurate with the task and time frame.

3.2.13. Forage and fodder sorghum

Introduction of multi-cut sorghum hybrids, and single-cut and dual-purpose sorghums which can be grown for quality green forage production in most of the states of India, is helping to sustain livestock security. The multi-cut variety, SSG 59-3 (Meethi Sudan) with a potential of four cuts, became popular due to its high green foliage, yield potential, regeneration and excellent forage attributes. Recently, the multi-cut hybrids CSH 20MF and CSH 24MF have been released by AICSIP. They are more tolerant to leaf diseases besides having higher productivity and dry matter digestibility (DMD). The forage varieties, CSV 21F, Pant Chari 5, Pusa Chari 9, and Haryana Chari 6 are the popular single-cut forage sorghums with resistance to lodging and leaf diseases. These varieties also exhibited higher per-day productivity and improved DMD, and total soluble sugars (TSS) with comparable stalk crude protein content. A few other varieties released at the state level also provided the base for varietal transformation in forage sorghum. Still, the private sector is dominating and marketing notified hybrids MFSH 3 and Harasona as they target relatively rich farmers and dairies in Western India. Nevertheless, there is a ready and growing market for high-yielding multi-cut forage sorghum hybrids to support the growing dairy business.

The project has developed dual-purpose lines with brown midrib (bmr lines) which have higher digestibility. It is estimated that a 1% increase in digestibility increases milk yield by 5%, resulting in higher income for farmers. Furthermore, DSR is aiming at developing both female and male parents with brown midrib (brown midrib gene is recessive) so as to develop hybrids with high stover digestibility. Most forage and sweet sorghum hybrids are developed using female parents of grain sorghum. Selecting grain MS lines with same maturity and slightly shorter height as that of Sudan grass pollinator is essential for good seed production. The high-yielding grain MS lines with sweetness in stock and having staygreen traits, crossed with Sudan grass pollinator will give ideal forage hybrid with high stover digestibility. Utilization of unexploited germplasm, especially Sudan grass having succulent stems, low HCN content and good tillering and regeneration habit, is essential to diversify the genetic base of the hybrids. (Tonapi et al. 2011).

There is enormous demand for dry fodder, particularly during lean winter and summer seasons in the arid and semi-arid regions. Fodder (stover) demand is additionally linked to demand for milk and milk production. Sorghum fodder is the main roughage in the semi-arid regions of Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat and Rajasthan and the Bundelkhand region of Uttar Pradesh. It is estimated that sorghum fodder constitutes 20-45% of the total dry weight of feed of dairy animals during normal seasons and up to 60% during the lean summer and winter seasons. With increase in milk demand, the production demand for dry fodder is expected to rise. There is already an emphasis on the fodder component of the yield in parts of Tamil Nadu, Karnataka, Andhra Pradesh, Rajasthan, Gujarat and Uttar Pradesh. The extent of the trade off between grain yield and fodder yield acceptable in a cultivar varies among different regions. This situation, however, did not receive adequate attention in the national sorghum improvement program till recently. Earlier, rainy season high-yielding varieties (HYVs) yielded 80% more grain and 30% lesser fodder than the local cultivars. More favorable environment increases the percentage share of grain over fodder, while the reverse is the case under less favorable environments. The inability of HYVs to give high fodder yield under less favorable production systems is one of the reasons for their low adoption in such areas. However the recently released dual purpose types in rainy season (CSV 15, CSV 20 and CSV 23) and the improved postrainy season cultivars at national and state levels will aid in meeting the dry stover demand in India to usher in fodder security.

With the release of CSH 1, the first commercial hybrid in 1964, sorghum became the second crop after maize to develop high-yielding hybrids using the cytoplasmic-genetic male sterility system. Since CSH 1, 26 more hybrids were added to the Center-released list. A few more hybrids adapted to specific regions were released at state levels. Hybrids CSH 1 to CSH 26 are a testament to the success of Indian sorghum breeding not only in terms of yield enhancement, but also in terms of diversification of parental lines and progressive advances in the incorporation of acceptable levels of resistance against major pests and diseases. The hybrids played a major role in pushing up productivity and production, particularly in the rainy season sorghum. Among the rainy season hybrids, the role played and being played by CSH 1, CSH 5, CSH 6, CSH 9, CSH 14 and CSH 16 needs special mention. While CSH 5 and CSH 6 had a yield potential of 3400 kg ha^{-1}, this potential was raised to 4000 kg ha^{-1} in CSH 9. It is now further advanced to more than 4100 kg ha^{-1} in CSH 16, CSH 23 and CSH 25 hybrids with distinctly superior quality grain and fodder yield.

3.2.14. Hybrid seed production

Seed, the vehicle for delivering the benefits of technology, is the most important basic input, influencing the growth and sustainability in agriculture. Availability of good quality seed at the right time, the right place and the right price plays a major role in enhancing adoption rates. The organized Indian seed industry has contributed significantly to ensure continued access to hybrid seed by Indian farmers (Ramakrishna et al. 2006). India is served by both formal and informal seed systems. The informal sector has to concentrate on OPVs. Informal seed supply systems broadly include farm-saved seed and farmer-to-farmer exchange, farmer cooperatives, community groups, seed growers associations and non-governmental organizations. More than 80% of the postrainy season sorghum in India is planted from the seed stocks selected and saved by the farmers. Trainings and extension work related to scientific techniques to save the seed for self use at farmer’s level are very crucial. The trainings to both men and women farmers regarding selection of ‘on-type’ of plants, factors affecting genetic contamination, postharvest technology, seed treatment and storage are essential. Monitoring of informal seed systems by the research organizations through extension workers is most important for the seed security of the improved varieties at the household and community levels. These informal seed systems are strengthened by promoting the seed village concept through farmers’ associations and self help groups (SHGs).

The advent of hybrid sorghums gave birth to an organized hybrid seed industry in the public (NSC, SSC) and private sectors. The formal system is interested in profit-making cultivars (hybrids). This industry played a significant role in stabilizing hybrid seed production in nontraditional postrainy sorghum-growing areas of Andhra Pradesh and Karnataka. The public and private sector seed companies have standardized the hybrid seed production technology. Public sector research organizations have provided information regarding isolation distance, planting ratio of seed (A) to pollen parent (B/R) row ratio (6:2, 4:2), rouging of off-types, synchronization of hybrid parents for flowering and plant height, stigma receptivity and pollen viability, postharvest technology, storage, transport and marketing. Private seed companies have played a key role in seed production and marketing of hybrid seed.

3.2.15. Breeding of hybrids in the private sector

Several high-yielding hybrids developed by private seed companies were also released through the AICSIP testing system. Some of them include JKSH 22, JKSH 528, PAC 54003, SVSH 99, MLSH 151, MLSH 64, GK 4009, GK 4013, G 4245, Mahabeej 177, Kaveri 388, VJH 545, VJH 550, Shrihari 555, POC 404 and POC 406. Truthful seed of hybrids, released or evaluated in their testing system, are produced and marketed in India by the private seed companies (Rao 2006).

3.2.16. Role of ICRISAT

ICRISAT in partnership with Indian NARS (both public and private sectors) worked on various R&D projects. Indian breeders took advantage of germplasm and breeding products and this partnership resulted in the release of 22 improved cultivars in India (Reddy et al. 2007). These included CSV 11, CSV 13, CSH 11, SPH 840, Parbhani Moti (SPV 1411), PVK 801 (SPV 1333), NTJ 2, and DSV 3. The seed parent of recently released hybrid CSH 25 has been developed at AICSIP Parbhani center from the breeding material selected from the ICRISAT nursery.

Development of partnership cultivars (54 hybrids) by private seed companies by using ICRISAT bred lines had more than 50% coverage in the total area planted under hybrids in the country. For instance, hybrids like JKSH 22, VJH 540, MLSH 296, GK 4009 and GK 4013 are widely adopted in India. The formal partnership research projects and several joint scientific publications are well known in the scientific community.

3.2.17. New biotechnology tools

The new tool of science – marker assisted selection – is used for resistance to shoot fly, *Striga* and drought (staygreen) both in Indian NARS and ICRISAT. Genetic engineering to transfer Bt genes to control stem borer is also under way in these programs.

Several mapping studies involving two resistance sources (IS 18551 and IS 2122) for shoot fly revealed two major quantitative trait loci (QTL) for resistance traits like glossiness (on SBI-05 and SBI-10) and trichome density (both on SBI-10). These QTL are being extensively deployed under the DBT network project using marker-assisted introgression at DSR, ICRISAT and MAU and the material is at advanced stages of field evaluation and validation. Farmer-consumer preference for a bold, globular, shiny and pearly grain requires special biotechnological and breeding efforts. A similar approach is also required for enhancing micronutrient (Fe, Zn and Vitamin A) concentration in sorghum (Ashok Kumar et al. 2013). This approach is warranted since malnutrition is prevalent in sorghum consumers in India. Similarly, breeding efforts are needed to improve fodder quality with high biomass in sorghum (Tonapi et al. 2011).

3.2.18. Alternative uses of sorghum

Sorghum, by virtue of its C4 photosynthetic system and rapid dry matter accumulation, is an excellent bio-energy crop. Ethanol is a clean burning fuel with high octane rating and it can be blended easily with petrol to the extent of 15-20%. Demand for renewable energy sources and bio-fuel which would minimize pollution are expected to rise rapidly in the coming years. Juice from sweet sorghum stalks can be competitive raw material for molasses for producing ethanol. Diversification and value addition of rainy season sorghum as a bio-energy crop has vast potential and great economic relevance in the context of the huge annual national burden on import of fossil fuel. This can also be profitable as a rainfed crop in rainy season and irrigated in summer season. Cultivars like SSV 84, RSSV 8, CSV 19SS and CSH 22SS are the released sweet-stalked cultivars. Varieties like ICSV 93046 and ICSV 25274 developed by ICRISAT are also quite promising. There are a few private hybrids in the market such as Madhura, JK Ricova, PAC 52053 and Sugargraze. Efforts are on for development of sweet stalked sorghums for various specific end-uses such as production of alcohol, ethanol, and syrup. Research institutes like DSR, Hyderabad, AICSIP centers from Maharashtra (Rahuri, Parbhani and Akola) and ICRISAT are actively involved in the R & D activities related to this subject (Rao 2006).

The major thrust is to create demand for rainy season grain for the nonfood sector, particularly for feed, bio-fuel, starch and beverage industries. Molded rainy season grain, which fetches lower market value, is a cheap raw material for production of potable or industrial alcohol. Sorghum is the second-best grain after barley for malting. Sorghum grain is also useful for production of starch, glucose and liquid glucose. Sorghum is a cheap source of energy, protein, iron and zinc in the dominant production areas. Current research is discovering many new potential health benefits from sorghum, such as high antioxidant levels, improved cholesterol profiles of the consumer, and as a source of safe food for persons with celiac disease. Sorghum grain has high fibre content, moderate digestibility and rich mineral content compared to other cereals like rice and wheat. Therefore, sorghum foods are recommended for diabetic and jaundice-affected persons and for fighting obesity. Targeting micronutrient-dense sorghum cultivars would help to recover from 'hidden hunger' caused by micronutrient malnutrition. Though sorghum is nutritionally superior, its consumption has been decreasing due to nonavailability of processed clean grain in market. To increase sorghum consumption among the urban population, development of processing technologies is a prerequisite. Sorghum is becoming popular as a part of multigrain *atta*, snacks and sweets. Food uses such as flakes, vermicelli, pasta and biscuits are also becoming popular.

The emerging role of rainy season grain as feed in the domestic and international circuits is a viable and harnessable opportunity. The genetic potential of this crop to provide cultivars with good malting quality, competitive starch production and good source of beta glucan may also receive recognition. There is hardly any other single dryland cereal crop which has all such potential. Industrial linkages for expansion, marketing and commercialization by brand promotion of sorghum products will secure a stable and profitable market for sorghum.

The DSR, Hyderabad and 18 centers of AICSIP located in SAUs are instrumental in developing high-yielding cultivars and cultivation technology in the country. The popularity of nationally released sorghum hybrids (CSH 1 to CSH 26) and varieties (CSV 1 to CSV 23) are a testament to the success of the Indian sorghum program not only in terms of yield enhancement, but also in terms of diversification of parental lines and progressive advances in the incorporation of resistance against major pests and diseases (Tonapi et al. 2011). Regional level releases of cultivars and standardization of cultivation technology helped foster spectacular R & D in India.

3.3 ICRISAT strategies

ICRISAT has been involved in sorghum crop improvement through pre-breeding as well as breeding research strategies since the early 1970s[2]. The details of the strategies are elaborated below:

[2] See also Bantilan et al. (2004) and BVS Reddy et al. (2008) for more details

a. Pre-breeding research: Collection, characterization and maintenance of landraces are essential for crop improvement, and ICRISAT has given high priority to this activity. ICRISAT made a major effort to collect and conserve representative sorghum germplasm from the areas of origin as well as areas of cultivation. ICRISAT has been playing a catalytic role in maintaining and distribution of sorghum core germplasm as well as development of parental lines/cultivars in Asia (especially in India) and Sub-Saharan Africa (SSA) during the last three and half decades. The ICRISAT Gene Bank now serves as a major repository of sorghum germplasm in the world. As of May 2012, a total of 37,949 sorghum germplasm accessions from 91 countries have been conserved at ICRISAT. The existing collections represent about 80% of the variability present in the crop. Despite such large collections, there has been very limited use of germplasm in crop improvement programs due to lack of information about the usefulness of these collections preserved in gene banks. To further enhance the use of germplasm effectively in crop improvement, the concept of core collection (10% of entire collection) of 2247 accessions and mini core collection which includes 242 accessions (10% accessions of core or 1% of entire collection) was developed. The collected germplasm is conserved as an active collection under medium-term storage conditions (4°C and 20% RH) and base collection at -20°C for long-term storage. The collected germplasm samples are characterized for morphoagronomic characteristics, evaluated and finally documented for future references (Upadhyaya et al. 2006a). More than half of this collection is from five countries: India, Ethiopia, Sudan, Cameroon and Yemen. A total of 32 varieties (details in Appendix 3) have been directly released from the distributed sorghum germplasm in 17 countries of Asia, Africa and Latin America (Gopal Reddy et al. 2006).

b. Sorghum breeding Research: ICRISAT has been involved in genetic enhancement of sorghum since its inception in 1972. The research strategy of ICRISAT is founded on four Global Research themes: Crop improvement, Biotechnology, Agro-general ecosystems and Markets, policies and impacts. The identification of geographic functional regions with a set of constraints has resulted in a gradual shift in breeding strategy from initial wide adaptability to specific adaptations, and to trait-based breeding for threshold traits through the 1980s and 1990s. Wide adaptability approach was abandoned by the early 1980s, and three research centers with regional hubs were established in Africa and one in Central America to take up breeding for region/production system-specific adaptations. However, its fundamental approach has been to develop various breeding materials, varieties, hybrid parents(A/B/R lines), segregating populations, lines and improved sources of diseases and insect resistance to strengthen the breeding programs of the NARS and private seed sector. External environment perceptions of the donors, the NARS capacity, changing crop requirement and opportunities and the ICRISAT research administration structures are some of the most important factors that have influenced some changes in sorghum breeding concepts, objectives and research approaches in the last 35 years. These changes could be perceived at six different phases of ICRISAT's research (BVS Reddy et al. 2008). They are:

Phase-I: Breeding for wide adaptability and higher grain yield (1972-75)
Phase-II: Breeding for wide adaptability and screening techniques (1976-79)
Phase-III: Regional adaptation and resistance breeding (1980-84)
Phase-IV: Specific adaptation and resistance breeding (1985-89)

Phase-V: Trait based breeding and sustainable productivity (1990-1994)
Phase-VI: Intermediate products and upstream research (1995 onward)

In the initial years after ICRISAT was established, the major emphasis was on developing improved population and composites, and OPVs of sorghum. However, with the rapid development of the hybrid seed industry in Asia and the comparatively higher yields (25-30% more than OPVs) and better adaptation to diverse climatic areas, ICRISAT-India (and to some extent ICRISAT programs in Sub-Saharan Africa) re-oriented the sorghum improvement programs to breed hybrids. Since 1995, emphasis was laid on developing improved hybrid parents at ICRISAT-India for Asia, and finished products (varieties and hybrids) at other ICRISAT locations in Africa, through partnership research. In Asia, the breeding programs focused on developing improved breeding lines and parental lines of potential hybrids, and delegating the responsibility for development, testing and release of hybrids to the public institutions and private sector seed companies. During the sixth phase, the emphasis is particularly on producing parental lines and gene pools. In early 2000s, ICRISAT also started a new initiative by joining hands with private seed companies (Box 1).

Box 1: ICRISAT-Private Sector partnerships in sorghum improvement (2000-2010)

The Hybrid Parents Research Consortia (HPRC) is an initiative of ICRISAT that was formed in 2000 with the basic objective of increasing the scope of accessibility to better hybrids by poor farmers through effective public-private partnerships. The consortia were initially started with 9 members and grew to include 35 seed companies by 2010 in the case of sorghum. This has greatly contributed to the development and marketing of improved hybrids and varieties in Asia. In India, more than four million ha of rainy season sorghum (80% of the total rainy season sorghum area) and one million ha of the summer season sorghum are planted with about 70 private sector based hybrids, of which 54 are based on ICRISAT-derived parental lines or their derivatives. This illustrates the power of partnership between ICRISAT and the private sector to develop and deliver desired products to the farming community (BVS Reddy et al. 2007).

3.4 Private seed companies

Another key stakeholder for rapid development of sorghum in India was the private seed companies (around 35 in number) which were very active from the late 1980s onward. A major driver for the spurt in private sector growth was the strong public sector research support program on sorghum. International agricultural research centers such as ICRISAT exchanged breeding material with both public and private research institutions. National agricultural research centers such as ICAR and the agricultural universities provided breeder seed to the national and state seed corporations as well as the private seed companies to be multiplied as foundation seed and distributed through company outlets, farmer cooperatives, and private dealers. For private firms, their association with ICRISAT or ICAR and State Universities is thus invaluable, as these public institutions provide developed inbred lines free of cost. By 2009, private sector participation in total rainy season sorghum seed distribution in India was approximately 44%. Similarly, their share in the total supply of HYVs in sorghum was around 75%. Nearly four million ha of sorghum cropped area in the country was covered by private company hybrids (Pray and Nagarajan 2009 and 2012).

4. Current research focus/thrust in sorghum crop improvement

4.1 NARS focus

Over research efforts spanning four decades, DSR has developed and released 55 improved cultivars at the national level with traits of high yield, biotic and abiotic resistance, fodder types, sweet sorghum varieties etc. In continuation of the same spirit, recently DSR and AICSIP together took on new initiatives and challenges in sorghum crop improvement. Based on the decision of the 39th AICSIP Annual Group Meetings (AGMs) held at RVSKVV, Indore, 2009, a new scheme of national zonation research was developed and is currently under implementation for better targeting. The details of their characteristics and major centers/states covered under them are summarized in Table 6.

Table 6. Classification of the national zonation of sorghum research.

