International Crops Research Institute
for the Semi-Arid Tropics

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

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Contributed paper prepared for presentation at the
57th AARES Annual Conference, Sydney,
New South Wales, 5th-8th February, 2013

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Abstract

Sorghum is the third cereal crop after rice and wheat in India, mostly grown under marginal and stress-prone areas of Semi-Arid Tropics (SAT). NARS, ICRISAT and private seed companies are the major stakeholders working for sorghum crop improvement in the last five decades (1960-2012). Altogether more than 256 improved cultivars have been notified and made available to farmers during the same time. The current knowledge about spread and impact of sorghum improved crop varieties in the country is incomplete. The present study made an attempt to address these issues with help of primary as well as secondary sources of information. The analysis has concluded that nearly 80 per cent of total sorghum area is under improved cultivars which helped to increase the country productivity levels by 85 per cent during 1960 and 2010. This aptly proves that role of sorghum improved cultivars in sustaining the higher yields.

Keywords: Development of improved cultivars, diffusion of sorghum improved cultivars in India, Impact on yield Growth and variability

Introduction

Sorghum [*Sorghum bicolour (L.)*] is one of the main staple foods for the world's poorest and most food-insecure people across the semi-arid tropics of world. *Sorghum bicolour* ssp. *Verticilliflorum* is believed to be the progenitor of cultivated sorghum (Harlan, 1972).It is cultivated in wide geographic areas in the Africa, Asia, America and the Pacific regions. It is the fifth most important cereal crop in the world, after wheat, maize, rice and barley whereas in India, sorghum is the third large cereal crop after rice and wheat. But, sorghum is second major crop in Africa after maize. It is a staple food, produced and consumed by millions of rural poor in South Asia (SA) and Sub-Saharan Africa (SSA). Sorghum often a recommended option for farmers operating in harsh environment where other crops do poorly, as it is grown with limited rainfall (400 to 500 mm) and often without application of any fertilizers or other inputs. In India, nearly 30-40% of the rainy season sorghum grown as sole crop while the rest cultivated as an intercrop with pulses and oilseeds. However, around 90 per cent of the post-rainy sorghum grown as a sole crop which is most preferred for food consumption purpose. Sorghum is grown for a variety of uses like food, feed, forage and fuel. However, it is also used for beer, alcohol, starch, sugar, bread and biscuit manufacturing industries. Sorghum grains constitute the principal source of energy, protein, vitamins and minerals. Above all, sorghum crop is one among the climate resilient crops that can adapt quickly to climate change conditions.

On global front, sorghum was grown in 105 countries of the world in the year 2010-11 covering an area of approximately 40.5 m ha with grain production of 55.65 m tons and an average productivity of 1.374 tons per ha (FAO website: http://www.fao.org). During the last three decades period (1980-2010), cropped area and production reported an annual growth rate of -0.34% and -0.51% respectively. Development and adoption of the improved cultivars, improved management practices have increased the productivity levels significantly despite tumbling acreage of sorghum across the globe in recent past. Sorghum primarily produced in India (7.38 m ha) constitutes about 18.21% share in global area followed by Sudan 5.61 m ha (13.85%), Nigeria 4.7 m ha (11.6%), Niger 3.3 m ha (8.14%) and USA 1.94 m ha (4.79 %) during 2010-11. But, the lion share in 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 is about five times higher than the productivity in developing countries. The world highest productivity levels were observed in USA (4520 kg per ha) while the productivity in India is hovering around 949 kg per ha.

Objectives of the study

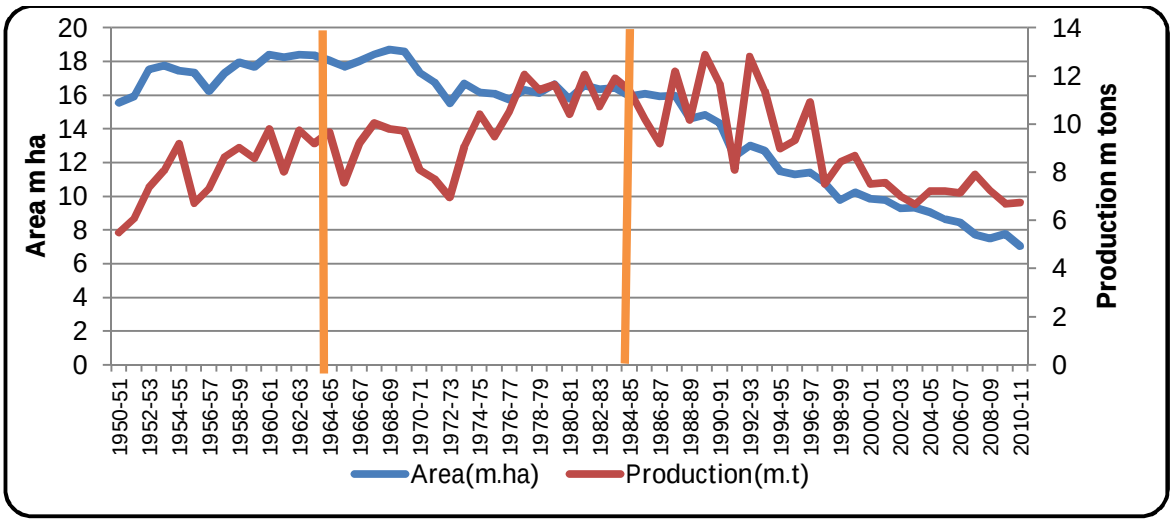
Realizing the importance of crop, the present paper made an attempt to understand the development and diffusion of sorghum improved cultivars in India over the period of last five decades. Indian Council of Agricultural Research (ICAR includes Directorate of Sorghum Research(DSR), Hyderabad and All India Coordinated Sorghum Improvement Project (AICSIP)) have been working for sorghum crop improvement in diverse agro-ecological zones of India since early 1960s. Similarly, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), an International Agricultural Research Centre (IARC) established at Patancheru, Hyderabad, Andhra Pradesh have also chosen sorghum crop as one of its five mandate crops and conducting research for its development from 1972. ICRISAT is playing a

catalytic role in maintaining and distribution of sorghum core germplasms as well as development of parental lines/ open pollinated varieties in Asia (especially in India) and Sub-Saharan Africa (SSA). Another key stakeholder for rapid development of sorghum crop in India was the private seed companies (around 35) whose presence was very active from late 1980s. A comprehensive and systematic study on development and diffusion of sorghum improved cultivars in major states of India would provide interesting insights about history of crop improvement. Current knowledge about 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 sub-national levels. With these issues in mind, the present study made an effort to understand the sorghum improved cultivars adoption and its impact in major states of India.

Performance of sorghum in India and major states

India is one of the major producers of sorghum in the world. It holds first and second ranks in terms of global area and production respectively (FAOSTAT, 2012).In early fifties, sorghum was referred as 'great millet' because it was major cereal staple occupied an area of more than 16 million ha. But, recently it has come down to 7.38 m ha by 2010-11(5.82% of GCA, India) and contributes about 7.0 m tons (2.86%) to India's total food production (see Fig 1).

