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

D.KumaraCharyulu, M.C.S Bantilan, S.Nedumaran and Uttam Kumar Deb[1]

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 fifty years. Altogether more than 293 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. Very little statistically valid information is available on the extent of adoption at national and sub-national levels. The present study made a humble attempt to address these issues with help of primary as well as secondary sources of data. The analysis has concluded that nearly 80 per cent of total sorghum areas are under improved cultivars which helped to increase the mean country productivity levels to the tune of 71 per cent between 1960 and 2010. The results also proved that adoption of improved cultivars increased the yields substantially and also reduced its variability in the country.

Key words: Improved cultivars, sorghum adoption in India, impact on growth and variability

[1] Research Program on Markets, Institutions and Policies (MIP), ICRISAT, Patancheru, Hyderabad

Development and Diffusion of Improved Sorghum Cultivars in India: Impact on Growth and Variability in Yield[2]

1. Introduction

Sorghumor Jowar[*Sorghumbicolour (L.)*] is one of the main staple foods for the world's poorest and most food-insecure people across the semi-arid tropics. It is the fifth most important cereal crop in the world, after wheat, maize, rice and barley; whereas, in India sorghum is the third cereal crop after rice and wheat.In India, it was one of the major cereal staple during 1950's and occupied an area of more than 16 million ha. But, recently its area has come down (48 per cent) to 7.67 million ha by 2009-10 (5 % of GCA). However, it is still contributes about 6.98 million tons (3.2%) to India's total food production and around 12.7% to the world's sorghum production(FAO, 2009-10).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. However, it is grown for a variety of uses in India as well as in the world. On the other hand, sweet sorghum was especially used for bio-ethanol production which is blended with petrol up to 5-10% in the developing and developed economies.

Majority of the crop in India is cultivated under marginal and stress-prone areas of the semi-arid tropics (SAT). It is primarily produced in India (7.67 million ha) constitutes about 19 % share in global acreage followed by Sudan 6.66 million ha (17%), Nigeria 4.74 million ha (12%), Niger2.55 million ha (6%), USA 2.23 million ha (6%), Mexico and Ethiopia 1.6 million ha each

[2] Authors are highly thankful to P.Parathasarathy Rao for providing necessary district level data used in this paper.

(4%) respectively during 2009-10.Sorghum is grown in nearly 92 countries of the world, covering an area of approximately 39.66 million ha with grain production of56.9million tons and with average productivity of 1.43ton per ha (FAOSTAT, 2009).In global production lion's share is contributed from USA with (17%) followed by India (13%), Mexico (11%) and Nigeria (11%).During the last five decades period (1960-2010),global area and production reported an annual growth rate of -0.30 and 0.36 per cent respectively due to decline in area followed by biotic and abiotic factors. The productivity levels in developing counties (900 kg/ha) were nearly four folds lower than the developed countries (4000 kg/ha). In India, it is grown mainly in Maharashtra, Karnataka, Madhya Pradesh, Rajasthan and Andhra Pradesh states.