Characteristics	Zones	Purpose	Major states covered
Rainy season sorghum			
	Zone I	Mainly dual purpose	Coimbatore (TN), Kovalpatti (TN), Palem (AP)
	Zone II	Mainly hybrids	Dharwad (Kar.), Parbhani (Mah.), Akola (Mah.), Indore (MP), Surat (Guj.)
	Zone III	Forage/dual purpose	Udaipur (RJ), Deesa (Guj.), Hisar (HR), Pantnagar (UK), Meerut (UP), Mauranipur (UP)
Postrainy season sorghum	-	Grain type	Tandur (AP), Bijapur (Kar.), Rahuri (Mah.)
Sweet sorghum	-	High sugar hybrids	Rahuri, Parbhani, Akola, Coimbatore and Phaltan
Forage sorghum	-	Forage/dual purpose	North zone (mainly fodder purpose) South zone (mainly grain and dual purpose)

So far, hybrid breeding in Indian sorghum has been targeted towards the rainy season; improvement of postrainy season sorghum did not receive as much emphasis and effort as rainy season sorghum until the late 1990s. Conventional breeding until now has been unsuccessful in developing higher-yielding sorghum hybrids for the postrainy season. Consequently, more area of rainy sorghum is now planted to hybrids and grain yields are also much higher in rainy sorghum than postrainy. Most of the postrainy areas are still under local landraces with lower productivity. Other ongoing research initiatives are postrainy season sorghum yield enhancement, grain mold resistance in rainy season, low rainy season productivity under moisture-stress conditions, fodder improvement on postrainy season parental lines with greater resistance to shoot fly by use of marker-assisted selections, promotion of hybrids in rice fallow lands (especially in Andhra Pradesh), fodder sorghum development with single-and multi-cuts and finally more emphasis is for technology transfer to the farmer fields.

4.2 ICRISAT focus

Since the last four decades, ICRISAT and National Agricultural Research Systems (NARS) across the sorghum-growing areas have been working on sorghum genetic enhancement for traits of global and regional importance. These extensive research efforts resulted in impressive gains by improving productivity levels. However, biotic and abiotic challenges such as shoot fly, stem borer, grain molds, and terminal drought stress continue to haunt sorghum growers across the world.

So far, ICRISAT has developed more than 680 A/B-pairs and more than 880 R-lines which were trait specific for direct use as parents in hybrid development. Out of the total developed parental lines of 1560 (A/B and R-lines), only 1058 have been characterized till now in three sets (Reddy BVS et al. 2007 and 2006) (Table 7). Considerable progress has been made in developing techniques to screen for resistance to four insect pests, five diseases and drought. Considerable information has also been generated on the mechanisms and inheritance of resistance to insects such as shoot fly, stem borer, shoot bug, aphid, midge and head bug. A total of 244 sorghum cultivars have been released globally using the ICRISAT-bred sorghum materials, both by private and public sector organizations including NARS partners across the world. ICRISAT gene bank germplasm have been screened and utilized in development of high-yielding male-sterile lines (like CK 60, 172, 2219) and restorers (IS 84, IS 3691, IS 3541). They are valuable sources for incorporating shoot fly and stem borer resistance (IS 1082, IS 2205, IS 2312, IS 5604, IS 5470, IS 1054, IS 18432, IS 18417, IS 18425), midge resistance (DJ 6514, IS 3443), multiple disease resistance (IS 3547 and IS 14387), *Striga* resistance (IS 18331, IS 2221), drought tolerance (IS 12611 and IS 69628), high lysine content (IS 11167, IS 11758), stalk sweetness (IS 20963, IS 15428), forage quantity and quality (IS 1044, IS 1059) and salinity tolerance (IS 164, IS 19604) (Ashok Kumar et al. 2011).

Table 7. Parental lines developed and characterized by ICRISAT.				
Serial No.	Parental line type	Set -1	Set-II	Set-III
1	High-yielding (early-maturity) sorghum B-lines	20	20	0
2	High-yielding (medium-maturity) sorghum B-lines	53	50	0
3	Disease-resistant (early-maturity) sorghum B-lines	9	14	0
4	Disease-resistant (medium-maturity) sorghum B-lines	42	83	0
5	Disease-resistant (late-maturity) sorghum B-lines	22	24	0
6	Stress (*Striga*) tolerant (early-maturity) sorghum B-lines	0	9	0
7	Stress (*Striga*) tolerant (medium-maturity) sorghum B-lines	11	13	0
8	Acid soil tolerant (medium-maturity) sorghum B-lines	5	9	0
9	Tillering (early-maturity) sorghum B-line	0	1	0
10	Tillering (medium-maturity) sorghum B-lines	2	0	0
11	Staygreen (early-maturity) sorghum B-line	0	1	0
12	Staygreen (medium-maturity) sorghum B-lines	6	4	0
13	Nonmilo (medium-maturity) sorghum B-lines	42	32	0
14	Insect pest-resistant (early-maturity) sorghum B-lines	0	8	0
15	Insect pest-resistant (medium-maturity) sorghum B-lines	44	57	0
16	Insect pest-resistant (late-maturity) sorghum B-lines	13	9	0
17	High-yielding (early-maturity) sorghum R-lines	53	48	0
18	High-yielding (medium-maturity) sorghum R-lines	85	101	83
19	High-yielding (late-maturity) sorghum R-lines	18	22	45
	Total	425	505	128
	Grand total	1058		

In addition, the current research focus at ICRISAT also includes adaptation to the postrainy season, grain mold tolerance, terminal drought tolerance, increasing micronutrient contents (Fe and Zn) in grain, sweet sorghum for ethanol and animal feed. Genetic and cytoplasmic diversification of hybrid parents and varieties for key traits is critical for sustaining the productivity gains. The grain and stover quality requirements of different market segments need special attention in sorghum improvement research to enhance its market value. More emphasis has been given to *guinea* and *durra* races in recent years for exploitation and capturing the genetic variation. Efforts are under way to diversify hybrid parents for SFR and grain mold resistance by introgressing genes from new and diverse sources of resistant germplasm lines, *guinea* race in particular. Similarly, development of postrainy season adapted sweet sorghum parental lines is in progress (Ashok Kumar et al. 2011).

5. Development of sorghum improved cultivars in India

There was little research emphasis on sorghum in the pre-independence period. Even after independence, sorghum received minimal research attention until the creation and expansion of the All-India Coordinated Crop Improvement Projects (AICRPs). In the early 1960s, the ICAR, with assistance from the Rockefeller Foundation, initiated research on hybrid sorghum. Under ICAR directions the research institute AICSIP was formed in 1969 to look after the sorghum research activities at national level. These programs initiated public research and conducted multilocation testing for identification of improved sorghum hybrid and varieties with support from SAUs, ICRISAT and other research stations in India. The first sorghum hybrid, CSH 1 (Coordinated Sorghum Hybrid), was bred in India and officially released for commercial cultivation in 1964. The formation of ICRISAT in 1972 further stimulated substantial research on sorghum. A major driver for the spurt in private sector growth was the strong public sector research support program on sorghum. Similarly, ICRISAT also exchanged breeding material with both public and private research institutions. Later, the release of most popular hybrids (CSH 5 and CSH 6 in the mid 1970s and CSH 9 in the early 1980s) augmented the spread of sorghum hybrids and OPVs and boosted productivity. Hybrids CSH 1 to CSH 26 are a testament to the success of the Indian sorghum breeding, not only in terms of yield enhancement, but also in the diversification of parental lines and progressive advances in breeding resistance to major pests and diseases (NRCS 2007; BVS Reddy 2008; Bantilan et al. 2004; Ashok Kumar et al. 2001).

A summary of the released improved cultivars by different stakeholders between 1964 and 2011 shows that ICRISAT has released around 37 improved cultivars in India either by sharing germplasm or breeding materials with NARS and private seed companies during 1975-2011 (Table 8). Similarly, ICAR has also released 55 improved cultivars nationally for growing in major sorghum states in India between 1964 and 2011.

Table 8. Sorghum improved cultivars released by different stakeholders.

Released period	ICRISAT-NARS (1975-2011)	NARS releases (1964-2011)		
		ICAR*	Other notified varieties**	Total
1961-70	0	5	8	13
1971-80	1	13	35	48
1981-90	6	12	55	67
1991-00	16	13	58	71
2001-05	3	6	20	26
2006-11	11	6	26	32
Total	37	55	202	257

*Only national releases

** Includes state, SAU releases and parental lines

The major sorghum-growing states, including their respective SAUs, released around 202 state notified cultivars which have location specific importance during the same period. The other notified category includes the notified parental lines which were widely used in the development of sorghum hybrid cultivars in the country. Until now, approximately 46 notified parental lines have been characterized and documented, and 257 improved cultivars have been released and made available to farmers through NARS in India. The releases were at their peak during the late 1990s (71) followed by the late 1980s (67). In general, the number of releases in the last decade has declined (to 57) when compared to the previous two decades. Specifically, the state releases have come down during the last decade (2001-2011).

5.1 NARS releases

The detailed break-up of national and other notified releases between 1960 and 2011 are summarized in Figures 8 and 9 respectively (for more details see Annexure 1 and 2). As we can see from the figures, there is a clear contrast between national and other releases over a period. The national releases were dominated by hybrids whereas the other notified releases were dominated by varieties[3]. Similarly, the details of total notified cultivars across the same period are given in Figure 10. It is clear that until the 1990s, mostly varieties were released whereas the major thrust on hybrids started afterwards.

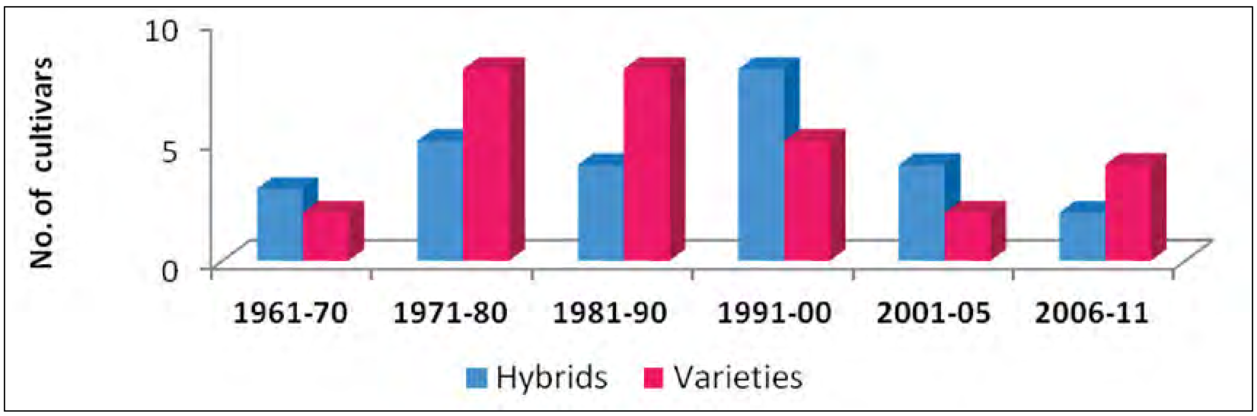

Figure 8. Pattern of sorghum national (ICAR) releases in India, 1964-2011.

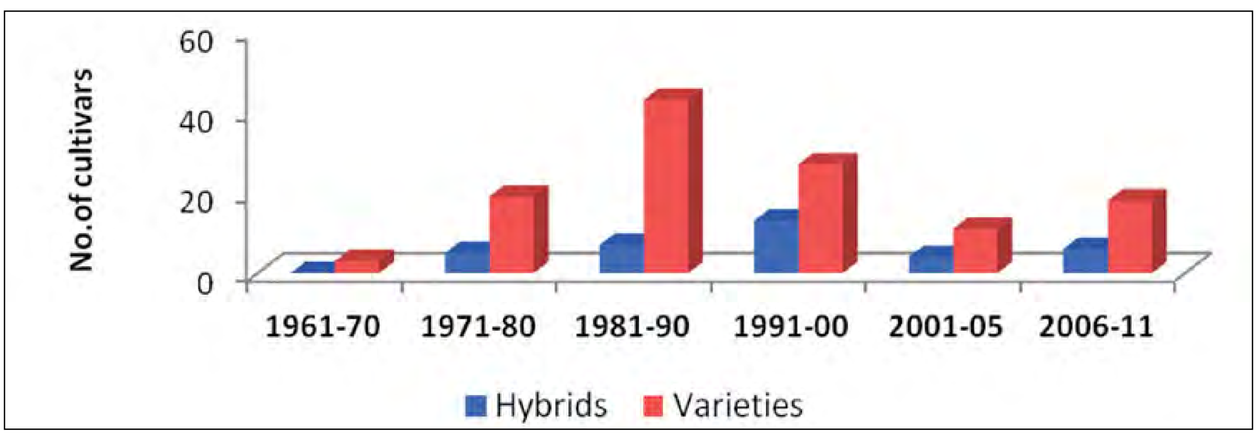

Figure 9. Pattern of sorghum state releases (including SAUs), 1964-2011.

[3] See also Tonapi et al. (2009) for further details

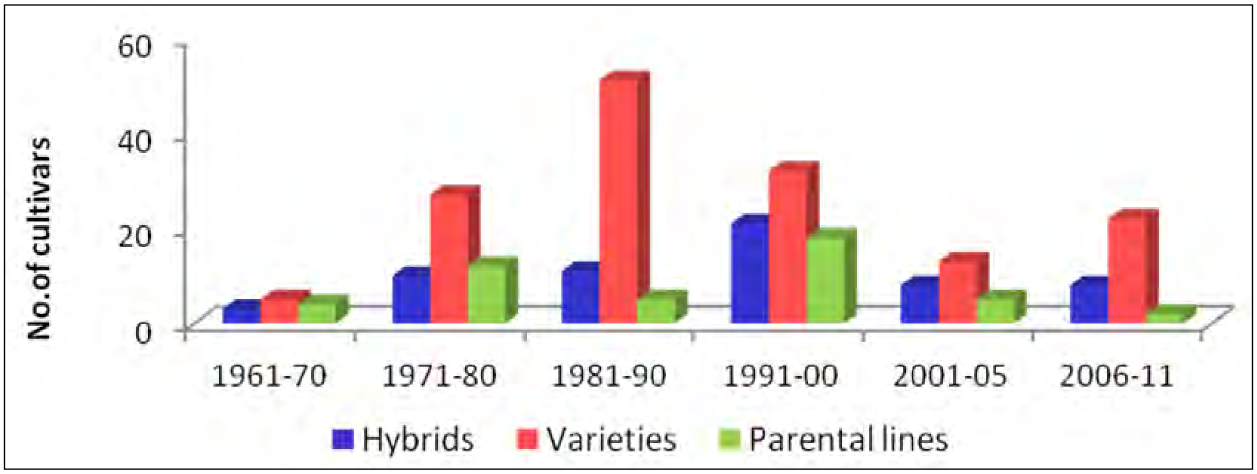

Figure 10. Sorghum improved cultivar releases by decade, 1964-2011.

The widespread research work on sorghum in the last 50 years resulted in development of a myriad of varieties, hybrids and parental lines in India. All the stakeholders (DSR, AICSIP, SAUs, ICRISAT and private seed companies) together notified around 257 as per available different sources of information from the Department of Agriculture and Cooperation and SAUs. Most of the private seed companies develop improved cultivars either based on ICRISAT parent material or public sector materials. But it is difficult to know the parentage of private hybrids due to confidentiality. However, most private seed companies that have released hybrids in India have close collaboration with ICRISAT under HPRC consortia.

5.2 Classification of cultivars by duration

The details of classification of total cultivars (around 211) based on duration are tabulated in Table 9. Nearly 50% of total improved cultivars were targeted on short duration (90-110 days) crop followed by medium (110-130 days) (43%) and long (130-150 days) duration (7%).

Table 9. 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
1961-70	1	1	1	0	0	0	1	1	0	0	1	1
1971-80	2	3	0	0	4	1	4	4	0	19	2	5
1981-90	1	3	0	5	2	0	3	5	0	14	22	1
1991-00	5	3	0	8	4	1	1	3	0	16	13	0
2001-10	4	2	0	5	3	2	3	4	0	15	10	2
Total	13	12	1	18	13	4	12	17	0	64	48	9

D-1: 90-110 days; D-2: 110-130 days; D-3: 130-150 days

Among the hybrid category, the major share goes to short duration followed by medium and large duration, in that order. The same pattern of distribution was also observed in OPVs. This trend clearly reveals that the farmers are showing preference toward short-duration cultivars rather than medium-and long-duration types.

5.3 ICRISAT-NARS releases in India

As a policy, ICRISAT does not release any improved cultivar directly in India or in any other country in the world. ICRISAT maintains close research collaborations with its NARS partners across countries and shares the breeding materials with them. The partners further improve them or put these materials in multilocation trials and release them as improved cultivars if they find these superior to check/local cultivars. Similarly, in India, ICRISAT has shared the germplasm or advanced breeding materials with NARS, SAUs and private seed companies since 1972. The details of sorghum seed sample types supplied from ICRISAT since 1997 are summarized in Table 10. Similarly, the details of seed sample beneficiaries and agencies are tabulated in Table 11.

Table 10. Type of sorghum seed sample supplied from ICRISAT.

Material	1997	2001	2005	2010
Varieties	433	621	1061	260
Hybrids	199	10	3	19
Male sterile lines	885	778	1263	12
A/B	0	0	0	794
Maintainer	901	827	1349	76
Restore	1469	334	1105	613
Drought resistance	0	3425	0	47
Population	2225	0	0	2
Pest resistance	3189	368	0	115
Disease resistance	2020	730	0	2
Striga resistance	643	0	0	0
Partially converted lines	5359	63	0	0
Early generation	1226	0	0	28
Sweet stalk sorghum	0	0	88	261
Forage sorghums	0	0	137	12
Other than above	31	807	148	0
IS numbers	56	28	48	0
Genetic stocks	0	410	0	1
High-yielding	0	413	0	0
Trial hybrids (SPSHD)	0	657	257	139
Acid tolerance lines	0	0	5	28
Salinity tolerance	0	0	123	21
RIL	0	0	0	9
Staygreen	0	0	25	0
PPB	0	0	36	0
BMR	0	0	0	2
BP	0	0	0	33
Bulk seed	0	0	0	0
Total	18636	9471	5648	2474

Source: ICRISAT sorghum crop improvement, 2012 personal communication

Table 11. Sorghum seed samples distributed to various agencies				
ICRISAT sister centers	1997	2001	2005	2010
ICRISAT out stations-Segregating	643	-	-	-
ICRISAT out stations-Nurseries	-	-	-	-
ICRISAT out stations-Trials	-	-	-	-
NARS (excluding India)	**-**	**-**	**-**	**-**
International public sector on request	2599	211	951	721
International public sector Nurseries	997	-	-	-
International public sector Trials	87	-	-	-
International state govt on request	-	389	-	-
International state-govt Nurseries	-	-	-	-
International state-govt Trials	-	-	-	-
India	**-**	**-**	**-**	**-**
Public-central Govt. on request	365	354	1708	138
Public-central Govt. Nurseries	-	4150	-	-
Public-central Govt. Trials	-	-	12	-
Public-state-Govt. on request	5072	542	654	513
public state Govt. Nurseries	-	256		-
Public state Govt. trials	-	-	289	-
Private seed companies on request	8901	2734	978	993
Private seed companies Nurseries	-	-	-	-
Private seed companies Trials	-	657	335	-
NGOs in India	-	-	-	4
Farmers	544	178	721	105
Total	19208	9471	5648	2474

Source: ICRISAT sorghum crop improvement, 2012 personal communication

ICRISAT initiated a Hybrid Parents Research Consortium (HPRC) with private seed companies as its members during 2000-01. The main aim of this consortium is quick generation of suitable parental lines and gene pools which would immediately fit in to the NARS as well as private seed company R & D. ICRISAT, in collaboration with NARS partners, released as many as 37 improved cultivars between 1975 and 2011. The details of ICRISAT-NARS releases in India are summarized in Table 12. Among the 37 improved cultivars, there are 12 varieties and 25 hybrids diversified for various traits and for their adaptation. The pattern of these releases is furnished in Figure 11. Apart from these Indian releases, ICRISAT also developed and released 207 cultivars globally for different regions (Fig. 12).