Fig 1 Sorghum area and production trends in different periods



Source: Ministry of Agriculture, GOI

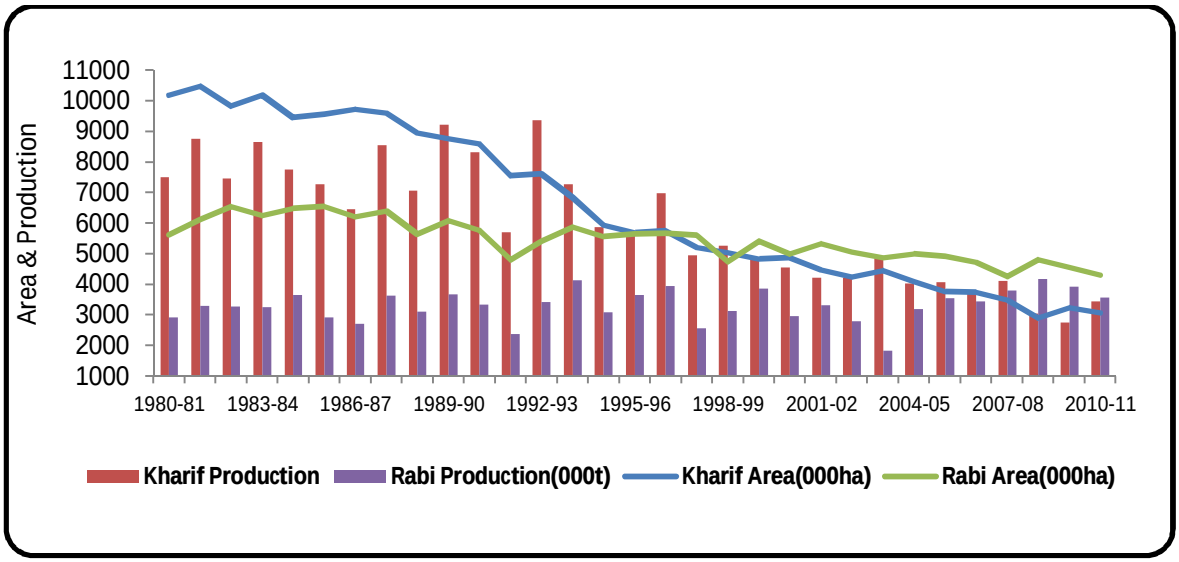
Broadly, the area, production and productivity trends in Indian sorghum reveals three distant time periods or phases : Phase-1: Post-independence period (1947-1965); Phase-II: Public-supported growth period (1965-85) and Phase-III: Private sector driven growth period (1986 to present). Although the total area is declining, the post-independence period witnessed major increase in production of sorghum due to increase in yields when compared initial years after independence. By the mid-60s, new hybrids of sorghum were developed as part of the AICSIP. Particularly, the CSH series of national system, which are high yielding and short duration were successful at raising yields. In the last period, from 1986 to the present 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.

The major factors attributed for this declining trend in area and production in recent past are improved irrigation facilities resulted in shift over to other commercial crops like groundnut, sunflower, soybean, pigeon pea, chickpea, maize, cotton and sugarcane. In addition to that, the changing food habits (Basavaraj *et al*., 2011& 2012; NSSO Report, 2004-05), availability of superior cereals at affordable prices (subsidized through public distribution system) and raising income levels, effect of biotic and abiotic factors etc. played crucial role. Some of the government policies favouring the commercial (cotton & sugarcane) crops cultivation through liberal loan facilities ruined the crop choices among farmers. This shift has serious concern on the cropping systems and the food and fodder security of these dry land regions of the country.

In India, sorghum crop is being grown in two seasons: kharif (rainy) season as a rainfed crop while in rabi (post-rainy) 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 post-rainy season. In 1965-66, the area shares between kharif and rabi in the total cropped area was 62.0 and 38.0 per cent respectively. But, these proportions have changed to 41.6 and 58.4 per cent respectively by 2010-11. The reason for these shifts was poor quality of kharif grains due to rains at the time of harvesting which was fetching lower prices in the market (see Fig 2 and Table 1).

Fig 2 Performance of kharif and rabi sorghum in India



The details of season-wise growth rates in area, production during periods 1980-2010 are summarized in Table 1. Kharif production has declined despite successful crop improvement efforts by public and private sectors due to declining in kharif sorghum area since 1980s.On the other hand, the yields are steadily increased to almost 1000 kg ha^{-1} due to adoption of improved cultivars (Pray and Nagarajan, 2009). Even though there is a slight fall in rabi area, the production was much stable over the study period. In fact, the rabi production growth rate was positive during 1980-2010. Overall trend indicates that the steep decline in total

sorghum area (-2.89%) and production (-1.95%) at all India level. Around 8 per cent of total sorghum cropped area in the country is under irrigated conditions. Nevertheless, the technological advancement in sorghum has kept the sorghum production a little stable regardless of decline in area planted.

Table 1 Sorghum area and production growth rates (%)

Period	Kharif area	Kharif production	Rabi area	Rabi 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& Statistics, 2012

In general, the average productivity levels are higher in kharif season when compared to rabi season. The main reasons for rabi low productivity are crop is grown on residual moisture, non- availability of high yielding varieties, partial or less use of chemical fertilizers, high seed rate and narrow row spacing etc. However, the grain quality is much superior in rabi season when compared to kharif season. Most of the kharif production goes for industrial and poultry uses while majority of the rabi production goes for human consumption.

Sorghum performance across major states

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

The details of sorghum performance in major producing states are summarized in Table 2. The area under Maharashtra has declined from 6.25 m ha in 1966-68 to 4.10 m ha in 2008-10. The production was much stable and productivity has increased significantly (61%) during the same period. Karnataka exhibited similar trend in area and production whereas the productivity has improved drastically (114%). Andhra Pradesh lost both area and production considerably but the mean yields have increased reasonably (170%). Gujarat almost followed the similar path of Andhra Pradesh during study period. Rajasthan also lost sorghum area appreciably between 1966 and 2010. In case of Madhya Pradesh, the cropped area has declined significantly to 20 per cent and production to one-third between 1966 and 2010. But, the productivity registered a substantial improvement from 725 to 1295 kg per ha.