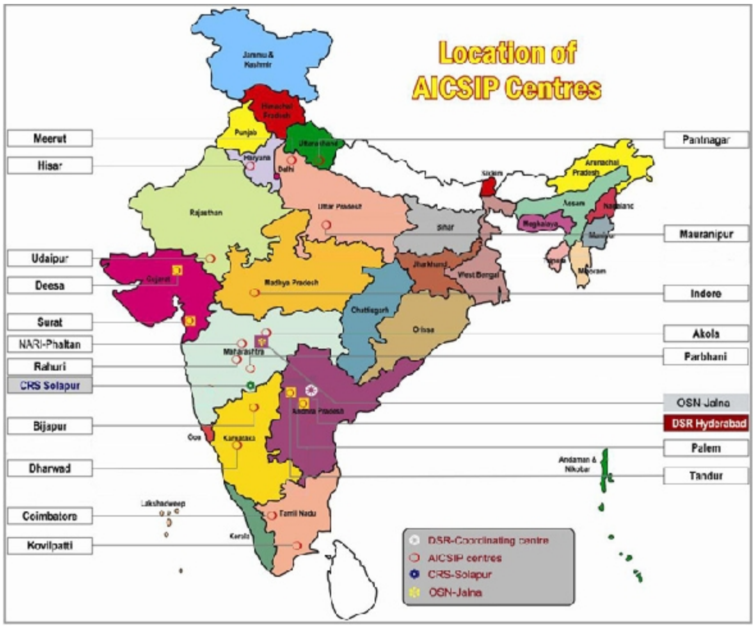
1.1 Objectives of the study

Realizing the importance of crop, the present paper made a humble attempt to understand the development and diffusion of sorghum improved cultivars in India over the period of last five decades (1960-2010). 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 chosen sorghum crop as one of its five mandate crops and conducting research for its development from 1972. ICRISAT has been playing a catalytic role in maintaining and distribution of sorghum core germplasms as well as developmental of parental lines/cultivars 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 25) 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 and its impacts on productivity and its stability. Scanty or lack of reliable information on crop varietal adoption is an important determinant of food security and poverty benefits generated by investments in crop genetic research and development. 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 benefits of sorghum improved cultivars adoption on small and marginal farmers of SAT India. The paper also discuss about the few innovative methods for sustaining this activity of monitoring varietal adoption in India in the future.

2. 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 centres: IARI (Indian Agricultural Research Institute) and the State Agricultural Universities in Haryana, Karnataka, and Andhra Pradesh. Directorate of Sorghum Research (DSR) (Formerly National Research Centrefor Sorghum) was established in 1987 also by ICAR. DSR is the nodal agency in the country dealing with all aspects of sorghum research and development including coordination and consultancy. DSR works closely with many other sister institutions of ICAR, State Agricultural Universities (SAUs) and national and international agencies such as ICRISAT and other institutions both in the public and private sector. DSR is also mandated with organizing and coordinating sorghum research at all India level through AICSIP, a network of 16 centres located in states having major sorghum growing area (see fig 1).

Fig 1: Location of AICSIP centres in India



The centre-wise thrust in sorghum crop improvement is summarized in table 1.While the DSR main centre located at Hyderabad is principally engaged in both basic and strategic research on sorghum. Region-specific research and other services are organized through its two centres situated at Sholapur and Jalna in Maharashtra state.Through its network centres located across the country in various geographical zones; ICAR has so far developed 26 hybrids (CSH 1 to CSH 25) and 24 varieties between 1964 and 2010. However, India is the unique center of origin for the post-rainy (rabi) season varieties of sorghum in the world (Annual Report, DSR, 2011).

Table 1:Centre-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
	Kovilpatti	TNAU	Insects, esp. of panicle	Dual purpose and sweet & forage
Karnataka	Dharwad	UAS	Insects, foliar diseases, mold	Hybrids and varieties, dual purpose
	Bijapur	UAS	Shoot fly, charcoal rot, drought	Rabi hybrids and varieties
Andhra Pradesh	Palem	ANGRAU	Insects, mold	Dual purpose, forage
	Tandur	ANGRAU	Rabi adaptation	Varieties
	Warangal	DSR	Borer, storage pests	Forage
Maharashtra	Parbhani	MAU	Mold, shoot fly, borer, shoot bug	Hybrid and verities, sweet stalk
	Rahuri	MPKV	Shoot fly, char-coal 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 and forages
	Deesa	SDAU	Shoot fly, borer, foliar diseases	Forages single- and multicut

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

3. Crop improvement strategies

3.1 ICRISAT

ICRISAT involves in sorghum crop improvement through pre-breeding as well as breeding research strategies since early 1970s[3]. The details of these methods are elaborated below:

a. Pre-breeding research:Collection, characterization and maintenance of landraces are essential for crop improvement and ICRISAT has given high priority to this activity. As of December 2010, a total of 37,904sorghum germplasm accessions from 90 countries have been conserved at ICRISAT.This gene bank now serves as a major repository of sorghum germplasms in the world. More than half of this collectionsare from five countries: India, Ethiopia, Sudan, Cameroon and Yemen. About 63% of the total numbers of accessions are from African countries and about 30% are from Asian countries. Between 1974 and 2008, ICRISAT has distributed about 351,846 germplasm samples of sorghum to 105 countries based upon request from different users. During evaluations trails, some landraces collected from different countries have been identified as superior to existing cultivars. A total of 32varieties have been directly released from the distributed sorghum germplasms in 17countries of Asia, Africa and Latin America(Gopal Reddy *et al.,* 2006).