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

S. No.	ICRISAT Name	V/H	Release Name	Year of release	Salient features
1	IS 6928	V	Moti	1978	High-yielding postrainy season landrace - released for all India
2	ICSV 1	V	CSV 11	1984	High-yielding dual purpose variety - released in India
3	ICSH 153	H	CSH 11	1986	High-yielding dual purpose hybrid - released in India
4	ICSV 112	V	CSV 13	1987	High-yielding dual purpose variety - released in India
5	ICSV 145	V	SAR 1	1988	*Striga* resistant variety - released for southern states in India
6	ICSV 239	V	BSR 1	1989	Good grain variety, released in Tamil Nadu
7	E 1966 (IS 30468)	V	NTJ 2	1990	High-yielding postrainy season landrace - released in A.P.
8	Parent Source	H	CSH 14	1993	High-yielding hybrid released for all India
9	Parent Source	H	PJH 55	1993	Private sector hybrid popular with farmers
10	Parent Source	H	PJH 58	1993	Private sector hybrid popular with farmers
11	Parent Source	H	PKH 400	1993	Private sector hybrid popular with farmers
12	Parent Source	H	PSH 8340	1993	Private sector hybrid popular with farmers
13	ICSV 745	V	DSV 3	1993	Midge resistant variety released in Karnataka
14	ICSV 197	V	ICSV 197	1993	Midge resistant variety/source
15	Parent Source	H	MLSH 36	1994	Private sector hybrid popular with farmers
16	Parent Source	V	CSV 15	1994	Released variety by NRCS for all India
17	IS 15845	V	Paiyur 2	1996	TNAU released for general cultivation to replace CO 4 in Dharmapuri and Salem Dists
18	ICSA 91001 x ICSR 90017	H	ASH 1	1997	Dual purpose late hybrid released for A.P.
19	Parent Source	H	JKSH 22	1999	Private sector hybrid popular with farmers
20	ICSH 86686	H	PSH 1	1999	Dual purpose hybrid released for A.P.
21	PVK 400	V	PVK 400	1999	Grain mold resistant white grain variety released for Maharashtra
22	Parent Source	H	SPH 840	2000	White grain dual purpose hybrid - released stage

Table 12. continued

S. No.	ICRISAT Name	V/H	Release Name	Year of release	Salient features
23	GD 34553	V	PVK 801 (Parbhani Swetha)	2000	Grain mold resistant white grain variety released for Maharashtra
24	GD 31-4-2-3	V	Parbhani Moti (SPV 1411)	2002	Released variety by MAU, Parbhani for Maharashtra suitable for postrainy season in A.P., Karnataka
25	Parent Source	H	JK Jyothi	2003	
26	Parent Source	H	CSH 22/ NSSH 104	2005	Sweet sorghum hybrid released for India
27	Parent Source	H	Bayer 8320	2007	Rainy season hybrid for grain and fodder
28	Parent Source	H	Bayer 8340	2007	Rainy season hybrid for grain and fodder
29	Parent Source	H	Bayer 8562	2007	Rainy season hybrid for grain and fodder
30	Parent Source	H	Bayer 8568	2007	Rainy season hybrid for grain and fodder
31	Parent Source	H	Bayer 8712	2007	Postrainy season hybrid for grain and fodder similar to Maldandi
32	Parent Source	H	CSH 25 (Parbhani Sainath)	2007	Dual purpose sorghum hybrid released for all India
33	Parent Source	H	PAC 501	2007	Rainy season hybrid for grain and fodder
34	Parent Source	H	PAC 537	2007	Rainy season hybrid for grain and fodder
35	Parent Source	H	SPH 2ab	2007	Rainy season hybrid for grain and fodder
36	ICSA 467 (female parent) x Pant Chari 6)	H	CSH 24 MF	2009	-
37	ICSA 51 x TNS 30	H	CO 5	2011	-

Source: ICRISAT database 2012

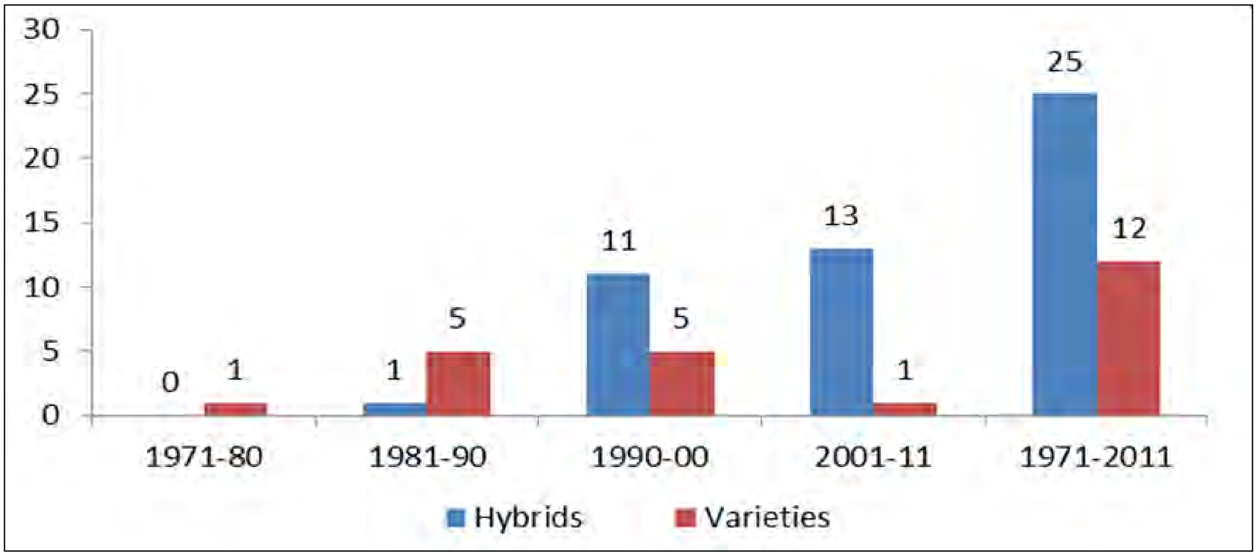

Figure 11. ICRISAT-NARS sorghum releases in India, 1975-2011.

Source: ICRISAT Dryland Cereal Program, 2012

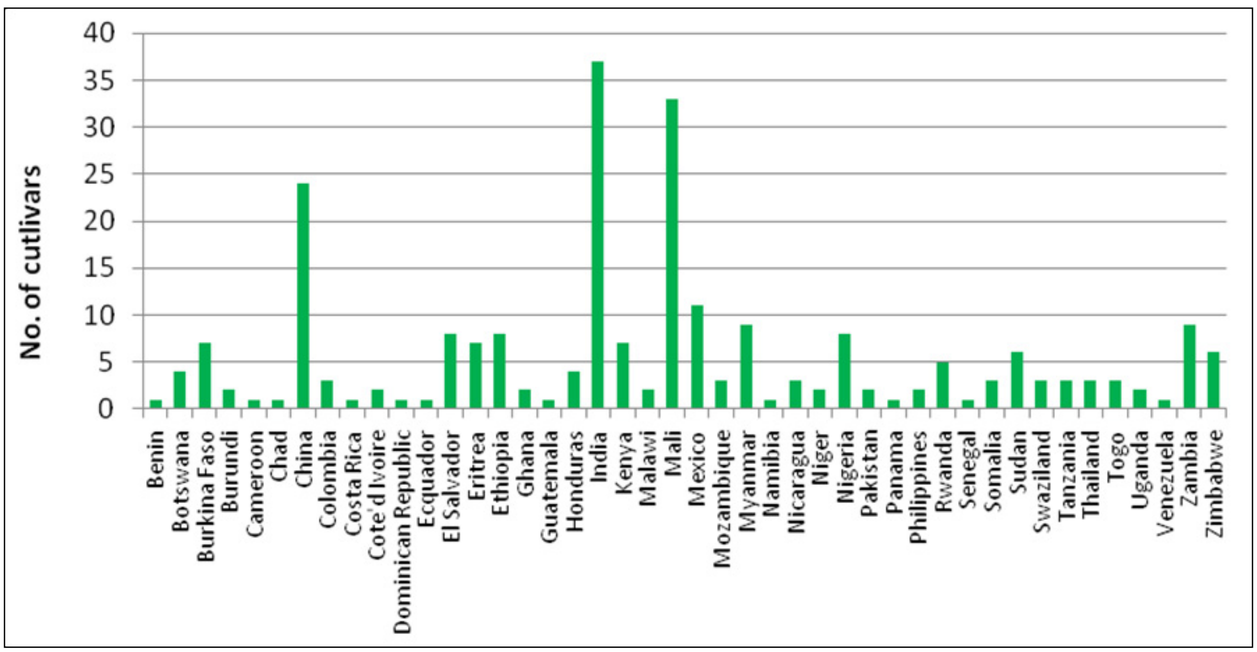

Figure 12. Sorghum cultivar releases by country, 1975-2011.

Source: ICRISAT database

The details of the total number of improved sorghum cultivars (varieties and hybrids) released by ICRISAT through supply of germplasm and breeding materials to NARS in different regions of world between 1975 and 2011 is summarized in Table 11. Altogether, 244 improved cultivars were released in 44 countries of Asia, Africa and America during this period. Almost 54.1% of these releases were concentrated in African countries followed by Asia (31.56%) and America (14.34%). The top three individual country beneficiaries from ICRISAT research and materials are India (37 cultivars), Mali (33) and China (24). The presence of ICRISAT headquarters in India and the existence of a strong NARS system to make use of breeding materials might have helped to gain relatively higher advantage. The releases were at their peak during the early 1990s across all the regions which contributed nearly a total of 54 improved cultivars. After that, the number of releases is decreasing in trend over time but the numbers of countries using ICRISAT materials and releasing improved cultivars is increasing.

Table 13. ICRISAT global releases of sorghum cultivars, 1975-2011.

Years	Africa	America	Asia	Total	India	Other Asia
1975-80	9	4	2	15	1	1
1981-85	5	7	10	22	1	9
1986-90	31	11	6	48	5	1
1991-95	28	9	17	54	9	8
1996-00	24	4	18	46	7	11
2001-05	21	0	10	31	3	7
2006-11	14	0	14	28	11	3
Total	132	35	77	244	37	40
% share	54.10	14.34	31.56	100	15.16	16.39

The detailed break-up (variety or hybrid) of the total releases across regions is summarized in Table 13. ICRISAT released 185 varieties and 59 hybrids during 1975-2011 among four regions. Within Africa, more releases took place in ESA (71) compared to WCA (61) during the same period. Around 65.95% of total varieties and 16.95 percent of total hybrids have been released in Africa alone. The American region also released more varieties than hybrids. In Asia, this trend was reversed in order i.e. 17.3% of total varieties and 76.27% of total hybrids (Table 14). NARS systems across the globe have evaluated hybrids/varieties developed in partnership with ICRISAT in their network or regional trials to select material for local specific/ adaptation. The pattern of their distribution has been summarized in Figure 13. The period 1985-2000 was most productive, with maximum number of releases in different sorghum-growing countries. During the last decade (2001-2010), the release pattern is relatively lower and is gaining momentum through different interventions.

Table 14. ICRISAT global releases by region and type.

Region	Varieties	Hybrids	Total
WCA	57	4	61
ESA	65	6	71
America	31	4	35
Asia	32	45	77
Total	185	59	244

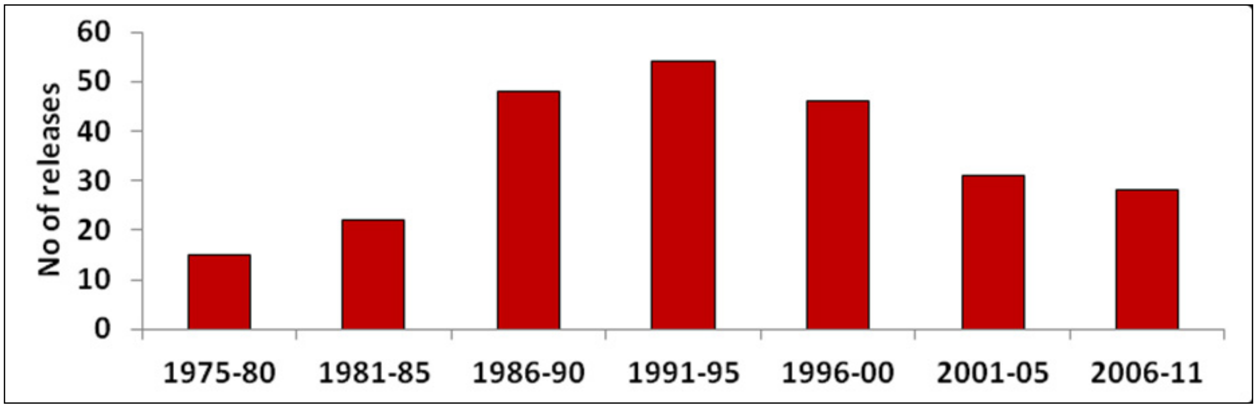

Figure 13. Pattern of ICRISAT sorghum releases globally.

Deb and Bantilan (2003) observed that countries with weak NARS, especially in Africa, benefited primarily from ICRISAT-developed varieties and through technology spillover. On the other hand, countries with strong NARS in Asia benefited largely from elite breeding materials developed by ICRISAT. However, another study conducted by Shiferaw et al. (2004) concluded that about 95 varieties have had spillover effects in different countries. Although ICRISAT's African programs have released a few hybrids (especially in Sudan, Botswana and Nigeria) their adoption is low mainly due to the nonavailability of sufficient seeds. Similarly, materials have also come from Africa to Asia, which were tested and released subsequently (e.g., PARC-SS-2 and NTJ2).

5.4 Variability in annual cultivar releases

Table 15 summarizes the variability in annual varietal releases by different stakeholders in India between 1964 and 2011. The highest coefficient of variation (CV) was observed in ICRISAT, followed by ICAR and other notified releases. ICRISAT releases include the formal releases of national and state programs as well as private seed company varieties using ICRISAT materials. The mean annual release rate in ICRISAT was 1.09, but there were 15 years with zero releases between 1978 and 2011.

Table 15. Variability in annual cultivar releases of sorghum in India, 1964-2011.

Institutions	Mean annual release rate	Years with zero releases	Standard deviation of releases	Coefficient of variation
ICAR*	1.12	20	1.32	117.34
ICRISAT(1978-2011)	1.09	15	1.91	175.77
Other notified varieties **	4.12	8	3.95	95.71
Total India#	5.22	3	4.70	89.98

* Includes national hybrids and varieties
** Includes state and SAU releases and parental lines
# All formal releases including national and other notified varieties

In ICAR, the mean annual release rate was slightly higher at 1.12, and there were 20 years with zero releases between 1964 and 2011. Since the rate of other notified releases including SAU annual release rate is higher than ICAR and ICRISAT at 4.12, and the coefficient of variation was relatively low at 95.71 after we combined the total releases in India, the mean annual release rate surged to 5.22, years with zero releases slipped to 3 and the CV slightly declined to 89.98%.

5.5 De-notified sorghum cultivars in India

The details of sorghum de-notified improved cultivars are compiled and presented in Table 16. Information about 10 cultivars was officially available in the various Central Variety SubCommittee Reports published by the Seed Division of ICAR.

Table 16. Sorghum de-notified varieties in India, 1975-2010.

Hybrid/ variety	Release type	Notified date	De-notified Date
CSH 1	Central	4045/24.9.69; 786/2.2.76	29.04.76
Vidisha 60-1	State	786/02.02.76	30.08.91
K 6	State	19(E)/14.01.82	30.08.91
CSH 2	Central	4045/24.9.69	17.09.97
CSH 3	Central	566(E)/21.9.74	17.09.97
CO 22	State	540(E)/24.7.85	17.09.97
CO 23	State	19(E)/14.01.82	17.09.97
CO 24	State	19(E)/14.01.82	17.09.97
COH 3	State	615(E)/17.8.93	17.09.97
CO 21	State	540(E)/24.7.85	08.06.99

Source: Compiled from various Central Varietal SubCommittee Reports

6. NARS research strength and investment pattern in sorghum crop improvement

At ICRISAT, nine sorghum breeders located in Asia and Africa are involved in breeding. Twenty other scientists including agronomists, crop physiologists, genetic resource specialists, entomologists, pathologists and social scientists generate required information for effective use by the crop breeders. In India, another 25-30 sorghum scientists are working for sorghum improvement in the private sector. Unlike private sector scientists, the NARS scientists devote most of their time to sorghum crop improvement. The details of NARS staff involved in sorghum crop improvement in the Xth and XIth Five Year Plans are summarized in Table 17. Among the total 279 personnel, 219 are scientific and technical persons whereas the remaining 60 are support staff. Nearly 36% of the scientific staff works at DSR, Hyderabad while remaining 64% staff is with AICSIP centers. The full time equivalent (FTE) of staff specialized in sorghum crop improvement was 84.5 as in 2010-11 (Table 18). The remaining 19 people are devoted to other purposes such as teaching, guiding students, training programs, and extension by the scientific persons. The major chunk of FTEs is concentrated for sorghum breeding followed by crop management. In terms of their educational qualifications, around 78.72% of FTEs hold doctorates and 5.74% hold master's degrees (Table 19).

Table 17. Total NARS strength.						
	AICSIP		DSR		Total	
Category	X FY	XI FY	X FY	XI FY	X FY	XI FY#
Scientists	63	63	32	40	95	103
Technical	76	77	39	39	115	116
Others*	17	16	44	44	61	60
Total	156	156	115	123	271	279

* Number of other supporting staff as on 2010-11

Table 18. Full time equivalents of scientists on sorghum crop improvement (2010-11).				
	Actual staff #			
Discipline	DSR**	AICSIP	Total	FTE
Agronomist	3	10	13	10.7
Plant breeder	10	27	37	30.3
Entomologist	6	11	17	13.9
Pathologist	3	10	13	10.7
Physiologist	2	2	4	3.3
Genetic resources	2	0	2	1.6
Social scientist	4	0	4	3.3
Biochemistry	2	1	3	2.5
Postharvest/ food tech	0	1	1	0.8
Molecular biology	0	0	0	0
Seed technology	1	0	1	0.8
Soil science	0	0	0	0
Genetics /cytogenetic	3	0	3	2.5
Eco-botany	1	0	1	0.8
Computer applications	1	0	1	0.8
Biotechnology	2	1	3	2.5
Total	40	63	103	84.5

** includes CRS, Sholapur # Includes scientific staff only

Table 19. Full time equivalents of scientific staff by education, 2010-11.			
Institution	Ph.D.	M.Sc.	Total
AICSIP	46.74	4.92	51.7
DSR	31.98	0.82	32.8
Total NARS	78.72	5.74	84.5

Table 20 summarizes the expert elicitation with sorghum crop improvement scientists, especially with regard to their research focus in sorghum crop improvement. During personal interactions, we asked the scientists to give two priority research themes in sorghum crop improvement and their respective time allocations. The responses collected from 103 scientists (equivalent to 84.5 FTE) were analyzed and ranked. In case of Priority 1 most of the scientists gave highest responses for pests and disease management followed by breeding for higher yield and better grain quality and development of dual purpose hybrids. In case of Priority 2 breeding for higher yield, technology assessment and pests and disease management were the top three ranked research themes.

Table 20. Research focus of NARS scientists on sorghum crop improvement.