Table 2 Sorghum performance in major producing states (A – m ha; P – m tons and Y – kg/ha)

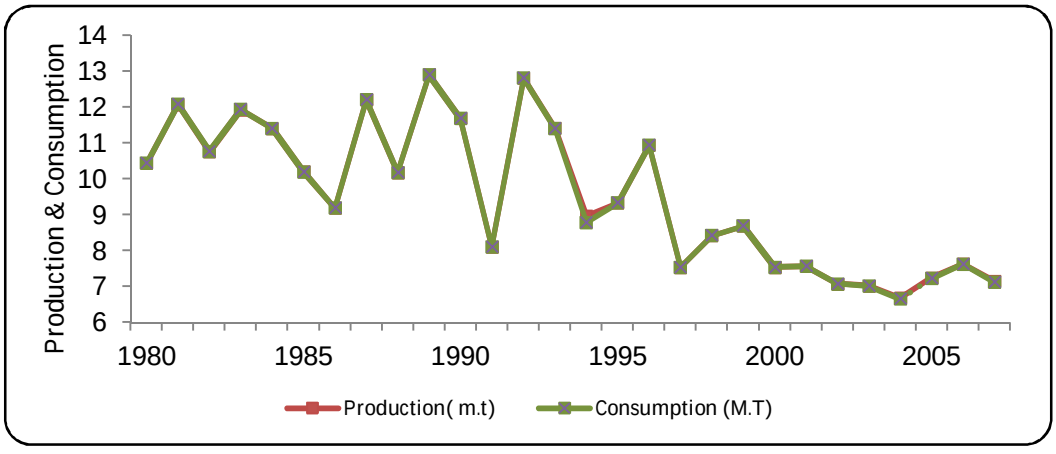
State	1966-1968			1976-1978			1986-88			1996-1998			2008-2010		
	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield	Area	Prod	Yield
Andhra Pradesh	2.57	1.24	483	2.21	1.31	587	1.51	0.87	568	0.80	0.56	695	0.30	0.39	1304
Gujarat	1.31	0.35	264	1.03	0.57	553	0.73	0.27	354	0.29	0.25	862	0.15	0.17	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& Statistics

Utilization pattern of sorghum in India

In the last two decades the nature and utilization of sorghum grain has undergone a change from staple food to industrial uses such as livestock and poultry feed, potable alcohol, starch and ethanol production (Kleih *et al.,* 2000). Additionally, 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*, *khichdi* etc. which are, though in the nascent stage, are likely to be significant avenues for diversifying utilization trends of sorghum. In India, consumption is more or less analogous to the production trend. However, grain as a whole consumption declining with the falling production figures with an annual growth rate of around -2.06% (see Fig 3).

Fig 3 Sorghum production and consumption in India



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

Development of sorghum improved cultivars in India

There was little research emphasis on sorghum in the pre-independence period. Even after independence these crops received tiny research attention, until the creation and expansion of the All India Coordinated Crop Improvement Projects (AICRPs). In the early 1960s, the ICAR, with Rockefeller Foundation assistance, initiated research on hybrid sorghum. Under ICAR direction, AICSIP has formed in 1969 to look after the sorghum research activities at national level. These programs initiated public research and conducted multi-location testing for improved characteristics of sorghum hybrid and varieties with support from state agricultural universities, 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 HYVs and open pollinated varieties and boosted productivity. Hybrids CSH-1 to CSH-23 are a testimony to the success of 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; Belum VS Reddy, 2008; Bantilan *et al.,* 2004).

Table 3 summarizes the releases of improved cultivars by different stakeholders between 1964 and 2011. ICRISAT has released around 41 improved cultivars in India either by sharing their germplasms or breeding materials to NARS and private seed companies during 1975-2011. Similarly, ICAR has also released 55 improved cultivars nationally for growing in major sorghum states in India between 1964 and 2011.

Table 3 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	7	12	55	67
1991-00	18	13	58	71
2001-05	3	6	20	26
2006-11	12	6	25	31
Total	**41**	**55**	**201**	**256**

*only national hybrids and varieties
** Includes state, SAU's releases and parental lines from NARS

The major sorghum states including their respective state agricultural universities have released around 201 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. Till now

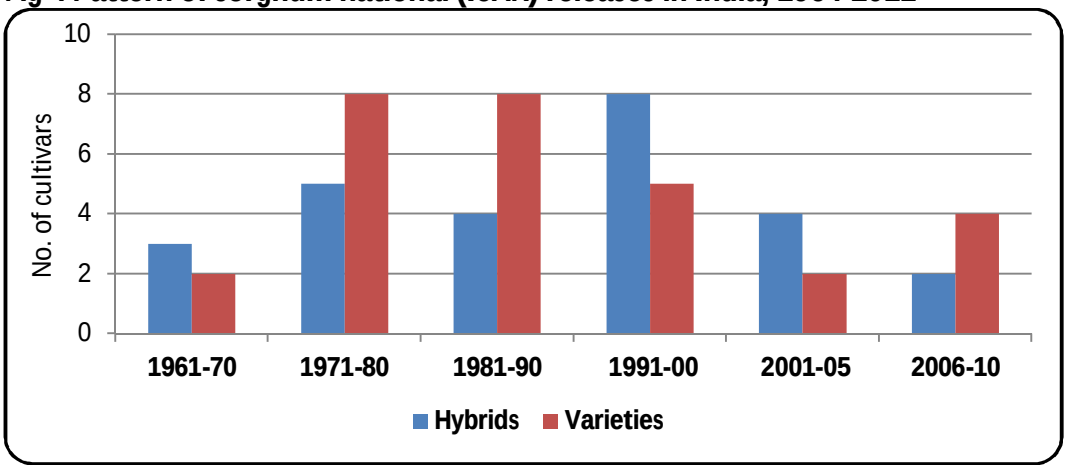
approximately 46 notified parental lines have been characterized and documented. A total of 256 improved cultivars have been released and made available to farmers through NARS in India. The releases were at their peak during late 1990s (71) followed by late 1980s (67). In general, the no. of releases in the last decade has declined to 57 when compared to earlier two decades. Specifically, the state releases have come down during the last decade (2001-2011).

NARS releases

The detailed break-up of national and other notified releases over a period of 1960 to 2011 are summarized in Fig 4 and Fig 5 respectively. 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[1]. Similarly, the details of total notified cultivars across the same period are also furnished in Fig 6. It is clearly conspicuous from diagram that till 1990s mostly dominated by varieties whereas the major thrust on hybrids have been started rigorously afterwards.

The wide spread research work on sorghum crop in last fifty years period resulted in development of myriad of varieties, hybrids and parental lines for sorghum crop improvement in India. All the stakeholders (DSR, AICSIP, SAUs, ICRISAT and Private seed companies) together notified around 256 as per available different sources of information from Department of Agriculture and Cooperation and State Agricultural Universities. 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, all private seed companies that have released hybrids in India have close collaboration with ICRISAT under HPRC consortia.