b. Sorghum breeding strategies: ICRISAT has been involved in genetic enhancement of sorghum from the inception. The identification of geographic functional regions witha set of constraints has resulted in the gradual shift inbreeding strategy from initial wide adaptability to specificadaptations, and to trait-based breeding for thresholdtraits through the 1980s and 1990s. After abandoned of wide adaptability approach by early 1980s, three research centres

[3] See also Bantilan *et al.,* (2004)

with regionalhubs were established in Africa and one in Central Americato take up breeding for region/production system-specificadaptations. However, the fundamental approach has been to develop various breeding materials, varieties, hybrid parents(A/B/R lines), segregating populations and improved sources of diseases and insect resistanceto strengthen the breeding programs of the NARS and the private seed sector. External environment donors' perceptions, the NARS capacity and the ICRISAT research administration structures are some of the most important factors that have influenced some changes in sorghum breeding concepts, objectives and the research approaches in the last 35 years. These changes could be perceived at six different phases of ICRISAT'sresearch (Reddy *et al*., 1998). They are:

Phase 1: Breeding for wide adaptability and higher grain yield (1972-75)
Phase 2: Breeding for wide adaptability and screening techniques (1976-79)
Phase 3: Regional adaptations and resistance breeding (1980-1984)
Phase 4: Specific adaptation and resistance breeding (1985-1989)
Phase 5: Trait-based breeding and sustainable productivity (1990-1994)
Phase 6: Intermediate products and upstream research(1995 to present)

During the sixth phase, particularly the emphasis is to produce parental lines and gene pools (see box1). Accordingly, the objectives of the program are changed to breed resistant seed parents and restorer lines, to develop specific new gene pools and novel plant types and to identify and use molecular markers for location specific needs. Recently, ICRISAT has also changed its strategy towards harnessing the new tools of biotechnology and giving major thrust on development of post-rainy season crop improvement.

Box1: ICRISAT-Private Sector partnerships in sorghum improvement (2000-2010)

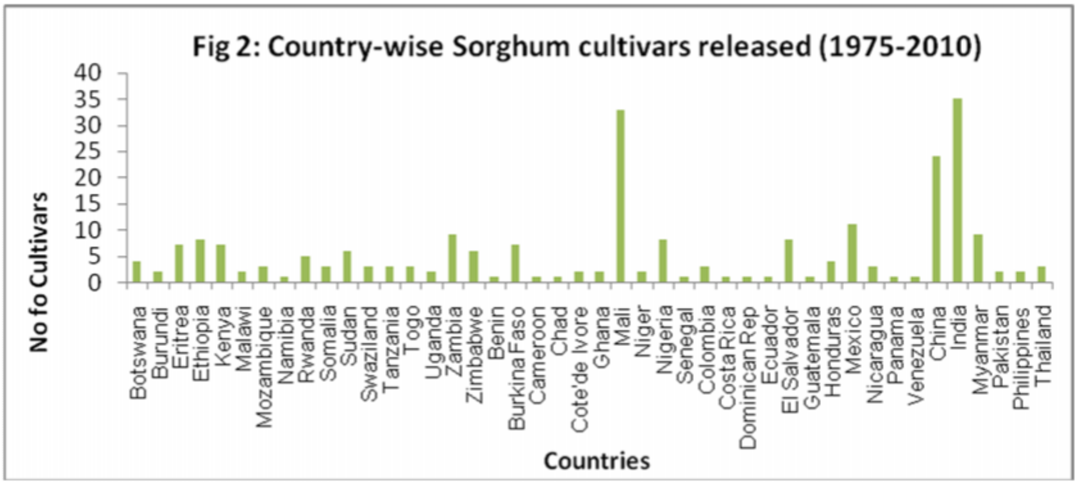
The Hybrid Parents Research Consortia (HPRC) is an initiative of ICRISAT that was formed in 2000 with the basic objective of increasing the scope of accessibility to better hybrids by poor farmers through effective public-private partnerships. The consortia were initially started with 9 members and have grown up to 35 seed companies by 2010 in case of sorghum. It 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 percent of the total rainy season sorghum area) and one million ha of the summer season sorghum are planted with about 70 PS-based hybrids, of which 54 are based on ICRISAT-derived parental lines or their derivatives. Another high-yield potential hybrid resulting from the ICRISAT-PS partnership, VJH 540, has been extremely popular, increasing in area planted from 650 ha in 1997 to 14,020,000 ha in 2003 (in rainy season in major sorghum growing areas)—based on the increase in seed sales from 6.5 tons in 1997 to 1420 tons in 2003. These examples illustrate the power of partnership between ICRISAT and the PS to develop and deliver desired products to the farming community. Several other private sector hybrids, such as MLSH 296, GK 4009 and GK 4013, are also widely adopted in India. The high rate of adoption of ICRISAT-based hybrids is due to their large grain size and high grain and fodder productivity. These hybrids have made substantial contributions to enhance cultivar diversity, productivity, and yield stability, and have improved the livelihoods of poor farmers in the dry areas(Reddy *et al*., 2007).