S.No	Research themes	Priority-1	Priority-2
1	Breeding for higher yield and better grain quality	17.2(2)	11.5 (1)
2	Pest and disease management	23.8 (1)	16.4 (3)
3	Dual purpose and fodder yield	10.7(3)	7.4(6)
4	Salinity tolerance	0.8	1.6
5	Drought tolerance	4.1	9.8 (4)
6	Conservation of germplasm	2.5	8.2 (5)
7	Technology assessment and refinement	9.8 (4)	12.3 (2)
8	Development of short duration varieties/hybrid	3.3	5.7
9	Sweet sorghum	4.9(6)	3.3
10	Agronomy crop management	4.9 (5)	5.7
11	INM	2.5	2.5
Total	Scientist FTEs	84.5	84.5

Note: Figures in parentheses indicate the rank in that priority

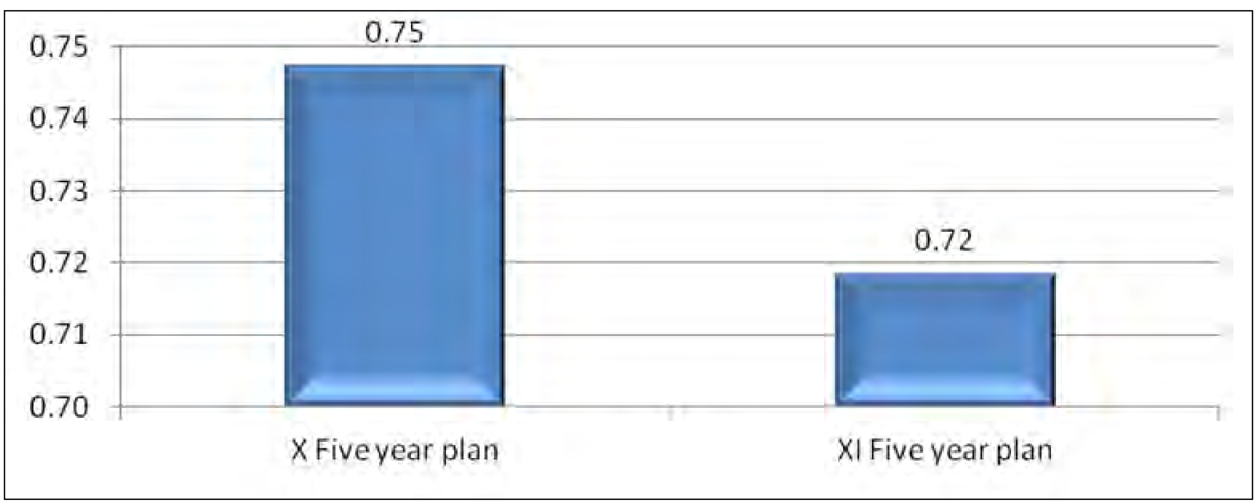

Figure 14. Sorghum crop production per scientist (100,000 t).

Figure 14 compares the mean sorghum production in the country per scientist between Xth and XIth Five Year Plan period. The sorghum production per crop improvement scientist has gone down from 75 to 72 thousand t between the two five year plans. This may be due to the sharp decline in crop area and production in the country.

Table 21 summarizes the NARS research allocations for sorghum crop improvement in the country during Xth and XIth Five Year Plans. The resource allocations were increased very sharply between the two plans, almost double of previous allocations. The available research expenditure per scientist working in sorghum crop improvement was calculated. The mean available research allocations per scientist was Rs. 4.144 million during the Xth Plan, which increased up to 8.41 million by XIth Five Year Plan. This clearly indicates that ICAR is presently giving more emphasis to sorghum crop improvement through high resource allocations.

Table 21. NARS research allocation during X^{th} and XI^{th} Five Year Plans (Rs in '00,000).

	DSR		AICSIP			
Year plan	Plan	Non -plan	Plan	Non -plan	Total NARS	Expenditure per scientist
2002-2007	729.58	1767.93	1439.68	Nil	3937.19	41.4
2007-2012	1772.70	3675.00	3212.68	Nil	8660.38	84.1

Source: DSR, Hyderabad

Table 22 furnishes information about annual research allocations to sorghum crop improvement during the XIth Plan. Over this period, the research allocations were in increasing trend. The research allocations per FTE scientist went up significantly between 2007 and 2008. After 2007-08, this share went up further and then decreased slightly during 2010-11. However, sorghum production in the country is decreasing in trend due to area decline. The research costs per ton of sorghum production in the country went up during the study period.

Table 22. Sorghum research expenditure over the last four years (Rs '00,000).

Year	DSR	AICSIP	Total	Allocation per scientist FTE*	Sorghum Production ('00,000 t)	Research cost per t (Rs)
2007-08	689.00	416.85	1105.85	13.8	79.0	14.0
2008-09	1103.10	755.29	1858.39	23.1	72.0	25.7
2009-10	1683.00	633.55	2316.55	28.8	69.8	33.2
2010-11	1374.00	659.89	2033.89	25.3	73.8	27.5

*Considered scientist FTE only.
Source: DSR Annual Report, 2010-11

Table 23 shows the state-wise breakup in research allocations during 2009-10 for sorghum crop improvement. Details of the state-wise actual and FTE staff working for sorghum crop improvement are summarized in the table. Among the total FTE of 84.5, nearly 17.5% scientific staff are working in Maharashtra alone, followed by 9% in Gujarat. More than 7% of the total research allocations are going to Maharashtra followed by 4.69% to Karnataka. The research allocation per each scientist FTE was the highest in Rajasthan, followed by Karnataka and Haryana. This may be because of the lower number of scientists and their respective FTEs in these states.

Table 23. Sorghum research expenditure by state, 2010-11 (Rs '00,000).						
	Actual			FTE of	Research expenditure	Research allocation
State	Technical	Scientific	Total	scientist	(2009-10)	per scientist FTE
Maharashtra	25	18	43	14.76	145.21	9.8
Andhra Pradesh	7	6	13	6.56	45.20	6.9
Madhya Pradesh	5	6	11	4.92	28.65	5.8
Tamil Nadu	6	5	11	4.10	50.05	12.2
Rajasthan	6	4	10	3.28	61.77	18.8
Haryana	2	3	5	2.46	30.61	12.4
Gujarat	3	9	12	7.38	65.46	8.9
Karnataka	12	8	20	6.56	95.30	14.5
Others states	11	4	15	1.64	137.64	83.9
DSR	39	40	79	32.80	1374.00	41.9
Total	116	103	219	84.50	2033.89	24.1

7. Tracking of improved cultivar adoption in India

Due to the high importance of sorghum, substantial amounts of money have been invested in crop improvement in the recent past by national and international research centers. International research institutes, in partnership with national research systems (both public and private), have made concerted efforts to develop improved sorghum hybrids parents and cultivars and increase the yields for the well-being of the producers and consumers of sorghum. This benefit of research can reach farmers only when released cultivars are adopted by the farmers. Based on the Department of Agriculture, GOI estimates, the area under improved cultivars is increasing over time (Fig 15). Based on 2007-08 crop estimates, the proportion of area under modern cultivars has reached almost 80%. Over the study period, the share steadily grew until 1999, after which a slight slump was observed between 1999 and 2003. However, from 2004 onward, it has again been in the increasing trend.

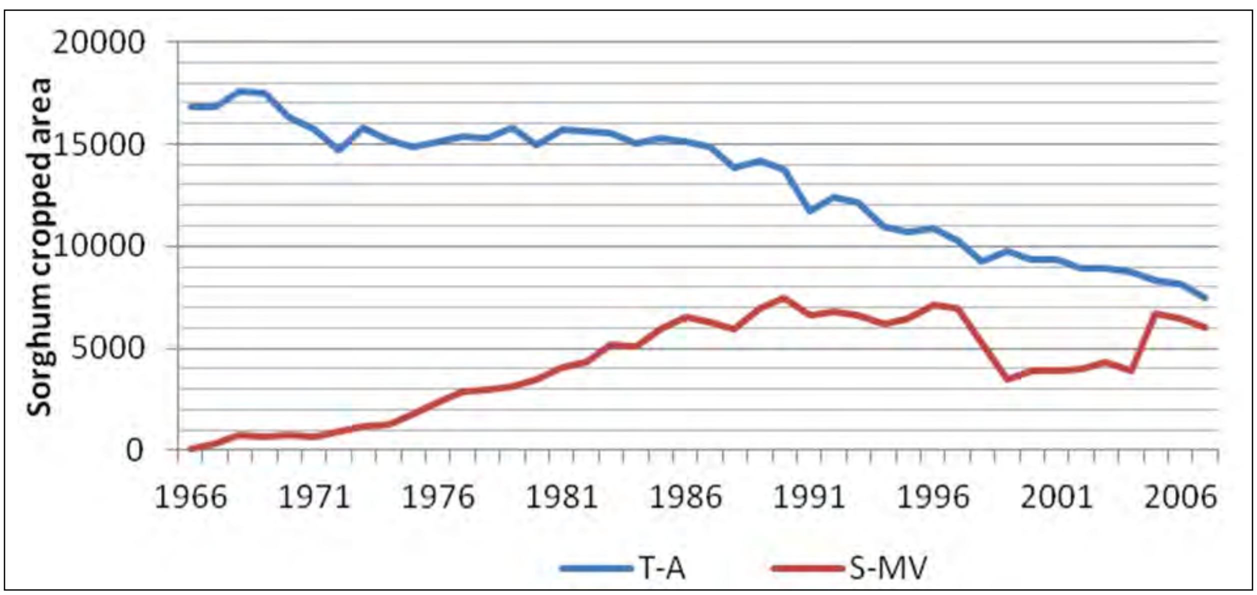

Figure 15. Sorghum cropped area under modern varieties in India.

The rate of adoption of improved sorghum cultivars in different states is presented in Table 24. Based on 2006-08 mean crop estimates, the highest adoption was noticed in Maharashtra, followed by Madhya Pradesh and Tamil Nadu. Karnataka is next with 75% area under improved cultivars. Except in Andhra Pradesh, the area under improved cultivars was in increasing trend in all studied states between 1996-98 and 2006-08. There was a steep decline in area under improved cultivars in Andhra Pradesh (-54.4%) during the same period. Overall, at the all-India level, the area share has gone up and registered a growth of 19.4% (see also Fig. 16 and 17).

Table 24. Diffusion of improved cultivars in major states (percent area).

State	1966-68	1976-78	1986-88	1996-98 (P1)	2006-08 (P2)	P2 over P1%
Maharashtra	2	22	59	87	94	8.0
Karnataka	1	24	24	31	75	141.9
Andhra Pradesh	1	11	35	68	31	-54.4
Madhya Pradesh	1	18	48	71	85	19.7
Rajasthan	0	1	4	10	29	190.0
Gujarat	0	3	25	33	47	42.4
Tamil Nadu	2	13	40	63	82	30.1
All India	1	18	43	67	80	19.4

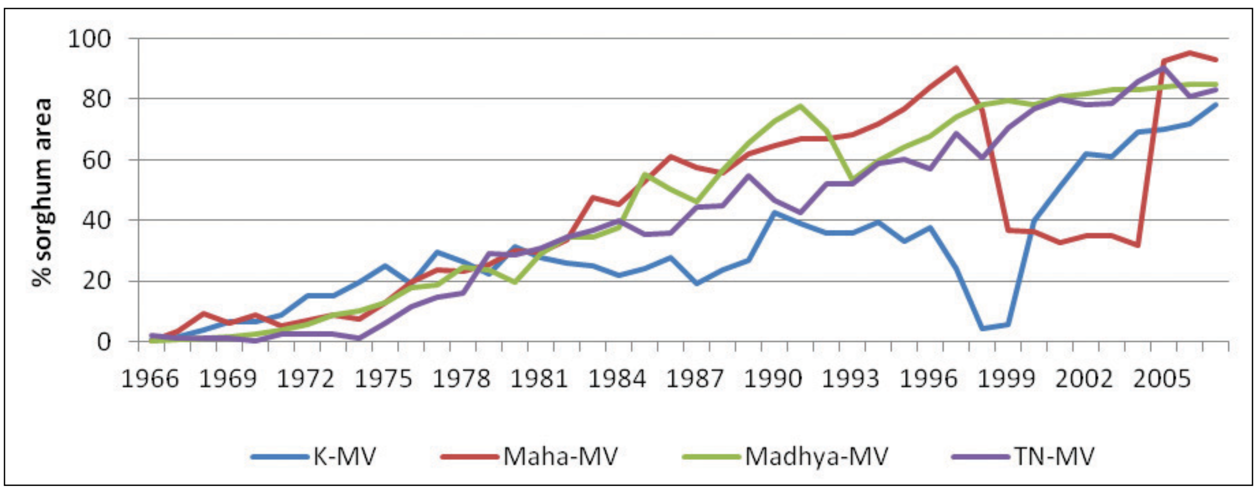

Figure 16. Diffusion pathways of sorghum improved cultivars in the major four states.

In India, improved OPVs were less popular than the hybrids from the start (Rana et al. 1997), and there were different phases in the spread of improved sorghum cultivars in India. Until 1975, only CSH 1 was dominant, and it replaced traditional local cultivars. Between 1976 and 1986, the dominant improved sorghum cultivars were CSH 5 and CSH 6. This phase was characterized by the replacement of traditional and initial improved cultivars (CSH 1, CSH 2, and CSH 4) by new cultivars (CSH 5, CSH 6). After 1986, the initial cultivars were replaced by new cultivars (CSH 9, MSH 51 and JKSH 22) at a faster rate. During this period, Indian farmers made use of the large number of private-sector hybrids in the market (Deb and Bantilan 2003).

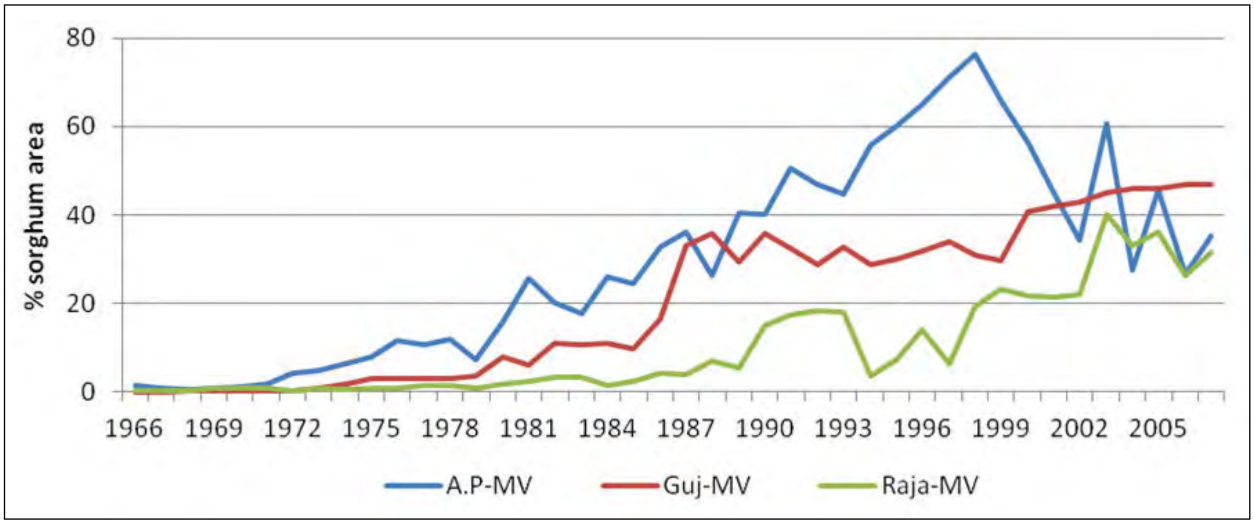

Figure 17. Diffusion pathways of sorghum improved cultivars in the major three states.

7.1 Cultivar-specific adoption estimates in major states

ICRISAT has assessed the cultivar-specific adoption estimates in major sorghum-growing states under the *'Tracking varietal Change for Future Assessment of the Impact of Crop Genetic Improvement in South Asia* (TRIVSA)' project supported by the Bill and Melinda Gates Foundation (BMGF). ICRISAT has adapted a series of expert elicitations for obtaining reliable adoption estimates for each state. For conducting the elicitations in major states, ICRISAT collaborated with NARS, specifically with DSR and AICSIP. The TRIVSA team officially took part in the 41st Annual Meetings of AlCSIP held at Dharwad, Karnataka during April 2011. Normally, all the scientists who are working on sorghum crop improvement in India attend these meetings for planning of their next year technical program for crop development. It was one of the rarest opportunities where the TRIVSA team was able to meet all the sorghum improvement scientists (around 150) in India at one place. The project team innovatively took advantage of this opportunity and explained the TRIVSA initiative and collected feedback from each AICSIP center separately. This could be one of the fastest methods of updating cultivar-specific adoption information.

Overall, ICRISAT conducted the expert elicitations in two rounds. The first round of expert elicitations were conducted with scientists of respective AICSIP centers located in each state. In general, each expert elicitation consisted of at least 4-5 scientists based at each AICSIP center. The elicitation group always represented scientists with diverse backgrounds (breeding, plant protection, agronomy, extension and seed science etc.). Based on the group's knowledge and skills, the information was collected either at regional or state level. After obtaining these preliminary adoption estimates from each state, ICRISAT conducted the second round of elicitation with state/national level experts in a separate sorghum workshop (Annexure 4).
The details of state-wise cultivar-specific adoption estimates of improved varieties and hybrids are summarized in Tables 25 through 28. Additional secondary source of information was also collected from State Seed Development Corporation (SSDC) and State Seed Certification Agency (SSCA) for the same period. However, concerted efforts are in place to collect similar information from private seed companies and distributors/dealers. National Seeds Corporations and (SAUs)/extension departments were some other avenues for validation of this information.

Maharashtra

In Maharashtra, the postrainy season crop is dominated by varieties and local landraces whereas rainy season crop is dominated by hybrids. The popular cultivars preferred during the postrainy season are PVK-809 (dual purpose variety), Parbhani Moti (PVK-801) (rich fodder crop) and M-35-1. Local cultivars (landraces of Maldandi) occupy nearly other 50% of total cropped area. Lack of suitable improved cultivars is a major constraint for low adoption rate in the postrainy season. In rainy season, nearly 75% of the area is under hybrids such as CSH 9, MAHABEEJ-7-7A (SPH-981), CSH 16, MLSH 296, CSH 14 etc. The remaining 25% is occupied by OPVs like Parbhani Swetha (PVK-801) and CSV 15. The information clearly reveals that most of the preferred rainy season cultivars are those released in late 1990s. The mega varieties (whose occupancy >10% cropped area) identified in Maharashtra are Phule Vasudha, Parbhani Moti, CSH 9, CSH 16, MLSH 296, CSH 14 and MAHABEEJ-7-7A (Table 25).

Table 25. Maharashtra and Madhya Pradesh cultivar-specific adoption estimates, 2010-11.

Maharashtra			Madhya Pradesh		
Cultivar	Release year	% share in area	Cultivar	Release year	% share in area
Rainy season			Rainy season		
CSH 9	1983	40	CSH 15	1995	13.9
CSH 14	1992		CSH 18	1999	12.3
CSH 16	1997		Ajeet 997	-	10.7
MLSH 296	1997	30	Pradhan	-	10.0
MAHABEEJ-7-7A (SPH-981)	2000		CSH 14	1992	8.9
Other private hybrids			GK-4010	-	6.5
CSV 15	1996	10	CSH 16	1997	5.8
Parbhani Sweta (PVK-801)	2000		GK-4009	-	3.9
Others		20	CSH 9	1983	3.1
All MVs		100	JJ-1041	1999	0.9
Postrainy season			JJ-938	1996	0.7
M-35-1	1968	20	RS-29	1991	0.1
Phule Vasudha	2008				
Parbhani Moti	2005	30			
CSH 15R	1995	Negligible			
All MVs		50	All MVs		77

Source: TRIVSA Expert Elicitation Survey 2011, with reference to 2010 season

Madhya Pradesh

In Madhya Pradesh, area under sorghum has been continually decreasing and being replaced by commercial crops, particularly soybean. Madhya Pradesh holds an average share of around 7-8% of the total Indian sorghum acreage. The prominent varieties ruling in Madhya Pradesh are CSH 15, CSH 18, Ajeet-997 and Pradhan. According to the experts, landraces and local varieties are spread over 23% of the sorghum area and the remaining share (77%) is covered with improved cultivars developed between 1990 and 2000.