Fig 4 Pattern of sorghum national (ICAR) releases in India, 1964-2011



[1] See also Vilas Tonapi *et al.*, (2009) for further details

Fig 5 Pattern of sorghum state releases (including SAUs), 1964-2011

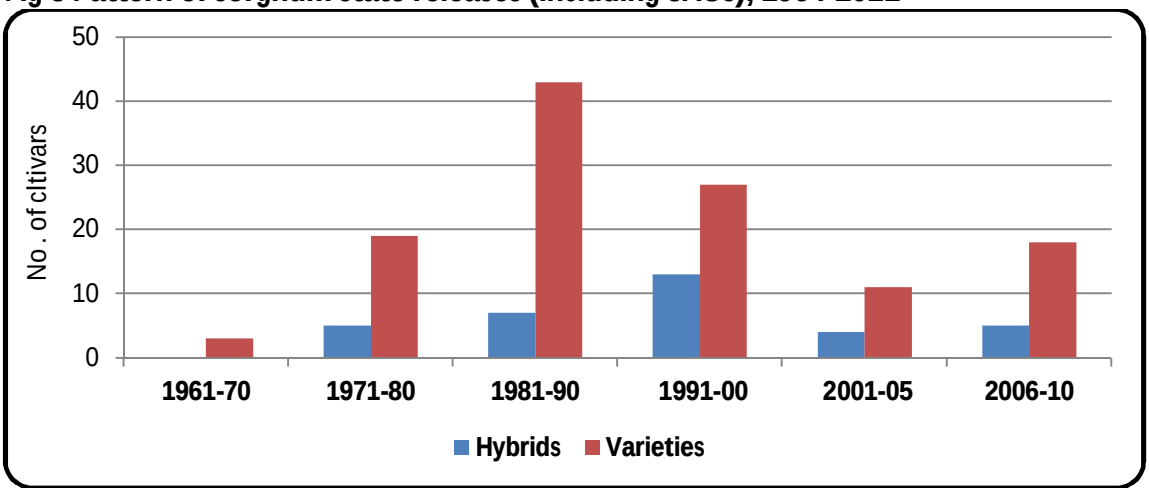
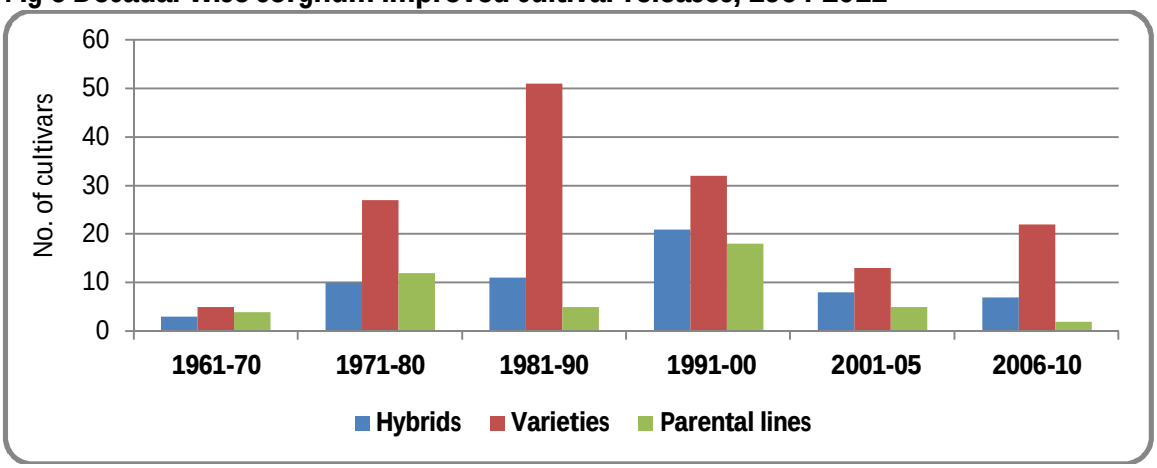


Fig 6 Decadal-wise sorghum improved cultivar releases, 1964-2011

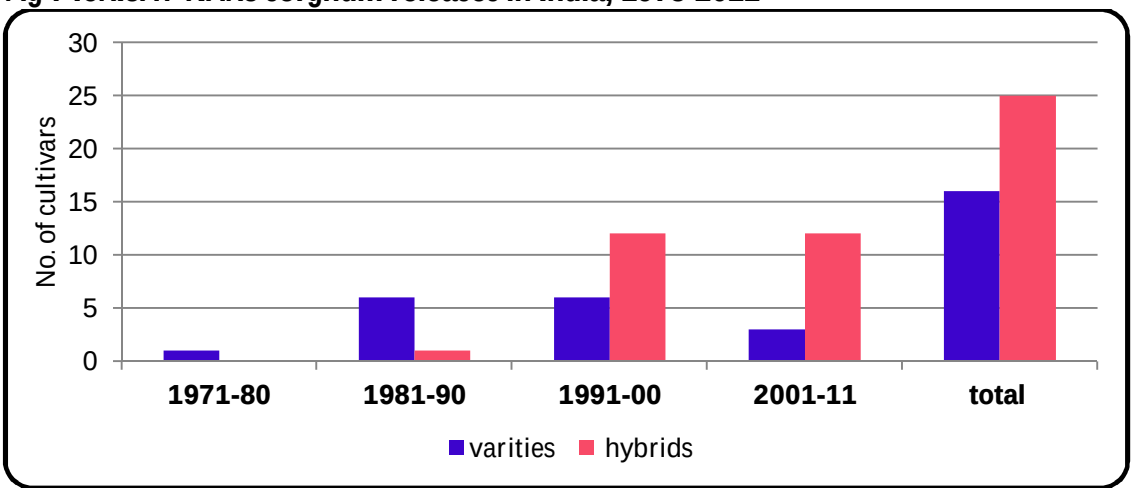


ICRISAT-NARS releases in India

ICRISAT doesn't release any improved cultivar directly in India or any other country in the World. ICRISAT do maintain close research collaborations with the NARS partners in a particular country and share the breeding materials with them. The partners put these materials in multi-location trials and release them as improved cultivars if they found superior over check/local cultivars. Similarly in case of India, ICRISAT either shared the germplasms or advanced breeding materials with NARS, SAUs and private seed companies since 1972.

Of late, ICRISAT has also initiated Hybrid Parents Research Consortium (HPRC) with private seed companies as its members during 2000-01. The main aim is quick generation of the suitable parental lines and gene pools which would immediately fit in to the NARS as well as private seed companies' research. Like this, ICRISAT in collaboration NARS partners have released as many as 41 improved cultivars between 1975 and 2011. Among the 41 improved cultivars, there are 16 varieties and 25 hybrids with diversified salient features and traits. The pattern of these releases is furnished in Fig 7. Apart from these Indian releases; ICRISAT also developed and released 209 cultivars (except Indian releases) globally for different regions (also see Fig 8).