Andhra Pradesh

In Andhra Pradesh total acreage under sorghum cultivation is approximately 100-150 thousand ha. Sorghum crop is taken up in two seasons, mainly the rainy season and postrainy season, with occasionally a small portion of area in *maghi* (late rainy or early postrainy season). According to experts, the adoption rate of improved cultivars of sorghum is around 40% and remaining 60% area is under local landraces. The prominent local cultivar is yellow/*paccha jonna* because of its good quality for roti preparation. The most preferred rainy season varieties are SPV 462, CSV 15, CSV 20, NTJ-2, and NTJ-4. Nearly half of the postrainy season cropped area is under modern cultivars. C-43 (Mahindra male) is most popular hybrid having a share of roughly 10% under MVs. M-35-1, CSH 9, Mahalaxmi and JKSH 22 are other popular cultivars that occupy the remaining 40% area under improved cultivars (Table 26).

Table 26. Cultivar-specific adoption estimates in Andhra Pradesh, 2010-11.

Cultivar	Release year	% share in area	Cultivar	Release year	% share in area
Rainy season			Postrainy season		
SPV-462 ((PSV-1)	1996	20	Mahindra Male (C-43)	1997	10
CSV 15	1996	2.5	M35-1	1968	10
CSV 20	2009	2.5	CSH 9	1983	10
NTJ-2	1990	2.5	Other private hybrids (Mahalaxmi, JKSH 22)	1997	20
NTJ-4	1992	2.5			
Private sector hybrids (JKSH 22)	1999	10			
All MVs		40	All MVs		50

Rajasthan

Rajasthan holds a share of 8-10% of total sorghum acreage in the country. Sorghum is grown mostly during rainy season and rarely in summer (SSG varieties preferred) under irrigated conditions. The most preferred varieties are dual purpose (both for food and fodder). Important sorghum cultivars ruling in Rajasthan are CSH 9, CSV 10, CSV 15, SSG-593, JKSH-592, KSH-6363, JK-222, JK-234, Amarnath-206 and CSV 17. Overall, local/traditional cultivars dominate the major share (around 65%), while improved cultivars occupy an area of 35% (Table 27).

Table 27. Cultivar-specific adoption estimates in Rajasthan, 2010-11.		
Cultivar	Release year	% share in area
CSV 15	1996	10.9
JKSH 592	-	4.4
SSG-59-3	1978	2.9
CSV 10	1986	2.4
KJH 6363	-	2.2
CSH 9	1983	1.1
Others	-	11.1
All MVs	-	35.0

Karnataka

In Karnataka sorghum is cultivated both in rainy season and postrainy seasons, with the major share of total production being contributed by the rainy season crop. Nearly 3.3 million ha are cultivated in the rainy season, whereas the spread from postrainy season sorghum is 1.2 milion ha. According to experts, the adoption of improved cultivars in the rainy season is around 90% while in the postrainy season it is approximately 25-30%. The lower adoption in the postrainy season is because M-35-1 is considered as a traditional cultivar in Karnataka and holds a major chunk of 20% in the postrainy season. The sorghum cultivars ruling in the rainy season are CSH 14, DSV 2, DSV 6, and CSV 16. In the postrainy season the most preferred cultivars are M-35-1 for its better grain quality and early maturing. The other preferred cultivars are Muguthi 4-5-1, DSV 4, DSV 5, CSV 216 R, CSV 22, and CSH 19R. Sunflower and pigeonpea are the competitive crops to sorghum in nontraditional sorghum-growing areas. M-35-1, Muguthi 4-5-1, CSH 14, DSV 2, DSV 6, CSV 16 are considered as mega varieties in Karnataka and they hold more than 10% to the total crop area under each variety. Private sector cultivar share is insignificant in the total cropped area (Table 28).

Table 28. Cultivar-specific adoption estimates in Karnataka, 2010-11.					
Rainy season			Postrainy season		
Cultivar	Release year	% share in area	Cultivar	Release year	% share in area
CSH 14	1992	40	M-35-1	1968	15
DSV 2	1986	18	Mugthi 4-5-1	1969	15
DSV 6	2009	15	DSV 4	1998	
CSH 16	1997	15	DSV 5	1997	
Nirmal-59	-	2	CSV 216R	2000	20
			CSV 22	2007	
			BJV 44	2012	
All MVs		90	All MVs		50

The patterns of varietal replacement by age for major sorghum-growing states in India are summarized in Table 29. In general, the initial results are comparable with secondary information collected from respective state agricultural departments and state seed corporations. However, some slight deviations were noticed which will be further clarified during the state-level large-scale adoption surveys. Overall, the cultivars released during 1990-2000 occupied major shares of cropped areas in different states. In the postrainy season sorghum area in Maharashtra and Andhra Pradesh, M-35-1 still dominates, even though it was released during the 1960s.

Table 29. Pattern of varietal replacement in major states by release year.

Released years	Andhra Pradesh		Maharashtra		Madhya Pradesh (rainy season)	Rajasthan (rainy season)	Karnataka	
	Rainy season	Postrainy season	Rainy season	Postrainy season			Rainy season	Postrainy season
1960-70	0	10	0	20	0	0	0	30
1970-80	0	0	0	0	0	3	0	0
1980-90	0	10	15	0	0	4	15	0
1991-00	38	30	45	1	77	11	55	7
2001-10	2	0	20	29	0	0	15	13
Period unknown	0	0	20	0	0	17	5	0
% area under MVs	40	50	100	50	77	35	90	50

7.2 Preferred traits in major sorghum-growing states

Table 30 shows the state-wise preferred traits which were collected during the workshop from biophysical scientists. The specific reasons for the preferences are also incorporated.

Table 30. Preferred traits in major sorghum-growing states.		
S.No	Most Preferred Traits	Reason
Andhra Pradesh		
1	Good *roti* making quality (taste, keeping quality)	Higher market price
2	Quality fodder (with juicy stalk)	Palatability to farm animals
3	Medium tall plant height with strong stem	To avoid lodging
4	Loose or semi compact panicle	To overcome grain mold disease
5	High-yielding and early maturing	Good returns
6	SFR, grain mold tolerance	To minimize the loss of yield
7	Durable purpose	Maximize the returns
8	Drought tolerance in red soil areas	
Maharashtra		
1	Shoot fly resistance, charcoal rot tolerance	
2	Medium height (180-300 cm), early maturity (105-125 days)	
3	Good fodder quality	Palatability to farm animals
4	Pearly round grains	Higher market price
5	High-yielding	
6	Drought tolerance and low temperature tolerance	
Rajasthan		
1	Multi-cut	Green fodder during summer
2	Single-cut	Most preferred dry fodder
3	Feed	Concentrate for animals
4	Poultry feed	Cheaper feed
Madhya Pradesh		
1	High-yielding	
2	Early maturity	
3	Shoot fly resistance	
4	Number of grains per cob	
Karnataka		
1	High yielding dual purpose cultivars	For grain and fodder need
2	Good *roti* making quality	For good market price
3	Resistance to foliar diseases	To reduce the crop loss
4	Tolerant to grain mold and charcoal rot diseases	To minimize yield loss

Source: Elicitation survey results 2012, ICRISAT

8. Major constraints in adoption and influences of various policies

For any newly introduced agricultural technology, initially there is usually a lower acceptance rate at farmer level. In addition, there are many other barriers in the process, hindering the agriculture technology adoption and development. This particular study, however, is restricted to collecting information on major constraints in the adoption of sorghum improved cultivars in major producing states. Broadly, the major constraints elicited are summarized in Table 31.

Table 31. Constraints in adoption of improved cultivars.

Particular	Maharashtra	Andhra Pradesh	Rajasthan	Madhya Pradesh	Karnataka
Nonavailability of quality seed	√	√			√
Lack of reasonable market price	√				√
Low seed replacement rate	√			√	
Poor extension services	√				√
Nonavailability of resistant cultivars			√		
Low net returns			√	√	
Nonavailability of improved fodder types			√		
Nonavailability of drought tolerant types		√			
High grain mold susceptibility		√			
Short supply of labor		√			
Lack of knowledge on improved cultivars	√	√	√		√
Lack of preferred trait varieties			√		
Lack of proper distribution channel		√			√
Changing food habits			√		
Poor awareness about value addition		√	√		
Shoot fly and charcoal rot		√			√
Inability to compete with commercial crops like soybean and cotton				√	
Storage of grain and fodder					√

Need for policy amendments

- With the changing demand and utilization pattern of sorghum across regions, the selection of hybrid or variety from the improved varietal pool and its suitability to a particular region plays a vital role, for which a thorough screening mechanism is needed.
- Rapid diffusion and adoption of improved cultivars can take place only when there is a strong back-up of seed multiplication and distribution system. Innovative formal and informal seed-multiplication mechanisms should be encouraged through various policies/incentives.
- Periodical assessment and upgradation of seed chain varieties is critical for enhancing the adoption of new cultivars and gradual replacement of the old varieties.

- As per the Government of India Seed Division information, rainy season sorghum SRR are satisfactory at 90-95% whereas for the postrainy sorghum it is around 12-15% only. However, the recent national statistics indicates that around 60% of sorghum area is under the postrainy season area. So there is a need for clear strategy for promotion of improved cultivars in the postrainy season.
- Rapid and innovative breeding strategies/techniques should be used for development of postrainy sorghum improved cultivars/hybrids for quick adoption and replacement of M-35-1 types for enhancing the yields and quality.
- The mismatch between the traits identified for breeding/crop improvement process and market-preferred (including the value chains) traits should be minimized. e.g. The farmers in Rajasthan prefer to grow dual purpose varieties but most of the available varieties are grain type.
- The Government of India should develop and support a strategy for enhancing the per capita consumption of sorghum grains. Sorghum must be inter-linked with the public distribution system (PDS) for enhancing the demand as well as providing competitive prices to farmers.
- Lack of sufficient agricultural credit lending to the dryland crops like sorghum. The lending policies are more favorable and flexible to commercial crops which is ruining the crop choices.
- There is also need for enhancing the alternative uses of sorghum (food, feed, fodder and fuel) in the country, which in turn stabilizes the crop area and protects the interest of SAT farmers.

9. Seed production, availability and seed replacement rates

Sorghum production is dependent on quality of inputs and the production environment. Of all the inputs, functional and healthy seed is one of the most important factors in improving agriculture production with assured economic yield. Lack of efficient seed production and distribution programs have been limiting progress and impact of crop improvement research programs in many developing countries like India. After the release of the improved cultivars by the breeder, multiplication and distribution of the seed is carried out by competent private or public agencies including experienced growers. At the time of release of a variety, a small quantity of seed normally known as nucleus seed is available with the plant breeder. Commercial quantity of seed is produced after a series of multiplication steps. In general, the seed is multiplied in four stages: nucleus seed, breeder seed, foundation seed and certified seed.

Table 32. Seed production and availability of sorghum seeds in India.				
Year	Total acreage (million ha)	Breeder seed requirement ('00 kg)	Actual breeder seed produced ('00 kg)	Deficit/surplus
1999-00	-	87.4	141.2	+77.06
2000-01	-	-	-	-
2001-02	9.79	40.47	90.5	+50.03
2002-03	9.29	-	84.1	-
2003-04	9.33	-	118.3	-
2004-05	9.09	-	91.9	-
2005-06	8.66	44.1	159.84	+115.74
2006-07	8.47	48.5	96.98	+48.48
2007-08	7.76	18.45	52.6	+34.15
2008-09	7.7	54.0	210.1	+156.07
2009-10	7.67	74.65	272.4	+197.73
2010-11	9.79	25.8	120.6	+94.82

Source: Compiled from various AICSIP Annual Reports

The sorghum seed production scenario in India during the last one decade (1999-2010) reveals that the breeder seed production is generally higher than the actual seed requirement (Table 32). Subsequent seed multiplication (foundation, certified and truthful) particularly by the state seed corporations is very limited. However, despite enough breeder seed production, the seed replacement ratios exhibit huge variations from one state to the other due to several reasons.

9.1 Seed Multiplication Ratios (SMR)

The seed multiplication ratio in sorghum is high, particularly, in OPVs. In general, 12 kg of seed is more than sufficient to sow one hectare of cropped area. This will produce at least 1200 kg of clean seed even at a moderate level of soil fertility with multiplication ratio of 100. The SMR is nothing but the number of seeds to be produced from a single seed when it is sown and harvested. According to expert group of sorghum scientists, the SMR for sorghum is 1:100.

9.2 Seed Replacement Rate in India

Seed Replacement Rate is the percentage of area sown out of total area of crop planted in the season by using certified/quality seeds other than the farm saved seed. In India, sorghum SRR was around 26.2% in the year 2008-09, much lower than the recommended level of 40% (Table 33). This lower SRR rate is attributed to a number of factors like government policies; farmers' financial conditions and their preferences for taste; unavailability of improved seed quantity and lack of information/awareness on improved cultivars.

Table 33. Seed Replacement Rate of sorghum in India %.	
Year	Seed Replacement Rate
2003-04	26.7
2004-05	19.3
2005-06	19.0
2006-07	19.3
2007-08	19.9
2008-09	26.2

Source: Directorate of Economics and Statistics, Government of India

9.3 Sorghum seed replacement rates by state

The state-wise SRR over the last eight years have been summarized in Table 34. The seed replacement ratio has witnessed decline in Andhra Pradesh with declining sorghum acreage and state subsidy on seeds. The extent of 90% subsidy on hybrid seeds in 2001-02 has decreased to 50% during 2002-03 which influenced the decline in seed replacement ratios. The subsequent surge in quantum of subsidy to 75% during 2003-04 has boosted the replacement further. From 2004-05 onward, the subsidy from government was at a standstill at 33.3% which stabilized the SRR at around 50%. However, the extent of subsidy played a key role in determining in the SRR in the state.

The failure of the rainy season seedmultiplication program due to unprecedented rains during anthesis and grain development dampened the seed availability and led to increase in F_1 seed cost. This situation weighed on the farmers' purchase decision and led to stagnant seed replacement ratios in the states like Rajasthan, Karnataka and Maharashtra. Though seed replacement ratios have shown signs of improvement in the recent past, a steep increase in market prices of sorghum seed has witnessed with strong export demand.

Table 34. Sorghum seed replacement rates by state, 2001-2008.

State	2001	2002	2003	2004	2005	2006	2007	2008
Karnataka	13	17	20	21.5	21.5	26	26	25
Andhra Pradesh	91	53	11	14	60	63	54	49
Maharashtra	15	14	14	14	14	10	10	13
Madhya Pradesh	5.9	8.9	10.2	10.6	19.9	14.3	13.3	13.3
Rajasthan	1.4	3.8	4.5	2.8	5.4	7.5	8.2	8.7
Tamil Nadu	6	4	6	1	8	6	NA	NA
Gujarat	33	NA	NA	NA	NA	NA	NA	NA

Source: Directorate of Economics and Statistics, Government of India

10. Impact of modern cultivars and unit cost reductions

In general, impacts of crop improvement research/technology could be perceived in terms of yield gain, reduction in 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 research impacts. This is particularly true for crops such as sorghum that 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 sorghum can have large effects on yields (Deb and Bantilan 2003). However, the area under sorghum has been declining since the 1980s; the productivity gains observed in all major growing states were due to the increased adoption of improved cultivars. The impact of improved cultivars on yield gains and its stability needs to be assessed deeply for further understanding. Similarly, the effect on reduction in the unit costs of production in major states needs to be estimated.

10.1 Data and research methodology

The study used data collected from two sources: 1. District-level secondary data published in the State Season and Crop reports and State Statistical Abstracts; and 2. Cost of cultivation data published by the Ministry of Agriculture and Cooperation, GOI. District-level yield data for 1966-2007 covering 164 sorghum-growing districts in seven states – Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Tamil Nadu – were used to estimate yield and stability gains. All these districts together accounted for about 99% of total sorghum cropped area and almost 96% of sorghum production in India (2005-07). However, the districts with negligible area (<500 ha) have been discarded in the further analysis. A fraction of 32 districts was removed in data analysis due to low cropped area and nonavailability of data. Hence, the total number of districts studied was 132 from seven states (Table 35).

Table 35. Selection of study districts in different states of India.

State	No. of sorghum-growing districts	No. of districts considered in the study	Discarded districts
Andhra Pradesh	20	18	East Godavari, Krishna
Gujarat	18	16	Amerli, Kutch
Karnataka	19	13	Bangalore, Kolar, Shimoga, Dakshina Kannada, Uttara Kannada, Kodagu
Madhya Pradesh	43	34	Durg, Bastar, Raipur, Bilaspur, Raigarh, Surguja, Balaghat, Mandla, Indore
Maharashtra	26	21	Bombay, Thane, Raigad, Ratnagiri, Bhandara
Rajasthan	26	22	Churu, Ganganagar, Jhunjhunu, Sikar
Tamil Nadu	12	8	Chengalpattu, Thanjavur, Nilgiris, Kanyakumari
Overall	164	132	-

Table 36 analyzes the mean and relative variability in yields in major sorghum-growing states during the last four decades. The highest productivity was observed in Andhra Pradesh followed by Madhya Pradesh and Gujarat during 1994-07. In Andhra Pradesh, the productivity levels across different time periods were increasing significantly but the coefficient of variation also increased substantially during the third period. This may be due to decrease in area under improved cultivars during that period. On the other hand, Gujarat has improved its productivity and reduced variability as the area under modern cultivar increases. Even though the productivity levels were slightly increased in Karnataka, the variability also increased during the last period. Similarly, in Madhya Pradesh, the productivity levels were relatively higher when compared with other states in all the three periods. The growth in productivity was also consistent but there was a slight increase in variability during the last period. The increase in productivity and decrease in coefficient of variation was conspicuous in Maharashtra as the coverage increases under improved cultivars. Rajasthan and Tamil Nadu exhibited almost stagnation in the yield levels over the study period. However, all-India mean yields were in increasing trend and the coefficient of variation was decreasing gradually over a period of time. This clearly indicates that the increase in area under improved cultivars increases the yields and reduces the variability.

Table 36. Mean and variability in sorghum yields by state.

State	1966-1979 (P-1)		1980-1993 (P-2)		1994-2007 (P-3)		P-3 over P-2 (%)	
	Yield (kg ha^{-1})	CV (%)	Yield (kg ha^{-1})	CV(%)	Yield (kg ha^{-1})	CV (%)	Yield (kg ha^{-1})	CV (%)
Andhra Pradesh	512	17.7	641	15.33	928	26.26	44.7	71.3
Gujarat	608	32.9	513	29.65	909	23.61	77.1	-20.3
Karnataka	784	24.6	753	12.55	856	23.50	13.6	87.3
Madhya Pradesh	825	16.4	866	14.16	925	16.56	6.8	16.9
Maharashtra	722	32.8	781	23.48	839	13.82	7.4	-41.1
Rajasthan	377	25.1	397	32.40	398	42.06	0.2	29.8
Tamil Nadu	874	11.8	927	18.54	874	17.66	-5.7	-4.7
All-India	567.0	16.8	726.5	14.4	827.2	10.7	13.8	-25.7

Table 37 presents the long-term trends in average yields and relative variability among different study states. The mean yields were the highest in Tamil Nadu during the last four decades, followed by Madhya Pradesh and Karnataka. The coefficient of variation was the lowest in Tamil Nadu and followed the same order. Highest variability in yields was observed in Gujarat, followed by Rajasthan and Andhra Pradesh. These three states have relatively lower adoption rates when compared to other states. The states with higher adoption rates of improved cultivars exhibited relatively lower variability in their yields. Overall, the country mean yield is hovering around 714 kg ha^{-1} which is far lower than other producing countries in the world. The variability in yields was 20% during the period from 1966 to 2007.

Table 37. Long-term mean and variability in sorghum yields, 1966-2007.

States	1966-2007	
	Yield (kg ha^{-1})	CV (%)
Andhra Pradesh	694	33.94
Gujarat	608	45.40
Karnataka	784	21.72
Madhya Pradesh	825	19.90
Maharashtra	722	28.21
Rajasthan	377	34.81
Tamil Nadu	874	16.89
All-India	713.1	20.0

The district-wise spatial distribution of sorghum yields are presented in Fig 18 and 19 respectively for rainy and postrainy seasons between 1980-82 and 2005-07. During 1980s, the rainy season sorghum yields are higher (>1000 $kgha^{-1}$) in Maharashtra (highlighted in green color) followed by Karnataka states. Medium levels of productivity were observed in case of Madhya Pradesh and Andhra Pradesh. Lower (<600 $kgha^{-1}$) productivity levels were noticed in case of Rajasthan. However, the productivity levels improved significantly by 2005-07 in Andhra Pradesh followed by Madhya Pradesh and Rajasthan. Similarly, the postrainy sorghum productivity levels were lower among major states except in Karnataka during 1980-82. But, these high productivity districts were dis-appeared in Karnataka by 2005-07 and expanded in Andhra Pradesh. These trends clearly lend the support that rainy season sorghum productivity in the country has increased significantly while the postrainy sorghum was stagnated during the study periods.

Table 38. Association between sorghum yields and instability in the study districts between 1986-95 and 1996-2007 (%).

States	Types of Association (% districts)			
	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	0	67	11	22
Gujarat	43	19	38	0
Karnataka	0	8	23	69
Madhya Pradesh	15	62	15	8
Maharashtra	5	0	67	28
Rajasthan	9	37	27	27
Tamil Nadu	25	0	25	50
Overall	12.8 (17)	34.2 (45)	28.8 (38)	24.2 (32)

Note: Figures in parentheses indicate number of districts

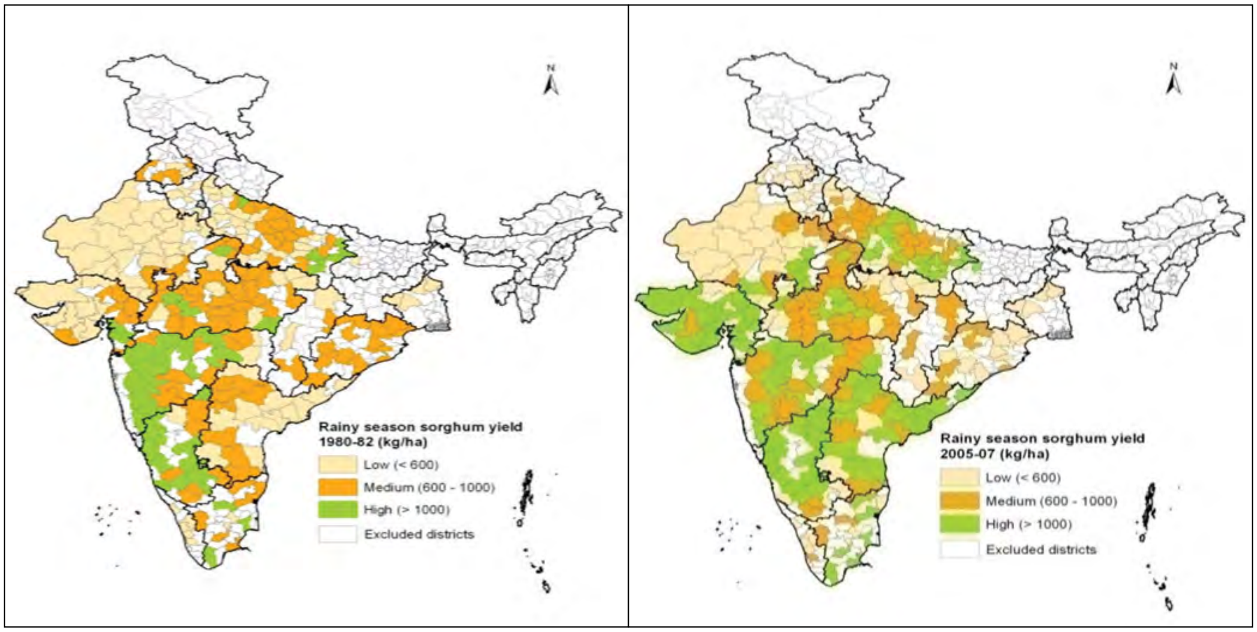

Figure 18. Spatial distribution of rainy season sorghum yields by district.

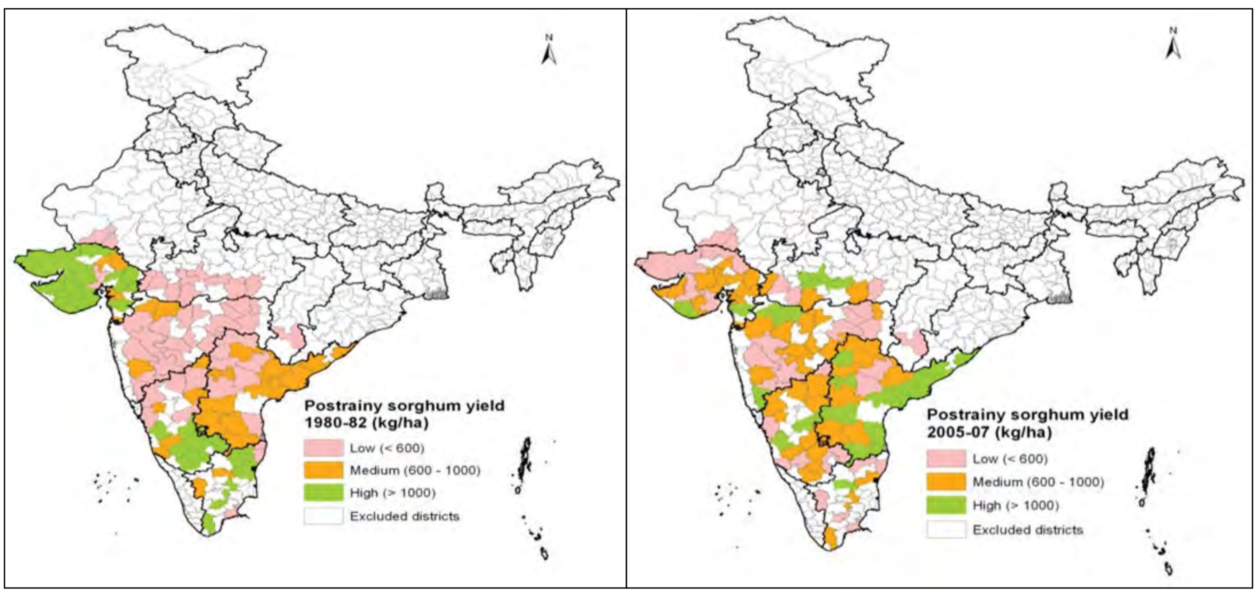

Figure19. Spatial distribution of postrainy season sorghum yields, by district.

Table 38 reveals the association between sorghum yields and instability in the study districts between 1986-95 and 1996-2007. Overall, only 17 out of 132 sample districts exhibited the increase in yield with decrease in variability. Around 45 study districts showed increased yield that was associated with increase in variability during study period. Nearly 70 districts revealed decrease in yield growth rate between these periods. Among these 70 districts, nearly 54% displayed decrease in yield variability, while the remaining were seen to show increase in variability. On the whole, nearly 60% of the study districts expressed increase in variability in their yields between these two periods. Except Maharashtra and Gujarat, the variability in yields increased in all the states during the study period. More in-depth analysis is required to probe the root causes for variability in yields in these districts.

Table 39. Distribution of sorghum districts based on instability in yields, 1966-2007.

	Instability (CV) in yield (% study districts)			
States	< = 25%	26-50%	51-75%	>75%
Andhra Pradesh	11	56	22	11
Gujarat	0	44	25	31
Karnataka	15	85	0	0
Madhya Pradesh	29	71	0	0
Maharashtra	0	100	0	0
Rajasthan	0	32	45	23
Tamil Nadu	0	100	0	0
All-India	10.6 (14)	66.6 (88)	13.7 (18)	9.1 (12)

Note: Figures in parentheses indicate number of districts

Table 39 summarizes the long-term instability analysis in yields of different districts during 1966-2007. The data clearly reveals that nearly 67% of study districts showed variability between 26%-50%. Only 14 districts displayed variability less than 25% during the study period. Nearly 30 districts exhibited high variability (>50%) in their yields for the same period. Based on these results, we cannot conclude that the adoption of improved cultivars would reduce the yield variability in the districts.

Table 40. Distribution of districts based on sorghum area under improved cultivars.

States	Percent total sorghum area under improved cultivars			
	< = 25%	26-50%	51-75%	76-100%
	1977-79			
Andhra Pradesh	17	1	0	0
Gujarat	14	2	0	0
Karnataka	5	4	4	0
Madhya Pradesh	24	8	2	0
Maharashtra	8	9	3	1
Rajasthan	22	0	0	0
Tamil Nadu	5	2	1	0
All-India	95	26	10	1
	1991-93			
Andhra Pradesh	0	8	6	4
Gujarat	6	7	2	1
Karnataka	2	5	5	1
Madhya Pradesh	12	3	12	7
Maharashtra	1	2	4	14
Rajasthan	20	1	0	1
Tamil Nadu	0	3	3	2
All-India	41	29	32	30
	2005-2007			
Andhra Pradesh	5	5	6	2
Gujarat	5	6	3	2
Karnataka	2	2	3	6
Madhya Pradesh	12	5	5	12
Maharashtra	0	0	0	21
Rajasthan	15	1	2	4
Tamil Nadu	0	0	0	8
All-India	39	19	19	55

Table 40 furnishes the distribution of sample districts based on the proportion of area under improved cultivars during 1977-79 and 2005-07. The data clearly reveals that the area under improved cultivars has increased significantly during the study period. However, the number of districts with adoption rate greater than 50% has gone up from 11 in 1977-79 to 74 in 2005-07. Similarly, the number of districts with adoption rate less than 50% has come down from 121 to 58 during the same time. Nearly 39 districts still showed adoption rates of less than 25%. These districts were mainly concentrated in Madhya Pradesh and Rajasthan. The districts with higher adoption rates were situated mostly in Maharashtra and Madhya Pradesh.

10.2 Impact on unit cost of production

An alternative measure of productivity gains is the reduction in unit cost of production. An analysis of cost of cultivation data collected from CACP reports in major sorghum-growing states showed that real cost of production per 100 kg of sorghum decreased to some extent but after some time it increased (Table 41). The data was collected from 1986-87 to 2007-08 and then the prices were converted to 1993 real prices. We can conclude from the table that the unit cost reduction was visible up to early 2000s from 1986-87. But, during the late 2000s the unit of production went up significantly when compared to 1986-87. This may be one of the reasons that farmers are moving out of sorghum crop in many states. Outbreak of biotic and abiotic stresses were other reasons for diversifying from sorghum to other cash crops.

Table 41. Impact of modern cultivars on unit cost reductions (Rs per 100 kg in 1993 real prices).

Year	A.P.	Karnataka	M.P.	Maharashtra	T.N.	Rajasthan
1986-87	3.48	3.12	2.64	2.62	N.A	N.A
1987-88	3.19	2.51	2.37	2.57	N.A	N.A
1994-95	3.66	N.A	2.92	2.79	3.01	N.A
1995-96	4	N.A	3.28	2.79	3.28	N.A
1999-00	5.25	4.61	3.86	3.71	4.74	5.47
2000-01	4.5	3.47	3.59	3.64	3	2.59
2005-06	3.74	3.85	3.79	3.38	5.63	3.42
2007-08	5.46	4.48	3.15	3.51	2.73	3.99
1986-88 avg	3.33	2.81	2.5	2.59	-	-
2005-08 avg	4.6	4.16	3.47	3.44	4.18	3.7
% Change	38.10%	48.00%	38.80%	32.80%	-	-

10.3 Determinants of inter-district differences in sorghum yield

A regression equation was fitted to examine the determinants of inter-district differences in sorghum yield for the period 2005-08 (triennium average) (Table 42). The district-level yields were regressed against the respective district sorghum cropped area, area under improved cultivars, area under irrigation and deviations in normal rainfall, ratio of rainy season to postrainy season sorghum area and with state dummies. To further scrutinize the variability at statelevel, six state-level dummy variables were added to the equation. The OLS method of estimation was used for calculations. The empirical form of the equation was as follows:

$Y_d = a+b_1a+b_2a_H+b_3a_I+b_4r_D+b_5a_R+b_6d_G+b_7d_K+b_8d_M + b_9d_{MA} + b_{10}d_R + b_{11}d_T$

Table 42. Determinants of inter-district differences in sorghum yields.				
Variables	Unstandardized Coefficient	Std. Error	t	Sig.
(Constant)	1217.789	78.460	15.521	.000*
Sorghum area	-1.838	.555	-3.313	.001*
% area under MV	1.218	.172	7.092	.000*
Irrigated area	-.618	4.402	-.140	.889
Deviations in RF	4.649E-02	.133	.350	.727
K/R ratio	-5.669E-03	.015	-.366	.715
D-Gujarat	-744.302	151.288	-4.920	.000*
D-Karnataka	-69.752	123.904	-.563	.575
D-Maharashtra	-61.739	127.656	-.484	.630
D-Madhya Pradesh	-1222.394	192.958	-6.335	.000*
D-Rajasthan	-527.854	106.906	-4.938	.000*
D-Tamil Nadu	-229.509	140.452	-1.634	.105
R-square	0.449			
N	132			

* Significant at 1% level

The R-square value of the regression equation fit was 0.449. The area under sorghum exhibited negative and significant relation with yield at the district level. This is true because districts with large sorghum area are expected to grow sorghum over a wider range of agroclimatic environments, which leads to increases in the probability of lower average yields in that district. Therefore, this relation was anticipated in the equation. The percentage area under improved cultivars showed a positive and significant relationship with district-level yields. Hence, we can argue that the adoption of improved cultivars not only increases the yields but also reduces the variability. The other variables like area under irrigation, deviations from normal rainfall during rainy season and ratio of rainy season to postrainy season area did not display any relationship with yields. However, among the six state-level dummies, Gujarat, Madhya Pradesh and Rajasthan dummies were significant at one percent level. This clearly indicates that the yields in these states were significantly different from the yields in Andhra Pradesh. Overall, the findings are in concurrence with the results obtained by Deb et al. (1999).

10.4 Determinants of variability in sorghum yield

Another regression equation was fitted to analyze the determinants of variability in sorghum district-level yields (Table 43). For this purpose, the coefficient of variation was calculated for all study districts yields for the period 1996-2007. This coefficient of variation was taken as a dependent variable in the regression equation. It was regressed against mean district yields, mean area under improved cultivars and mean deviations in district rainfall from normal for the same period. Altogether 132 observations were generated and fitted in the following form of equation:

$Y_{CV} = a + b_1 d_{Ym} + b_2 a_{Hm} + b_3 r_{Dm}$

Table 43. Determinants of variability in sorghum yields.

Variables	Unstandardized Coefficients	Std. Error	t	Sig.
(Constant)	50.734	4.002	12.678	.000*
SMV	-4.965E-02	.021	-2.397	.018*
YIELD	-1.899E-02	.004	-4.597	.000*
DRF	4.003E-03	.007	.572	.569
R –square	0.177			
N				

* Significant at 1% level

The explanatory power of the equation was rather low at 0.177. Among the three explanatory variables used in the equation, two are significant at the one percent level whereas the third variable was not significant. The proportion of area under improved cultivars exhibited negative and significant relationship with variability in district yields. This clearly shows that the increased adoption of improved cultivars reduces the variability in sorghum yields. Similarly, the yield level also had negative and significant relationship with its variability. So, the increases in the productivity in the district would reduce the variability in the district. However, the variable deviations in rainfall did not exhibit any relationship with yield variability. Hence, we can safely conclude that the increased adoption of improved cultivars would reduce the yield variability in that particular district. Since the explanatory power of the regression fit was low, we need to probe further for other causes for increase in variability in some districts in the sample.

10.5 Yield gap analysis in rainy season and postrainy season sorghum

Despite extensive research and transfer of technology from lab to land during the last five decades, there are huge gaps in sorghum yields between the potential yield and actual yields obtained by farmers. The new hybrids have a yield potential of more than 5 t ha^{-1} (PSH 1). Similarly, the modern OPVs will also yield more than 4 t ha^{-1} (NTJ-3). But according to the latest national statistics from Department of Agriculture and Cooperation, the sorghum yields are hovering around 900-1000 kg ha^{-1}. This indicates a huge gap between the potential and actual yields in the country. There is a substantial scope in the country for further increase in productivity levels. To understand this issue further at the statelevel, the study collected and collated the Field Level Demonstrations (FLDs) data conducted by DSR during the last one decade. FLDs have been conducted on an area of 1099 ha during rainy season and 878 ha in the postrainy season from 2000-01 to 2009-10 through its centers located in Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, Tamil Nadu and Uttar Pradesh on improved production technology. The state-wise details of FLDs of grain sorghum during rainy season are summarized in Table 44.

Table 44. Sorghum yield performance during rainy season FLDs.							
		Year-wise yield (kg ha^{-1})					
State	Plot	2000-01	2001-02	2004-05	2005-06	2009-10	Mean
Andhra Pradesh	FLD	1317	760	2388	1481	3500	1889
	Control	670	-	1597	1027	2450	1436
	SAY	988	960	1119	1530	1415	1202
	% Yield gap over					Control	32
						SAY	57
Gujarat	FLD	2870	2530	1602	-	2160	2291
	Control	1030	-	630	-	1630	1097
	SAY	627	971	1104	1224	1331	1051
	% Yield gap over					Control	109
						SAY	118
Karnataka	FLD	3400	809	2368	1471	-	2012
	Control	3000	-	2024	697	-	1907
	SAY	1464	1252	1376	1573	1376	1408
	% Yield gap over					Control	6
						SAY	43
Madhya Pradesh	FLD	2030	2650	1258	1618	2330	1977
	Control	1560	-	720	719	1860	1215
	SAY	722	904	957	1088	1193	973
	% Yield gap over					Control	63
						SAY	103
Maharashtra	FLD	2523	1370	2215	1714	2360	2036
	Control	1153	-	1726	1165	2100	1536
	SAY	1256	1164	1169	1328	1270	1237
	% Yield gap over					Control	33
						SAY	65
Rajasthan	FLD	1391	2370	1779	1805	1640	1797
	Control	465	-	623	697	350	534
	SAY	200	414	464	288	577	389
	% Yield gap over					Control	236
						SAY	462
Tamil Nadu	FLD	2240	3160	1466	1380	1220	1893
	Control	2375	-	744	907	730	1189
	SAY	685	712	663	746	715	704
	% Yield gap over					Control	59
						SAY	169
Uttar Pradesh	FLD	2140	2210	1693	-	-	2014
	Control	1250	-	961	-	-	1106
	SAY	948	958	1020	-	-	975
	% Yield gap over					Control	82
						SAY	107

Source: Status paper on millets, Directorate of Millets Development, Ministry of Agriculture 2010
SAY: State Average Yield

Table 44 clearly reveals that the largest yield gap over farmer practice was observed in Rajasthan (236%) followed by Gujarat (109%) and Uttar Pradesh (82%). The lowest gap was noticed in Karnataka (6%). Similarly, Rajasthan had the largest yield gap (462%) over state average yield, followed by Tamil Nadu (169%), Gujarat (118%) and Uttar Pradesh (107%). The lowest gap was identified in Karnataka (43%), followed by Andhra Pradesh (57%) and Maharashtra (65%). The largest yield gaps in Rajasthan may be because of poor soil fertility and wide rainfall fluctuations in the state. Overall, the wide yield gaps show a significant potential and scope for yield improvement of sorghum during the rainy season with the adoption of improved cultivars and effective management practices. The studies have also concluded that the application of protective irrigation at flag leaf and grain filling stages could boost the productivity of the crop significantly.

Table 45. Sorghum yield performance during postrainy season FLDs.