Fig 7 ICRISAT-NARS sorghum releases in India, 1975-2011



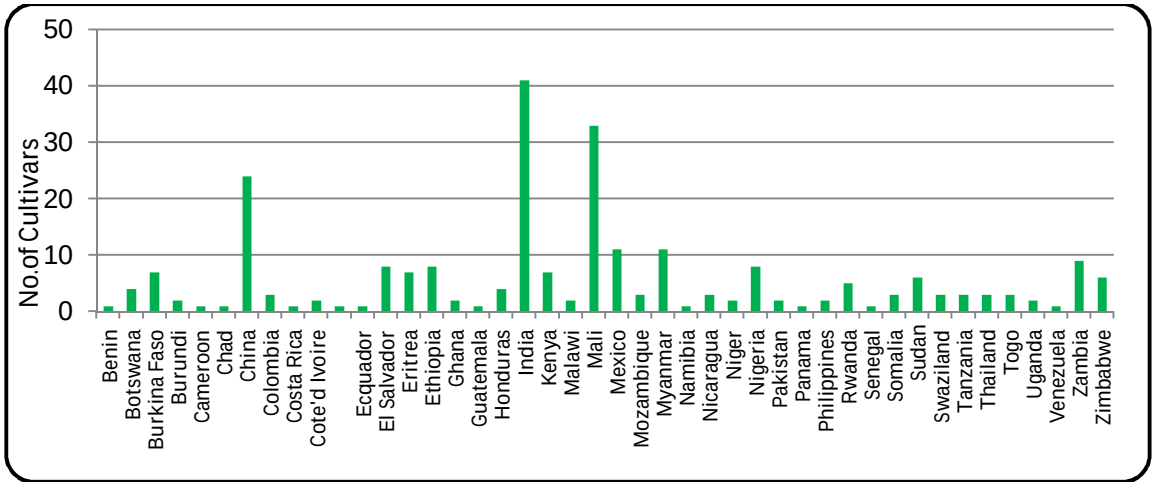
Source: ICRISAT Dryland Cereal Program, 2012

The details of total number of improved sorghum cultivars (varieties and hybrids) released by ICRISAT either through supply of germplasms and breeding materials to NARS in different regions of world between 1975 and 2011 is summarized in Table 4. A total of 250 improved cultivars were made available in 44 countries of Asia, Africa and America. Almost 52.8 per cent of these releases were concentrated in African countries followed by Asia (33.2%) and America (14%). The top three individual country beneficiaries from ICRISAT research and materials are India (41 cultivars) followed by Mali (33) and China (24). Due to the presence of ICRISAT headquarters at India and existence of strong NARS system to make use of breeding materials might have helped to gain relatively higher advantage. The country-wise releases during 1975-2011 are depicted in the Fig 8. The releases were at their peak during early 1990s across all the regions which contributed nearly a total of 56 improved cultivars. After that, the number of releases is decreasing in trend over time but the numbers of countries having improved cultivars are increasing.

Table 4 ICRISAT global releases of sorghum cultivars, 1975-2011

Years	Africa	America	Asia	Total	India	Other Asia
1975-80	9	4	4	17	1	3
1981-85	5	7	11	23	2	9
1986-90	31	11	6	48	5	1
1991-95	28	9	19	56	11	8
1996-00	24	4	18	46	7	11
2001-05	21	0	10	31	3	7
2006-11	14	0	15	29	12	3
Total	132	35	83	250	41	42
% share	52.8	14	33.2	100	16.4	16.8

Fig 8 Country wise sorghum cultivar releases (1975-2011)



The detailed break-up (variety or hybrid) of the total releases across regions are summarized in Table 5. In total, ICRISAT has released 191 varieties and 59 hybrids during 1975-2011 among four regions. With in Africa, more releases were took place in ESA (71) when compared with WCA (61) during the same period. Around 63.8 per cent of total varieties and 16.9 per cent of total hybrids have been released in Africa alone. American region also received more varieties when compared to hybrids. In case of Asia, this trend was reverse in order (19.9% of total varieties and 76.2% of total hybrids). NARS systems across the globe have evaluated hybrids/varieties developed in partnership with ICRISAT in their network or regional trials to select for local specific adaptation materials. The period 1985-2000 indicates most productive and maximum of releases in different sorghum growing countries. During the last decade (2001-2010), the release pattern is relatively lower and gaining momentum through different interventions.

Table 5 ICRISAT global releases by region and type

Region	Varieties	Hybrids	Total
WCA	57	4	61
ESA	65	6	71
America	31	4	35
Asia	38	45	83
Total	**191**	**59**	**250**

Deb and Bantilan (2003) have observed that countries with weak NARS, especially in Africa, benefited primarily from ICRISAT developed varieties and through technology spillovers. On the other hand, countries with strong NARS in Asia benefited largely from elite breeding materials developed by ICRISAT. However, the study also conducted by Shiferaw *et al.,* (2004) concluded that about 95 varieties from the total of 130 have had spillovers effects in different countries. Though ICRISAT's African programs have released few hybrids (especially in Sudan, Botswana and Nigeria) exhibited low adoption and spillovers mainly due to the non-availability of sufficient seeds. Similarly, materials have also come from Africa to Asia, which were tested and released subsequently (Eg. PARC-SS-2 and NTJ2).

Tracking of improved cultivars adoption in India

Due to the high importance of sorghum crop, substantial amounts of money have been invested for crop improvement in recent past by national and international research centres. International research institutes in partnership with national research systems (both public and private) have made concerted efforts to develop improved sorghum cultivars and increase the yields and ultimately the social well-being of the producers and consumers of sorghum. This benefit of research can reach farmers only when released cultivars are get adopted by the farmers. Based on Department of Agriculture, GOI estimates the area under improved cultivars are increasing over period of time (see Fig 9). Based on 2007-08 crop estimates, the proportion of area under modern cultivars have been reached almost 80 per cent. Over the study period, the share was steadily grown up to 1999. After that a slight slump was observed in the area share between 1999 and 2003. From 2004 onwards, it is again in the increasing trend.

Fig 9 Sorghum cropped area under modern varieties in India

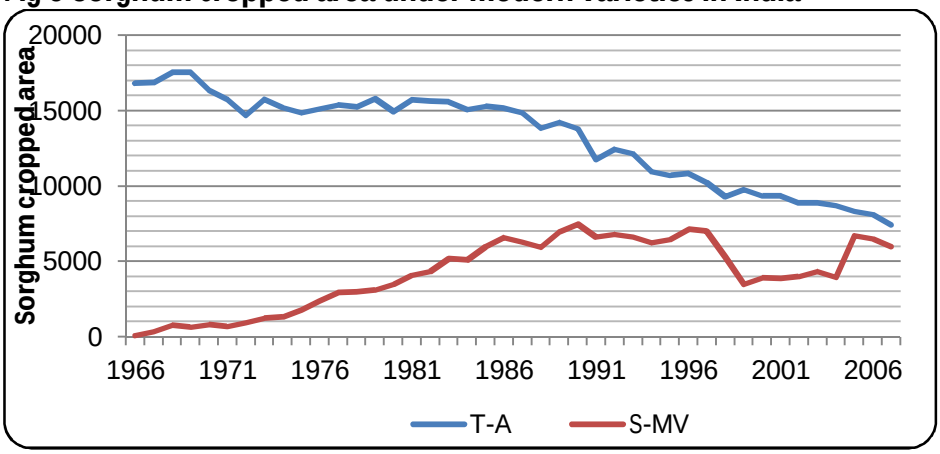


Table 6 Diffusion of improved cultivars in major states (per cent area)

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

In India, the rate of adoption of improved sorghum cultivars in different states is presented in Table 6. Based on 2006-08 mean crop estimates, the highest adoption was noticed in case of Maharashtra followed Madhya Pradesh and Tamil Nadu. Karnataka is next in the order with 75 percent area under improved cultivars. Except in case of Andhra Pradesh, the area under improved cultivars was in increasing trend in all study states between 1996-98 and 2006-08. There was steep decline in Andhra Pradesh state (-54.4%) in area under improved cultivars during the same period. Overall, the all India sorghum area under improved

cultivars share has gone up and registered a growth of 19.4 per cent (see also Fig 10 & 11 for state-wise adoption patterns of sorghum improved cultivars).