		Year wise yield (kg ha^{-1})					
State	Plot	2K-01	01-02	04-05	05-06	09-10	Mean
Andhra Pradesh	FLD	1700	1965	2720	1980	7550	3183
	Control	1290	667	-	1500	7110	2642
	SAY	843	1020	973	1180	1671	1137
	% Yield gap over					Control	20
						SAY	180
Gujarat	FLD	-	1965	-	-	-	1965
	Control	-	716	-	-	-	716
	SAY	-	794	-	-	-	794
	% Yield gap over					Control	174
						SAY	147
Karnataka	FLD	1260	1029	832	-	1375	1124
	Control	713	792	658	-	1220	846
	SAY	694	667	713	-	1137	803
	% Yield gap over					Control	33
						SAY	40
Maharashtra	FLD	1263	1664	1158	1528	1540	1431
	Control	946	658	694	894	980	834
	SAY	499	547	568	596	779	598
	% Yield gap over					Control	72
						SAY	139
Tamil Nadu	FLD	-	-	-	2844-	-	2844
	Control	-	-	-	2449	-	2449
	SAY	-	-	-	681	-	681
	% Yield gap over					Control	16
						SAY	318

Source: Status paper on millets, Directorate of Millets Development, Ministry of Agriculture 2010
SAY: State Average Yield

Table 45 presents the sorghum yield performance during the postrainy season FLDs conducted in major sorghum-growing states. The largest yield gap over farmer practice is witnessed in Gujarat (174%) followed by Maharashtra (72%). Tamil Nadu exhibited the lowest gap of 16% over farmer practice. However, the same state demonstrated the huge yield gap of 318% over state average yields (SAY). States like Andhra Pradesh (180%), Gujarat (147%) and Maharashtra (139%) also showed significant yields gaps over state mean yields. The larger gaps may be because the postrainy season sorghum grown on conserved moisture and productivity depends on intermittent rains received during the crop season. The technology of moisture conservation and use of rain water harvesting could help in improving productivity of postrainy season sorghum. An average yield of 7570 kg ha^{-1} has been recorded under FLD over an area of 10 ha organized under rice fallows in Guntur district of Andhra Pradesh during the postrainy season 2009-10. However, demonstration and up-scaling of these improved technologies to wide areas is the need of the hour.

10.6 District-level sorghum yield gaps

A thorough analysis of district-level data (DLD) in five major sorghum-growing states (Maharashtra, Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh) reveals interesting results about yield performances. Of the total number of districts for which data is available (185), only 133 grew sorghum during 1995-97 and 151 grew it in the 2005-07 study period. A comparison was made and the total number of sorghum-growing districts were classified based on mean country productivity of 900 kg ha^{-1}. The details of the analysis have been summarized in Figure 20 and clearly show that of the 133 districts growing sorghum during 1995-97, only 50 districts exhibited mean yields greater than the national average (900 kg ha^{-1}). The remaining 83 districts fell in the category of less than 900 kg ha^{-1}. However, increased awareness and adoption of improved cultivars have changed the mean yield trends significantly at district level during 2005-07. Of 151 districts growing sorghum in 2005-07, 87 demonstrated mean yields of more than 900 kg ha^{-1}. The remaining 64 districts fell on the other side of the coin.

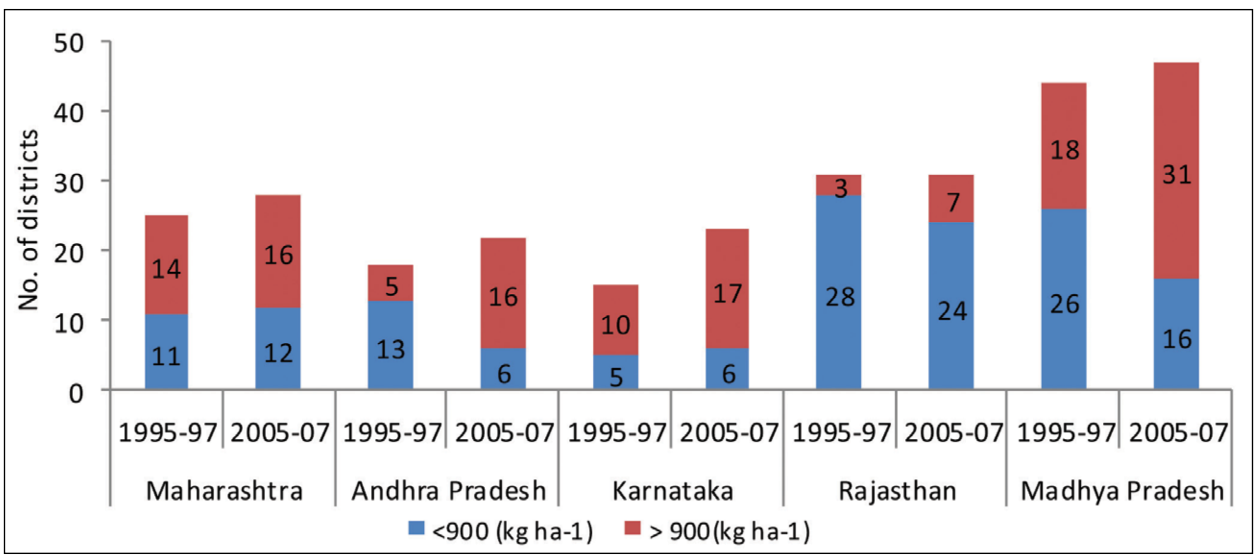

Figure 20. Sorghum yield gaps by district.

Source: District-level database, ICRISAT

11. Synthesis for future research and crop development priorities

Recent crop trends in India have indicated a steep decline in sorghum cropped area. However, sorghum continues to be the main staple food for the poor and marginal farmers of SAT India. The crop has huge potential and has also been identified as one among the climate resilient crops that can adapt quickly under changing climatic conditions. Sorghum can perform well in harsh and limited rainfall regimes (400-500 mm) without application of any fertilizers or other inputs. Furthermore, India has a unique adaptation in the form of postrainy season sorghum. Nearly twothirds of the area is under postrainy season cultivation whereas the remaining one third is grown during the rainy season. The mean productivity levels in the country are hovering around 1000 kg ha^{-1}. In general, the productivity levels are relatively higher in the rainy season when compared to the postrainy season.

Despite successful crop improvement efforts by both the public and private sectors, the rainy season crop production has declined due to sharp fall in cropped area. The postrainy season production pattern was relative stable even though there is a slight deviation in crop sown area. Maharashtra (49%), Karnataka (21%) and Madhya Pradesh (9%) together represent nearly 80% of production in the country. ICAR, ICRISAT and private seed companies are the major players for sorghum crop improvement in the country. A total of 257 improved cultivars have been released and made available to farmers through NARS in India between 1964 and 2012. The results clearly indicate a clear contrast between national and other releases over the study period. Overall, the national releases (55) were dominated by hybrids whereas the other notified releases including SAUs (202) were dominated by varieties. On the whole, the crop improvement research in India was tilted mostly toward varieties until the 1990s, after which a major, rigorous thrust was given on hybrids. Nearly 80% of the released cultivars are suited for short-duration (90-110 days) environments. The total FTE of staff with specialization in sorghum crop improvement in India was 84.5 as on 2010-11. The pattern of research investment by NARS is increasing in trend.

The benefit of sorghum research can reach farmers only when released cultivars are adopted by SAT farmers. Based on crop estimates provided by Department of Agriculture, nearly 80% of sorghum cropped area in the country has been covered by modern varieties (MVs). States like Maharashtra, Madhya Pradesh, Tamil Nadu and Karnataka have exhibited high coverage of MVs (> or =75%) whereas Andhra Pradesh, Rajasthan and Gujarat showed less than 50% of cropped area coverage. Two levels of expert elicitations conducted under a diffusion study in India (TRIVSA Project) by ICRISAT confirmed the secondary estimates with minor deviations. However, the country SRR were reported at 26% during 2008-09.

The coverage of modern cultivars in sorghum cropped area has been increasing since the 1960s. The crop production and productivity in the country have stabilized to some extent because of increasing rates of adoption of MVs. However, the adoption of improved cultivars in the country was more conspicuous in the rainy season (80-85%) when compared to the postrainy season (30-40%). Overall, the increased adoption of improved cultivars clearly pushed the average yields in the country over the last four decades. The mean yields in country have increased nearly 85% from 500 kg ha^{-1} in 1961-63 to 926 kg ha^{-1} during 2008-10. The detailed district-level data (DLD) analysis at an all-India level has confirmed that the increased yields were coupled with gradual decrease in coefficient of variation over the study period due to adoption of improved cultivars. These trends are more clear and conspicuous among the seven sorghum study states in India. Overall, the results substantiate the role of improved sorghum cultivars in sustaining the higher yields in the country.

Implications for future prioritization of sorghum research

In addition to biotic and abiotic challenges, presumed climate change is affecting the sorghum area and its importance globally. Climate change will modify the length of growing period and increase the predicted temperatures across the sorghum-growing regions. So, more thrust is needed on development of drought-resistant and heat-tolerant cultivars by using modern biotechnology tools. Similarly, high emphasis would be given for improvement of postrainy vintages for increasing the adoption rates. The other emerging areas of sorghum research are development of high-yielding sweet stalks, fodder quality and increasing the density of grain micronutrient traits. Adequate research focus is also needed to explore the preferred traits of nonconventional users/end-users for meeting their demands.

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Annexure-1. List of sorghum cultivars releases at national level.

S.No	Name of Cultivar	Pedigree	Center	Tested number	Year of release	Notification number and date
	Sorghum Varieties					
1	M35-1(Maldandi)	Selection form Maldandi landraces	ARS, Mohol, MH	Mohal	1968	S.O.596(E)/13.8.84
2	CSV 1(Swarna)	Selection Form IS 3924	NRCS	Swarna	1968	4045/24.9.69
3	CSV 6 (604)	IS 3922 X Aispuri	NRCS	CSV 604	1974	-
4	CSV 7R	IS 2950 X M 35-1	NRCS	R16	1974	-
5	CSV 2 (302)	IS 3922 X Karad local	NRCS	CSV 201(302)	1975	440(E)21.8.75
6	CSV 3 (370)	S 2954 X BP 53	NRCS	CSV 370	1976	786/2.2.76
7	CSV 4 (CS-3541)	S 3675 X IS 3541	NRCS	CS3541	1976	786/2.2.76
8	CSV 5 (148/168)	IS3687 X Aispuri	NRCS	CSV 148/168	1978	13/19.12.78
9	SSG 59-3	Non sweet Sudan grass X JS263	Hissar-Haryana	-	1978	-
10	CSV 8R	R 24 X R 16	NRCS	SPV 86	1980	470/19.2.80
11	CSV 9 (SPV-126)	CS 3541 X Tall Mutant	AICSIP-CU	SPV 126	1983	499(E)/8.7.83
12	Upchari-1	selection from germplasm.IS4776	Pantnagar		1983	
13	Swati(RSV-9R)(SPV 504)	SPV 86 X M 35-1	AICSIP, Rahuri	SPV 504	1984	540(E)/24.7.85
14	UP Chari-2	Vidisha 60-1 X IS 6953	Pantnagar	-	1985	295(E)/09.04.85
15	CSV 10 (SPV-346)	SB 1066 X CS 3541	Udaipur	SPV346	1985	295(E)/9.4.85
16	CSV 11 (SPV-351)	SC 108-3 X CS3541	ICRISAT	SPV 351	1985	295(E)/9.4.85
17	CSV 12(DSV 2) (CO26)	(IS 2947 X SPV 232) X 1022	Dharwad	SPV 462	1986	867(E)/26.11.86
18	CSV 13	(IS 12622 X555) X S 3612 X 2219B X E35-1	ICRISAT	SPV 475	1988	471(E)/5.5.88
19	CSV 14R (SPV-839)	M 35-1 X (CS 2947 X CS2644) X M 35-1	NRCS	SPV 839	1992	814(E)/4.11.92
20	CSV 15	SPV 475 PV 462	NRCS	SPV 946	1996	349(E)/20.5.96

21	Pant Chari-5(UPFS-32)	CS3541 X IS 6935	Pantnagar	UPFS32	1999	1050(E)/26.10.99
22	CSV 17 (SPV-1489)	SPV 946 X SPV 772	Udaipur	SPV 1489	1999	449(E)/11.02.09
23	CSV 216 (Phule Yashoda) (SPV-1359)	A selection from landrace	AICSIP, Rahuri	SPV 1359	2000	821(E)/13.9.2000
24	CSV 19SS	RSSV 2 X SPV 462	Rahuri	RSSV 9	2005	1172(E)/25.8.05
25	CSV 18	Selection From CR 4 X IS 18370	Parbhani	SPV 1595	2005	Awaited
26	CSV 21F	GSSV 148 X SR 897	Surat	SRF 286	2006	Awaited
27	CSV 22(SPV 1626)	SPV 1359 X RSP 2	AICSIP, Rahuri	SPV 1626	2007	1703(E)/5.10.07
28	CSV 23 (SPV-1714)	SPV 861 X SU 248	Rahuri	SPV 1714	2008	72(E)/10.1.08
29	CSV 20 (SPV-1489)	SPV 946 X kharif 89-246	NRCS	SPV 1489	2009	449(E)/11.02.09
	Sorghum hybrids					
1	CSH 1	CK60A XIS 84	NRCS	-	1964	4045/24.9.69; 786/2.2.76
2	CSH 2	CK60A XIS 3691	NRCS	-	1965	4045/24.9.69
3	CSH 3	2219Ax IS 3691	NRCS	-	1970	566(E)/21.9.74
4	CSH 4 (PSH-2)	1036A X Swarna	Parbhani and NRCS	PSH-2	1973	440(E)/21.8.75
5	CSH 5	2077 AX CS 3541	NRCS	-	1975	786/2.2.76; S.O.1004/23.3.78
6	CSH 6	2219Ax IS 3541	NRCS	-	1977	1004/23.3.78
7	CSH 7R	36A X168	NRCS and Parbhani	-	1977	1004/23.3.78
8	CSH 8R	36A X PD 3-1-11	Parbhani	SPH 18	1977	1004/23.3.78
9	CSH 9	296 A X CS 3541	NRCS	SPH 61	1983	19(E)/14.1.82
10	CSH 10	296AX SB 1085	Dharwad	SPH 196	1986	867(E)26.11.86
11	CSH 11	296AX MR 750	ICRISAT	SPH 221	1986	867(E)26.11.86

12	CSH 12R	296A X M148-138	Dharwad	SPH 221	1986	867(E)26.11.86
13	CSH 14	AKMS14AX AKR 150	Akola	SPH 468	1992	386(E)/15.5.90
14	CSH 13R	296 AXRS29	NRCS		1995	S.O.647(E)/ 9.09.1997
15	CSH 13K	296 AXRS29	NRCS	SPH 504	1995	527(E)/16.8.1991; 647(E)/9.9.97
16	CSH 15R	104AXRS585	NRCS	SPH 677	1995	1(E)/1.1.96
17	CSH 16 (SPH-723)	27AXC43	NRCS	SPH 723	1997	647(E)/9.9.97
18	CSH 17	AKMS14AX RS 673	NRCS	SPH 660	1998	425(E)/8.5.99
19	CSH 18	IM 9AX Indore 12	Indore, NRCS	SPH 960	1999	1050(E)/26.10.99
20	CSH 19R	104AXR354	Akola	SPH 1010R	2000	821(E)/13.9.00
21	CSH 20MF (UPMCH-1101)	2219AXUPMC503	Pantnagar	UPMCH 1101	2005	1172(E)/25.8.05
22	CSH 22SS (NSSH-104)	ICSA 38 X SSV 84	NRCS	NSSHJ 104	2005	1566(E)/05.11.05
23	CSH 23 (SPH-1290)	MS 7A X RS 627	NRCS	SPH 1290	2005	S.O.1566(E)/ 05.11.2005
24	CSH21	MLSA 848 X MLR 34	Mahendra	MLSH151	2005	S.O. 1177(E) dated 25.08.05
25	CSH 25	PMS28AXC43	Parbhani and NRCS	SPH 1567	2007	1108(E)/8.5.08
26	CSH 24MF (UTMCH-1302)	ICSA467Xpant chari 6	Pantnagar	UTMCH 1302	2009	O.S.2187(E)/ 27.08.09

Annexure-2. List of sorghum cultivars releases at state level.

Sr. No.	Name of Cultivar	Pedigree	(Center)	Tested number	Year of release	Notification number and date
	Sorghum varieties					
1	K1	Pure line selection from local irungu	Kovalpatti		1942	
2	Gujarat Jawahar-108	SURAT-1 X NURSERY-108	Gujarat		1969	19(E)/14.01.82
3	Muguthi Jola (5-4-1)	COTO- 2 X M. 35-1	Dharwad		1969	786/02.02.76
4	Annigeri-I (A-1)	M.35-1 X CS560-1-1	Karnataka		1969	
5	Pusa Chari-1	A selection from the original heterogeneous sample	IARI		1971	
6	Kovilpatti tall	2219 A X IS 3541	Kovalpatti		1972	786/2.2.76
7	JS-263		Punjab		1973	361(E)/30.06.73
8	JS-29/1		Punjab		1973	361(E)/30.06.73
9	JS-20		Punjab		1973	361(E)/30.06.73
10	Jaya	A selection from Aispuri Jowar	Rajasthan		1974	566(E)/21.09.74
11	SL-44	JS.263 X SG-59-3	Ludhiana		1975	440/21.08.75
12	Haryana Chari	A selection from the germplasm	Haryana		1976	786/02.02.76
13	Vidisha-60-1	Local material from Shankarpur village in Madhya Pradesh	MP		1976	786/02.02.76
14	MOTI	An induced mutant line from the variety IS 6928	ICRISAT, AP		1978	13/19.12.78
15	MAU TYPE-2		Uttar Pradesh		1978	13/19.12.78
16	M.P.Chari	Indore	Indore, Jabalpur		1978	13/19.12.78
17	SDM-9	*	Maharashtra		1978	13/19.12.78
18	Vasant-1	NMS8A X IS-84-Sel.1-2-2	NARI, Phaltan-MH		1978	13/19.12.78

19	MAU TYPE-1	Developed by selection from local material in Uttar Pradesh	Uttar Pradesh		1978	13/19.12.78
20	CO-23	Multiple cross involving four elite parents, 2077 A, 3660 A, 2219 A, AND CS 3541	Coimbatore	SPV136	1979	19(E)/14.01.82
21	CO-24(USV-5)	Ckharif60A X SPR. 1341	Coimbatore	SPV138	1980	19(E)/14.01.82
22	Pusa Chari-6	Pusa Chari 40 x Pusa Chari 67	IARI, New Delhi		1980	470/19.02.80
23	Jawahar Jowar-236 (SPV-236)	(VIDISHA 60-1 X CS 3687) 5 X (SWARNA X CS 3687) 596-2-3-3	Indore		1981	
24	Jawahar Jowar-235 (SPV-235)	(IS.2954 X CS 3541) 11X1	Indore, MP	I-781	1981	
25	K 6	A pure line selection from Usilampatti local sencholam	Kovalpatti		1982	19(E)/14.01.82
26	SB-1079	A derivative of the cross SHALLU X C.S. 3541	Karnataka		1982	19(E)/14.01.82
27	K 7	K 3 X M-35-1	Kovalpatti		1982	19(E)/14.01.82
28	Jawahar Chari-6	A selection from a sample received from Coimbatore	Indore		1982	19(E)/14.01.82
29	Jawahar Chari-69	A multicut Sudan type with regeneration capacity developed from the cross between kharif38 X J-98	Indore		1982	19(E)/14.01.82
30	HC-136	IS 3214 X PJ 7 R	Hissar, Haryana		1982	19(E)/14.01.82
31	NILVA				1983	
32	Gujrat Sorghum-35	A derivative of the cross (2077A X M.25) X MALVAN	Surat, Gujarat		1983	295(E)/09.04.85
33	Varsha	T22 X 5742-1A	Kanpur	-	1983	540(E)/24.7.85
34	SPV 297	CS 3541 X IS 3924	Parbhani	PVK9	1984	540(E)/24.7.85
35	GJ 36	(2219 A X BP 53)X BP 53	Surat	SPV596	1984	258(E)/14.05.86