Fig 10 Diffusion pathways of sorghum improved cultivars in major states

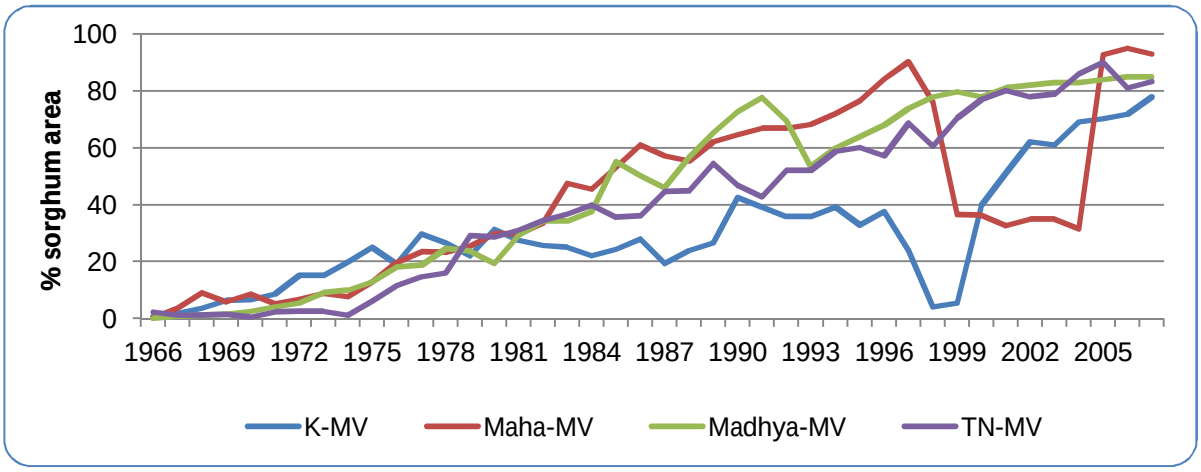
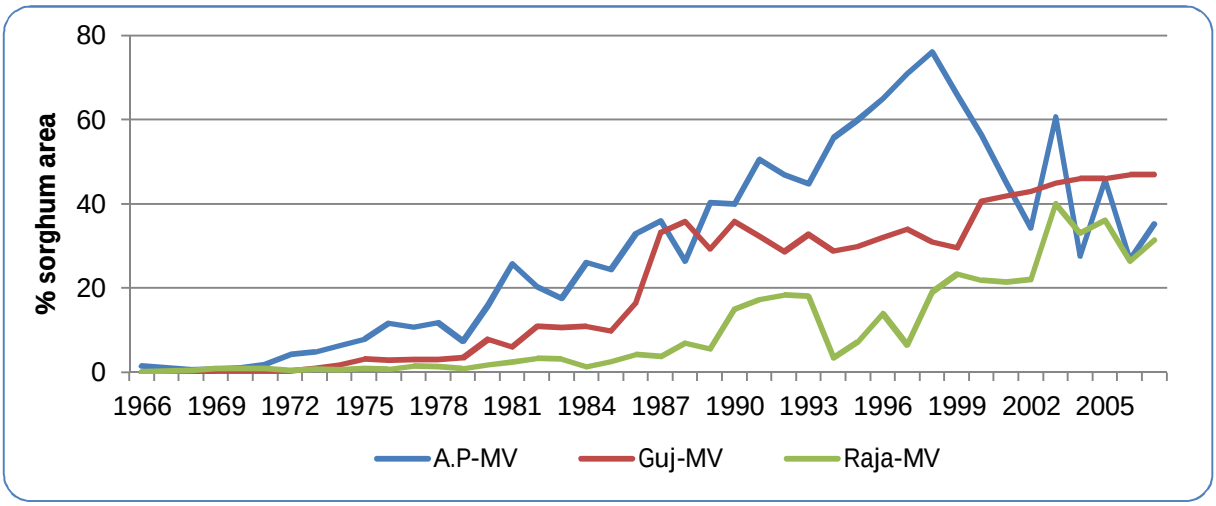


Fig 11 Diffusion pathways of sorghum improved cultivars in major states



In India, improved open-pollinated varieties were less popular than the hybrids from the beginning (Rana *et al*., 1997). There were different phases in the spread of improved sorghum cultivars in India. Until 1975, only CSH1 was dominant, and it replaced traditional local cultivars. Between 1976 and 1986, the dominant improved sorghum cultivars were CSH5 and CSH6. This phase was characterized by the replacement of traditional and initial improved cultivars (CSH1, CSH2, and CSH4) by new cultivars (CSH5, CSH6). After 1986, the initial cultivars were replaced by new cultivars (CSH9, 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).

Cultivar specific adoption estimates in major states

ICRISAT has assessed the cultivar-specific adoption estimates in major sorghum growing states under *'Tracking varietal Change for Future Assessment of the Impact of Crop Genetic*

Improvement in South Asia (TRIVSA)' project supported by Bill and Melinda Gates Foundation (BMGF). ICRISAT has adapted a series of expert elicitations for obtaining the reliable adoption estimates at each state-level. For conduct the elicitations in India and major states, ICRISAT has collaborated with National Agricultural Research System (NARS), specifically with Directorate of Sorghum Research (DSR) as well as All India Coordinated Sorghum Improvement Program (AICSIP). TRIVSA team officially took part in the 41st Annual Meetings of AICSIP held at Dharwad, Karnataka during April, 2011. Normally, this is the time that all the scientists who are working on sorghum crop improvement in India would attend these meetings for planning of their next year technical program for crop development. It was one of the rarest opportunities where TRIVSA team met all the sorghum improvement scientists (around 150) in India at one place. The project team innovatively took advantage of this chance and explained about TRIVSA initiative and collected the feedback from each AICSIP centre separately. This could be one of the fastest methods of updating cultivar specific adoption information in the country.