36	SB-1066	A selection of Purdue-Base No. 954	Dharwad	SPV 35	1985	295(E)/09.04.85
37	CO 21(USV-1)	Tall mutant from 699 dwarfs	Coimbatore	SPV 80	1985	540(E)/24.7.85
38	CO 22(USV-2)	2077A X 30660AX2219 X CS3541	Coimbatore	SPV 81	1985	540(E)/24.7.85
39	SPV 96	148 X 512	Udaipur	SPV 73	1985	540(E)/24.7.85
40	SPV 245	SB 1066 X CS 3541	Udaipur	-	1985	540(E)/24.7.85
41	Pusa Chari-9	selected from IS4870	IARI	-	1985	295(E)/09.04.85
42	Pusa Chari -23	Selection from an exotic F1, hybrid martin X 907010	IARI	-	1985	295(E)/09.04.85
43	Gujarat jowar -9	Pure line Selection From Brooch district	Surat	G J-9	1985	832(E)/18.11.85
44	SB 905	out cross from kalagunda	Dharwad	SPV 247	1985	540(E)/24.7.85
45	RJ Chari-1(SU-45)	CSV 6 X NCL 3	Udaipur	-	1985	295(E)/09.04.85
46	CO-25 (TNS27)	(IS.4283 X 699 TALL) X CS 3541	Coimbatore	SPV 542	1985	832(E)/18.11.85
47	CO 26	MS 8271 X IS 3691	Coimbatore	SPV 462	1985	867(E)/26.11.86
48	RJ Chari-2(SU-52)	selection from local type of Udaipur	Udaipur	-	1985	832(E)/18.11.85
49	DSV 2	(IS2947 x SPV 232) X C0 22	Dharwad	SPV 462	1986	S.O. 867(E)/26.11.1986
50	k-4	CO 18 X kharif2	Kovilpatti	-	1986	258(E)/14.5.86
51	CO 27	CO 11 X S.halepense	Coimbatore	-	1986	425(E)/08.06.99
52	HUNDI		Uttar Pradesh		1986	
53	GJ 37	(2077 X M28)X Cuandri	Surat	-	1987	165(E)/06.03.87
54	Haryana Chari 171(HC-171)	SPV 8 X IS 4776	Hissar	-	1987	834(E)/18.09.87
55	Haryana Chari-260	SPV 103 X PC-9	Hissar	-	1987	834(E)/18.09.87
56	SAR 1(SPV 694)	555 X 168	ICRISAT	-	1988	471(E)/5.5.88
57	Improved Ramkel		Akola		1988	
58	Haryana Chari-6		CCS Haryana Agricultural University, Hisar, Haryana		1989	

59	Pant Chari-3	Visarda 60-1 X IS 6953	Pantnagar	-	1989	527(E)/16.8.91
60	K 8	IS 12611 C X SC 108	Kovalpatti	-	1989	915(E)/6.11.89
61	DSV 1	SB-1066 X CS 3541	Dharwad	-	1990	639(E)/17.08.90
62	GFS 4	GJ 37 X Sudan type	Surat	-	1990	639(E)/17.08.90
63	AKSV-37	SPV 97 X SPV 29	Akola	SPV 669	1990	386(E)/15.5.90
64	N-14 (Nandyala)	Produtur local	Nandyal	NJ 1031	1990	639(E)/17.08.90
65	Nandyala Tella Jona-2	Pure line selection from E-1966	Nandyal	NJ-2122	1990	639(E)/17.08.90
66	JJ741 (Jawahar Jowar 741)	CSV 4 X E 35-1	Indore	SPV 741	1991	527(E)/16.8.91
67	K10	K7XSPV102	Kovalpatti		1991	
68	SSV 84	Selection from IS 23568	AICSIP, Rahuri		1992	S.O. 814(E)/04.11.92
69	PVK 400 (Panchali)	SDS 2650 X CS 3541	Parbhani	SPV 860	1993	615(E)/17.8.93
70	K 9	M 36200 X tenkasi villas	Kovalpatti	-	1993	615(E)/17.8.93
71	HES-4 (High Energy Sorghum)	Selection from SPV 670 (PVR 176) (SPV 126 X SPV 297)	Parbhani	-	1994	636(E)/02.09.94
72	GJ 39	M49 XM51	Gujarat, Surat		1995	408(E)/04.05.95
73	GJ 38	GJ 35 X 35-1	Surat	-	1995	408(E)/04.05.95
74	ICSV-745 (SPV-949)/DSV 3	SPV 692 X A-6250-4-1-1-1	U.A.S. Dharwad		1996	1(E)/01.01.96
75	Selection-3	Selection From local Bedar	Rahuri	-	1996	1(E)/1.1.96
76	JJ-938	SPV 221 X E602	Indore	-	1996	1(E)/01.01.96
77	Haryana Chari-308	SPV 8 X IS-4776	CCS Haryana Agricultural University, Hisar		1996	1(E)/01.01.96
78	PSV 1 (SPV 462)	MS-827 X IS-3691	Palem	SPV 462	1996	01(E)/01.01.96
79	BSR-1	CSC 108-3 X CSV 4	Bhavanisagar, Tamil Nadu	ICSV239	1997	360(E)/1.5.97

80	GJ-40	(2077 A X M 25) X Malvan	Surat	-	1997	3602(E)/01.05.97
81	Pant Chari-4 (UPFS-23)	IS4776 X RIO (sweet sorghum line)	Pantnagar	-	1997	360(E)/01.05.97
82	DSV 5 (GRS-1)	selection from Natte maldandi	Dharwad		1997	647(E)/09.09.97
83	APk-1	TNS 30 X CO-26	Aruppukottai	-	1997	662(E)/17.9.97
84	DSV 4	E 36-1 X SPV 86	Dharwad	-	1998	401(E)/15..5.98
85	JJ 1041	SPV 475 X SPV 462	Indore	SPV 1041	1999	425(E)/08.06.99
86	GJ-41	Developed from the cross of (M 250 X GJ 36) X GJ 37	Gujarat Agril . University, Athwa Farm	SPV(1038)	1999	425(E)/08.06.99
87	GFS-5(FS 113)	SPV1087XGSSV148	Surat		1999	
88	NTJ-3(NJ 2169)	NJ 2092 X POD-24	Nandyal	NJ 2169	2000	821/13.09.00
89	Phule Maulee (RSLG 262)	M 35-1 X Selection3	AICSIP, Rahuri	RSLG 262	2000	821(E)/13.9.2000
90	Parbhani sweta (PVk 801) (SPV-1333)	Selection From ICRISAT population GD 34-5-5-3	Parbhani	SPV 1333	2000	821(E)/13.9.2000
91	SSV 74	PAB 74	Dharwad	-	2000	-
92	Adilabad		AP		2000	
93	Paiyur-2	IS 15845	Tamil Nadu	-	2001	92(E)/2.2.01
94	CO(S) 28	CO 25 X SPV 942	Coimbatore	-	2001	1134(E)/15.11.01
95	CO(FS) 29	Derivative of the cross TNS.30 X S.SUDANENSE	TNAU, Coimbatore		2001	1134(E)/15.11.01
96	Palem -2(PSV 2)		RARS, Mahabubnagar		2002	
97	Pratap Jowar-1430 (SPV 1430)	Selection SPV 96	Udaipur	SPV 1430	2004	161(E)/04.02.04
98	PVK 809	PVK 801 X SOV 881	Parbhani	SPV 1474	2004	Awaited
99	K 11	K 7 X A 6552	Kovalpatti	KS 7657	2004	161(E)/04.02.04

100	Pantchari 6	selection from Zimbabwe germplasm line SDSL 92140	Pantnagar		2004	
101	Parbhani Moti (PVR 396) (SPV 1411)	Selection From ICRISAT population GD 31-4-2-3	Parbhani	SPV 1411	2005	122(E)/02.02.05
102	Bundela (SPV 1388) (MASS-9601)	SPV946 XKSE33	Mauranipur, AICSIP	SPV 1388, MASS-9601	2005	1566(E)/05.11.05
103	Gujrat Fodder Sorghum		Gujarat		2005	122(E)/02.02.05
104	Pusa Chari-615	Pusa chari40 X Pusa chari 67	IARI, New Delhi		2006	1572(E)/20.09.06
105	JJ 1022	SPV 475 X SPV 462	Indore	SPV 1022	2006	Awaited
106	Phule Uttara (RSSGV 3)	Gulbhendi X SGS 8-4	Rahuri	-	2007	122(E)/6.2.2007
107	Haryana jower 513(HJ513)	A derivative of S-305(PJ-7RX SPV-80) XHC-136	Hissar	S-513	2007	S.O.1178(E)/20.07.2007
108	Phule Amruta (RSSV 9)	RSSV 2 XSPV 462	AICSIP, Rahuri		2008	S.O.72(E)/10.01.08
109	Phule Chitra (SPV 1546) (RSV 237)	SPV 655 X RSLG 112	Rahuri	SPV 1546	2008	72(E)/10.1.08
110	Phule Vasudha (RSV 423) (TSV kharifranti)	RSLG 206 X SPV 1047	AICSIP, Rahuri	SPV 1704	2008	72(E)/1.1.08
111	DSV 6	SB101A X somapur local	Dharwad		2009	O.S.2187(E)/27.08.09
112	AkSSV-22	Sweet sorghum -Akola	Akola		2009	S.O.449(E)/11.02.09
113	Phule Anuradha (RSV-458)	RSLG 559 x RSLG 1175	Maharashtra		2010	S.O.2137(E)/31.08.10
114	Phule Revati	SPV 1502 x CSV 216	AICSIP, Rahuri		2010	
115	Phule Panchami	Selection from local landraces	AICSIP, Rahuri		2010	

116	Kinnerea (MJ-278)				2010	S.O.211(E)/29.01.10
117	HJ 541	SPV80 X 29/1(p20-1-1-2)	Hisar		2010	
118	Pantchari 8	selection from Zimbabwe germplasm [SDSL95102-MCT-2-93]	Pantnagar		2010	
119	Prathap chari 1080		Rajasthan		2011	
120	Pant chari 7	Rio X [(IS4907 XIS 4776)X(IS607 XIS8607)]	Pantnagar		2011	
121	K 3	K1 X periyamanjal cholam	Kovalpatti		2011	
Sorghum hybrids						
1	MSH-33	SMS35-X SL 292	Mahyco, Jalna		1975	1975
2	RSH-1	M31- 2A X LSR1	Dharwad		1976	S.O.786/02.02.76
3	MSH-37	SMS307 X SL 292	Mahyco, Jalna		1976	1976
4	MSH-21	SMS149 X SL 247	Mahyco, Jalna		1978	13/19.12.78
5	MSH-8	SMS-35X SL254	Mahyco, Jalna		1978	13/19.12.78
6	GFSH-1	3660A X IS4776	Anand, Gujarat	SPH 139	1983	295(E)/9.4.85
7	Gujarat sorghum hybrid -1	MS-2077A X NSV13	Surat, Gujarat		1984	
8	COH 3(USH-1)	2077A X 699 Tall	Coimbatore	-	1985	832(E)/18.11.85
9	DSH-1	296A X SB1085	Dharwad	SPH196	1986	867(E)26.11.86
10	SPH 201	296AXPVR10	Parbhani (AICSIP)	SPH 201	1986	867(E)26.11.86
11	MFSH-3	S31 X SG101	Mahyco	-	1990	386(E)/15.5.90
12	AKSH-73 (SPH-388)	296A X R73	Akola	SPH 388	1990	386(E)/15.5.90
13	JaduChari-988 (SSG-988)	(PFF1 x PFG 2) x pfm 1	ProAgro Seeds	SSG988	1991	527(E)/16.8.91
14	COH-4	296AXTNS30	Coimbatore	-	1993	615(E)/17.8.93
15	Punjab Sudex Chari-1	2077A X Sudan grassline,SLG87	Ludhiana	-	1994	408(E)/4.5.95
16	Hara Sona (855-F)	(PFS 5A X PFS 5C) X PFS 5R	ProAgro Seeds	855F	1995	408(E)/04.05.95

17	Pusa Chari Hybrid-106	MS2219XPC23	IARI	PCH106	1996	360(E)/1.5.97
18	MLSH-296 (MLSH-14)	309 A X SB-1085	Mahyco, Jalna	MLSH-14	1997	647(E)/9.9.97
19	Safed Moti	PSA 93016XFSR 93025	ProAgro Seeds	FSH 92079	1999	425(E)/8.6.99
20	Adilabad Sorghum Hybrid-1	PSA - 9 X PSR - 34	RARS, Palem		1999	1134(E)/15.11.01
21	Palem Sorghum Hybrid-1 (PSH-1)	PSA -3 X PSR - 23	Palem, RARS		1999	425(E)/08.06.99
22	JKSH 22 (JKSH 161)	323 A X SB-1085	JK Agri-Genetics	JKSH 161	1999	425(E)/8.6.99
23	MAHABEEJ-7	314 A X SB-1085	Mahabeej, Akola	SPH 981	2000	821(E)/13.9.00
24	SPH-840	MS 70A X ICSR 89058	Akola, AICSIP	-	2000	92(E)/2.2.01
25	DSH 4R	316 A X SB-1085	Dharwad	-	2000	937(E)/4.9.02
26	SPH-837	AKMS14A XSU556	Udaipur	-	2002	937(E)/4.9.02
27	DSH 3	SB 401A X SPV 7001	Dharwad		2002	
28	Pusa chari hybrid-109	AKMS14A X SSG611	Pusa, IARI	PCH -109	2005	S.O.1566(E)/5.11.2005
29	Sugar graze *			(PAC 52093)	2005	S.O. 1182(E)/22.08.05
30	SPH-1567	28A XC43	Maharashtra		2007	S.O.1108(E)/08.05.08
31	PAC-501 (ICI-501)	5101 F X 501 M	ITC, Zeneca Ltd. Bangalore – 560001.		2007	401(E)/15..5.98
32	MFSH4	*	Mahendra seeds, Hyd		2008	
33	MFSH5	*	Mahendra seeds, Hyd		2008	
34	GK905	*	Ganga Kaveri seeds		2009	
35	Co 5	Derivative of ICS 51A x TNS 30	TNAU		2011	

Annexure 3. Sorghum germplasm accessions or selections released (direct releases) as superior varieties in different countries.

S. No.	Accession number	Country of origin	Year of release	Country of release	Released name
1	IS 6928	Sudan	1978	India	Moti
2	IS 8965	Kenya	1980	Myanmar	Shwe-ni 1
3	IS 2940	USA	1981	Myanmar	Shwe-ni 2
4	IS 302	China	1980	Myanmar	Shwe-ni 10
5	IS 5424	India	1980	Myanmar	Shwe-ni 8
6	IS 30468	Ethiopia	1980	India	NTJ 2
7	IS 18758	Ethiopia	1983	Burkina Faso	E-35-1
8	IS 4776	India	1983	India	U P Chari-1
9	IS 9302	South Africa	1980	Ethiopia	ESIP 11
10	IS 9323	South Africa	1984	Ethiopia	ESIP 12
11	IS 2391	South Africa	1989	Swaziland	MRS 13
12	IS 3693	USA	1989	Swaziland	MRS 94
13	IS 8571	Tanzania	1989	Mozambique	Mamonhe
14	IS 23520	Ethiopia	1989	Zambia	Sima
15	IS 9321	South Africa	1990	Mexico	NA
16	IS 9447	South Africa	1990	Mexico	NA
17	IS 13809	South Africa	1990	Mexico	NA
18	IS 18758	Ethiopia	1990	Burundi	Gambella 1107
19	IS 9830	Sudan	1991	Sudan	Mugawim Buda-2
20	IS 3923	Zimbabwe	1994	Botswana	Mahube
21	IS 23496	Ethiopia	1995	Tanzania	Pato
22	IS 3924	Nigeria	NA	India	Swarna
23	IS 18484	India	1984	Honduras	Tortillerio 1
24	IS 8193	Uganda	2001	Rwanda	NA
25	IS 8193	Uganda	2001	Kenya	Kari Matama 1
26	IS 9468	South Africa	2000	Mexico	Marvilla No SOFO 430201092
27	IS 13444	Zimbabwe	2000	Sudan	Arous el Rimal
28	IS 29415	Lesotho	2000	Eritrea	Shiketi
29	IS 15401	Cameroon	2001	Mali	Soumalemba
30	IS 21219	Kenya	2001	Rwanda	NA
31	IS 25395	Kenya	2001	Rwanda	NA
32	IS 33844	India	2002	India	Parbhani Moti

Annexure 4. TRIVSA expert elicitation workshop held at ICRISAT on 11 November 2011

TRIVSA Project Workshop on
Tracking of Sorghum Improved Varietal Adoption in India
11 November, 2011
ICRISAT, Patancheru, Hyderabad 502324, AP, India

ICRISAT Science with a human face

List of participants who attended the 11th November 2011 Workshop:

Dr JV Patil, Director, DSR, Hyderabad (represented by other DSR staff)

Dr Aruna C Reddy, Senior Scientist, DSR, Hyderabad

Dr AV Umakanth, Senior Scientist, DSR, Hyderabad

Dr ST Borikar, Consultant, HOPE Project, Parbhani

Dr RB Ghorade, Professor, Panjabrao Deshmukh Krishi Vidyapeeth, Akola

Dr SP Mehtre, Associate Professor, Marathwada Agricultural University (MAU), Parbhani

Dr Prabhakar, Principal Scientist, DSR, Solapur

SR Gadakh, Senior Sorghum Breeder, MPKV, Rahuri

Dr SS More, Field Officer (COC), MAU, Parbhani, Maharashtra

Dr YD Narayana, Senior Scientist (Pathology), AICSIP, Dharwad

Dr BD Biradar, Senior Sorghum Breeder, AICSIP, Bijapur

Dr BR Ranwah, Sorghum Breeder, AICSIP, Udaipur

Dr MV Nagesh Kumar (Palem)

Dr CV Sameer Kumar (Tandur), Senior Scientist (Plant Breeding)

Dr MV Subba Rao, Principal Scientist (Millets), Perumallapalle, Tirupathi

Mr C Rama Krishna, Nuziveedu Seeds Pvt Limited, Secundrabad

G HariNarayana, Consultant, ICRISAT

ICRISAT staff who attended the workshop:

Dr Belum Subba Reddy, Consultant, ICRISAT

Dr MCS Bantilan, Program Director, MIP, ICRISAT

Dr A Ashok Kumar, Senior Scientist, ICRISAT

Dr P Srinivasa Rao, Senior Scientist, ICRISAT

Mr P Parthasarathy Rao, Principal Scientist, ICRISAT

Dr Naveen P Singh, Senior Scientist, ICRISAT

Dr Uttam Kumar Deb, Principal Scientist, ICRISAT

Dr D Kumara Charyulu, Scientist, ICRISAT

Dr S Nedumaran, Scientist, ICRISAT

Dr G Basavaraj, Scientist, ICRISAT

Dr A Amarender Reddy, Special Project Scientist, ICRISAT

Dr Lalmani Pandey, Visiting Scientist, ICRISAT

Ms A Rajalaxmi, Scientific Officer, ICRISAT

About **ICRISAT**

International Crops Research Institute for the Semi-Arid Tropics

ICRISAT is a member of the CGIAR Consortium

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 near Hyderabad, Andhra Pradesh, India, with two regional hubs and five 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.

ICRISAT-Patancheru (Headquarters)
Patancheru 502 324
Andhra Pradesh, 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-Addis Ababa
C/o ILRI Campus, PO Box 5689
Addis Ababa, Ethiopia
Tel: +251-11 617 2541
Fax: +251-11 646 1252/646 4645

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

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

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

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

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

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