Table 7 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
Kharif			Kharif		
CSH-9	1983	40	CSH-15	1995	13.9
CSH-14	1992		CSH-18	1999	12.3
CSH-16	1997		Ajeet 997	-	10.7
M LSH-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
Rabi			JJ-938	1996	0.7
M-35-1	1968	20	RS-29	1991	0.1
PhuleVasudha	2008	30			
ParbhaniMoti	2005				
CSH-15R	1995	Negligible			
All MVs		**50**	**All MVs**		**77**

Source: Elicitation survey 2012, ICRISAT

Overall, ICRISAT has conducted the expert elicitations in two rounds. First round of expert elicitations were conducted with scientists of respective AICSIP centres located in that state. In general, each expert elicitation was consists of at least 4 to 5 scientists who are based at that AICSIP centre. Always the elicitation group has represented scientists with diverse back grounds (breeder, plant protection, agronomy, extension and seed science etc.). Based on the group knowledge and skills, the information was collected either at regional or state level. After obtaining this preliminary adoption estimates from each state, ICRISAT has conducted the second round of elicitation with state/national level experts in a separate sorghum workshop on 11th November 2011.The details of state-wise cultivar specific adoption estimates of improved varieties and hybrids are summarized in the Tables 7, 8 and 9. 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 (NSC) and State Agricultural Universities (SAUs)/extension departments were some other avenues for validation of this information.

Table 8 Cultivar-specific adoption estimates in Andhra Pradesh, 2010-11

Cultivar	Release year	% share in area	Cultivar	Release year	% share in area
Kharif			Rabi		
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**

Table 9 Cultivar-specific adoption estimates in Rajasthan

Rajasthan		
Cultivar	Release year	% share in area
CSV-15	1996	10.9
JKSH-592	-	4.4
SSG-593	1978	2.9
CSV-10	1986	2.4
KJH-6363	-	2.2
CSH-9	1983	1.1
Others	-	11.1
All MVs	-	**35.0**

Table 10 Pattern of varietal replacement in major states by release year

Released years	Andhra Pradesh		Maharashtra		Madhya Pradesh (kharif)	Rajasthan (kharif)
	Kharif	Rabi	Kharif	Rabi		
1960-70	0	10	0	20	0	0
1970-80	0	0	0	0	0	3
1980-90	0	10	15	0	0	4
1991-00	38	30	45	1	77	11
2001-10	2	0	20	29	0	0
Period unknown	0	0	20	0	0	17
% area under MVs	**40**	**50**	**100**	**50**	**77**	**35**

The patterns of varietal replacement by their age are summarized in Table 10 for major sorghum growing states in India. 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 were occupied major shares of cropped areas in different states. In case of rabi sorghum area in Maharashtra and Andhra Pradesh, M-35-1 still dominates even though it was released during 1960s.

Impact of improved cultivars on yield and variability

In general, impacts of crop improvement research/technology could be perceived in terms of yield gain, reduction in unit production cost, technology spill over 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 is declining since 1980s; the productivity gains were observed in all major growing states due to the increased adoption of improved cultivars. Nevertheless, the impact of improved cultivars on yield gains and its stability needs to be assessed deeply for further understanding.

Data sources

The study mainly used secondary data collected from two sources: 1. district-level secondary data published in the State Season and Crop reports and State Statistical Abstracts 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 (see Table 11).

Table 11 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, DakshinaKannar, UttaraKannar, Kodugu
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, Tanjavur, Nilgiris, Kanyakumari
Over all	164	132	-

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 were removed in data analysis due to low cropped area and non-availability of data etc. Hence, the total no. of districts under study was 132 from seven states (see Table 11).

Table 12 analyse 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 case of Andhra Pradesh, the productivity levels across different time periods were increasing significantly but the coefficient of variation has also increased substantially during third period. This may be due to decrease in area under improved cultivars during that period. On the other end, Gujarat has improved its productivity and reduced the variability as the area under modern cultivar increases. Even though the productivity levels were slightly increased in case of Karnataka, the variability also increased during last period. Similarly in case of 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 is a slight increase in variability during the last period. The increase in productivity and decrease in coefficient of variation was clearly 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 increasing in area under improved cultivars increases the yields and reduces the variability.

Table 12 State-wise mean and variability in sorghum yields

State	1966-79 (P-1)		1980-93 (P-2)		1994-07 (P-3)		P-3 over P-2 (%)	
	Yield (kg/ha)	CV(%)	Yield (kg/ha)	CV(%)	Yield (kg/ha)	CV(%)	Yield (kg/ha)	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 13 Distribution of sorghum districts based on instability in yields, 1966-2007

States	Instability (C.V) in yield (% districts)			
	< = 25 per cent	26-50 per cent	51-75 per cent	>75 per cent
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 the parenthesis indicates no.of districts

Table 13 summarizes the long-term instability analysis in yields of different districts during 1966-2007. The data clearly reveals that nearly 67 per cent of study districts showed variability between 26 and 50 per cent. Only 14 districts displayed the variability less than 25 per cent 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 14 Distribution of districts based on sorghum area under improved cultivars

States	Per cent 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 14 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 no.of districts with greater than 50 adoption rate have gone up from 11 in 1977-79 to 74 in 2005-07. Similarly, the no.of districts with less than 50 per cent adoption rate have come down from 121 to 58 during same time. However, nearly 39 districts still showed the adoption rates less than 25 per cent. These districts were mainly concentrated in Madhya Pradesh and Rajasthan states of India. On the other end, the districts with higher adoption rates were situated mostly in Maharashtra and Madhya Pradesh states.

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) (see Table 15). The district level yields were regressed against respective district sorghum cropped area, area under improved cultivars, area under irrigation and deviations in normal rainfall, ratio of kharif to rabi sorghum area and with state dummies. To further scrutinize the variability at state-level,

six state-level dummy variables were added in the equation. OLS method of estimation was used for calculations. The empirical form of equation was as follows:

$Y_d = a + b_1 a + b_2 a_H + b_3 a_I + b_4 r_D + b_5 a_R + b_6 d_G + b_7 d_K + b_8 d_M + b_9 d_{MA} + b_{10} d_R + b_{11} d_T$

Table 15 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 (a)	-1.838	.555	-3.313	.001*
% area under MV ($a_{H)}$	1.218	.172	7.092	.000*
Irrigated area ($a_{I)}$	-.618	4.402	-.140	.889
Deviations in RF (r_D)	4.649E-02	.133	.350	.727
K/R ratio (a_R)	-5.669E-03	.015	-.366	.715
D-Gujarat (d_G)	-744.302	151.288	-4.920	.000*
D-Karnataka (d_K)	-69.752	123.904	-.563	.575
D-Maharashtra (d_M)	-61.739	127.656	-.484	.630
D-Madhya Pradesh (d_{MA})	-1222.394	192.958	-6.335	.000*
D-Rajasthan (d_R)	-527.854	106.906	-4.938	.000*
D-Tamil Nadu (d_T)	-229.509	140.452	-1.634	.105
R-square	0.449			
N	132			

* Significant at 1 per cent 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 district level. This is true because districts with large sorghum area are expected to grow sorghum over a wider range of agro-climatic environments, which leads to increases the probability of lower average yields of that district. Therefore, this relation was anticipated in 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 kharif season and ratio of kharif to rabi area did not displayed any relationship with yields. However, among the six state-level dummies; Gujarat, Madhya Pradesh and Rajasthan dummies were significant at one per cent level. This clearly indicates that the yields in these states were significantly different from the yields in Andhra Pradesh state. Overall, the findings are in concurrence with the results obtained by Deb *et al.,* 1999.

Determinants of variability in sorghum yield

Another regression equation was fitted to analyze the determinants of variability in sorghum district level yields (see Table 16). For this purpose, the coefficient of variation was calculated for all study districts yields for the period 1996 to 2007. This coefficient of

variation was taken as a dependent variable in 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. A total of 132 observations was 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 16 Determinants of variability in sorghum yields

Variables	Unstandardized Coefficients	Std. Error	t	Sig.
(Constant)	50.734	4.002	12.678	.000*
SMV (a_{Hm})	-4.965E-02	.021	-2.397	.018*
YIELD (d_{Ym})	-1.899E-02	.004	-4.597	.000*
DRF (r_{Dm})	4.003E-03	.007	.572	.569
R –square	0.177			
N	132			

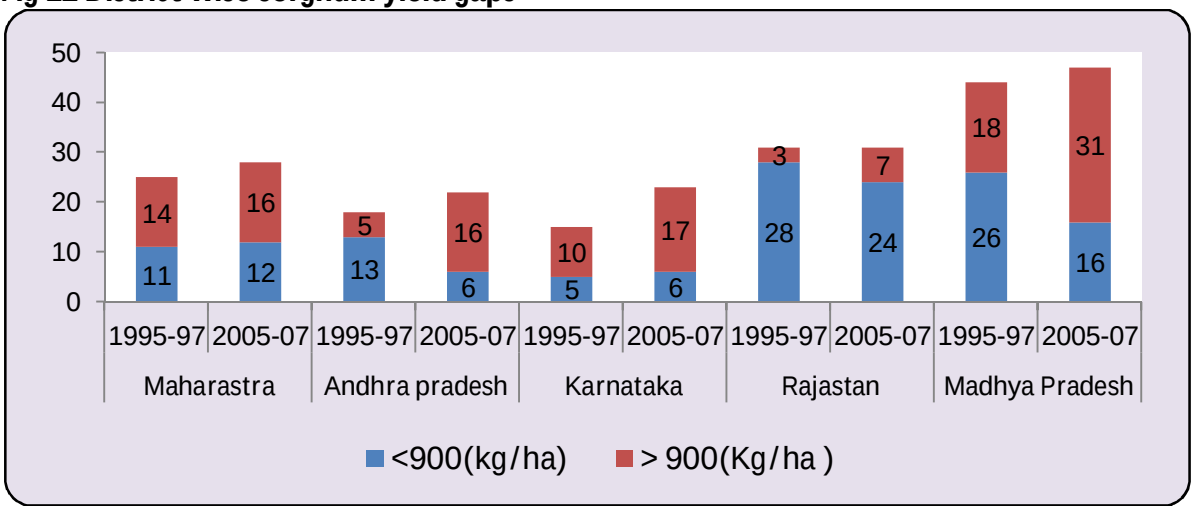
* Significant at one per cent level

The explanatory power of the equation was rather low at 0.177. Among the three explanatory variable used in the equation, two are significant at one per cent level where as 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 conclude that the increase adoption of improved cultivars reduce 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 increase 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.

District level sorghum yield gaps

Thorough analysis of District Level Data (DLD) in five major sorghum growing states (Maharashtra, Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh) reveals interesting results on yield performances (see Fig 12). Out of the total no.of districts data available (185), only 133 and 151 districts have grown sorghum respectively during 1995-97 and 2005-07 study periods. A comparison was made and classified the total no.of sorghum growing districts based on mean country productivity of 900 kg per ha. Further the details of the analysis have been summarized in Fig 12. It clearly shows that out of 133 districts growing sorghum during 1995-97, only 50 districts exhibited the mean yields more than national average (900 kg per ha). The remaining 83 districts fell in the category of less than 900 kg per ha. However, increased awareness and adoption of improved cultivars have changed the mean yield trends significantly at district-level during 2005-07. In a total of 151 districts growing sorghum in 2005-07, 87 districts demonstrated the mean yields of more than 900 kg per ha. The remaining 64 districts fell on the other-side of the coin.

Fig 12 District-wise sorghum yield gaps



Source: District level data base, ICRISAT

Synthesis for future research and crop development priorities

The recent crop trends in India have indicated that there is a steep decline in sorghum cropped area. However, sorghum continues to be the main staple food for poor and marginal farmers of SAT India. The crop has huge potential and 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 to 500 mm) without application of any fertilizers or other inputs. Further, India is the unique center of origin for the post-rainy (rabi) season varieties of sorghum in the World. Nearly 2/3rd of area is under post-rainy (rabi) cultivation whereas the remaining 1/3rd grown during rainy (kharif) season. The mean productivity levels in the country are hovering around 1000 kg per ha. In general, the productivity levels are relatively higher in rainy season when compared to post-rainy season.

The rainy season crop production has declined despite successful crop improvement efforts by both public and private sectors due to sharp fall in cropped area. The post-rainy 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%) states together represents nearly 80 per cent 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 256 improved cultivars have been released and made available to farmers through NARS in India between 1964 and 2011. The mean varietal release rate was 5.22 per year. The results clearly indicate that there is 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 (201) were dominated by varieties. On the whole, the crop improvement research in India was emphasized mostly on varieties till 1990s while major thrust on hybrids was given rigorously afterwards. Nearly 80 per cent of the released cultivars suits for short-duration (90-110 days) environment. The total Full Time Equivalent (FTE) of staff specialized in sorghum crop improvement in India is 84.5 as on 2010-11. The pattern of research investment by NARS is increasing in trend between 10th and 11th Five Year Plans.

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

The coverage of modern cultivars in sorghum cropped area has been increasing since 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 much conspicuous in kharif season (80-85%) when compared to rabi (30-40%) season. 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 per cent from 500 kg per ha in 1961-63 to 926 kg per ha during 2008-10. The detailed district-level data (DLD) analysis at all India has confirmed the increase yields were coupled with gradual decrease in coefficient of variation over a 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 the biotic and abiotic challenges, presumed climate change affects the sorghum area and its importance globally. Climate change will modify the length of growing period and increases the predicted temperatures across the sorghum growing regions. So, more thrust is need on development of drought resistant and heat tolerant cultivars by using modern biotechnology tools. Similarly, high emphasis would be given for improvement of post-rainy vintages for increasing the adoption rates in the country. The other emerging areas of sorghum research are development of high yielding sweet stalks, fodder quality and increasing the density of grain micronutrient traits. Equally, adequate research focus is also needed in exploring the preferred traits of non-conventional users / end-users for meeting their demands. The SRR should be enhanced by strengthening the seed multiplication and distribution systems.

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