ICRISAT–bred varieties, hybrids and those derived from ICRISAT materials by the national breeders have been tested in the AICSIP trails since 1979-80 and participation in these trails have been increasing over time. ICRISAT also taking part in network trails for selecting for local conditions in Africa, Asia and Latin America. As a result, these improved varieties and hybrids are released throughout the world.

Table 2 Summary of ICRISAT sorghum cultivars released globally during 1975-2010

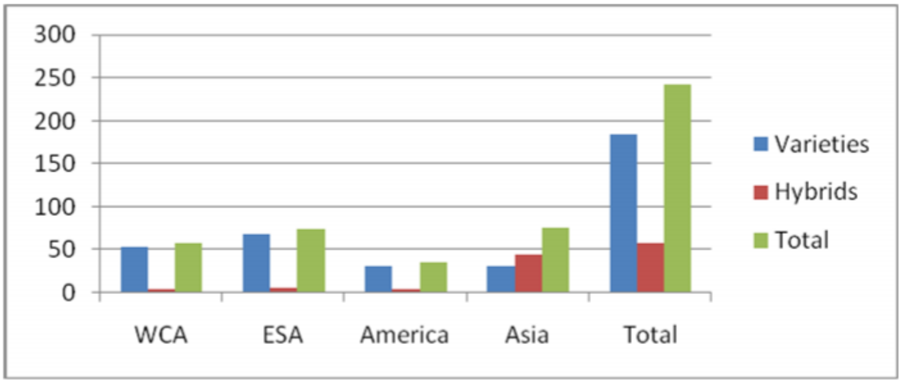
Years	Africa	America	Asia	Total	India	Other Asia
1975-80	9	4	3	16	1	2
1981-85	5	7	10	22	1	9
1986-90	31	11	6	48	5	1
1991-95	28	9	19	56	9	10
1996-2000	24	4	14	42	7	7
2001-05	21	0	11	32	3	8
2006-10	14	0	12	26	9	3
Total	132	35	75	242	35	40

Table 2 shows the total number of improved sorghum cultivars released globally using ICRISAT germplasms and breeding materials in different regions between 1975 and 2010. A total of 242 improved cultivars are available in 44 countries of Asia, Africa and America. Almost 54.5 per cent of these releases were concentrated in African countries followed by Asia (31.0%) and America (14.5%). The top three individual country beneficiaries from ICRISAT research and materials are India (35 cultivars) followed by Mali (33) and China (24). Due to the presence of ICRISAT head quarters 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 1975-2010 are depicted in the fig: 2.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.



The break-up (variety or hybrid) of the total releases across regions are summarized in Fig: 3. In total, ICRISAT has generated 184 varieties and 58 hybrids during 1975-2010 among four regions. Within Africa, more releases were took place in ESA (74) when compared with WCA (58) during the same period. Around 66 per cent of varieties and 17 per cent of hybrids have been released in Africa alone. American region also received more varieties when compared to hybrids. In case of Asia, this trend was observed to be in reverse (17 % in varieties and 76% in hybrids).Deb and Bantilan (2003) in their analysis also 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 from the total of 130 have had spillover effects in different countries. Similarly, materials have also come from Africa to Asia, which were tested and distributed to NARS trials and later released subsequently (eg. PARC-SS 2 and NTJ2).

Fig 3: Break-up of ICRISAT global releases, 1975-2010



3.2 NARS strategies for 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, its diversified utilization, to promote profitability from sorghum based cropping systems and to serve as national repository of sorghum germplasm.

Characteristics	**Zones**	**Purpose**	**Major states covered**
Kharif sorghum			
	Zone I	Mainly dual purpose	Coimbatore (TN), Kovilpatti (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)
Rabi 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)

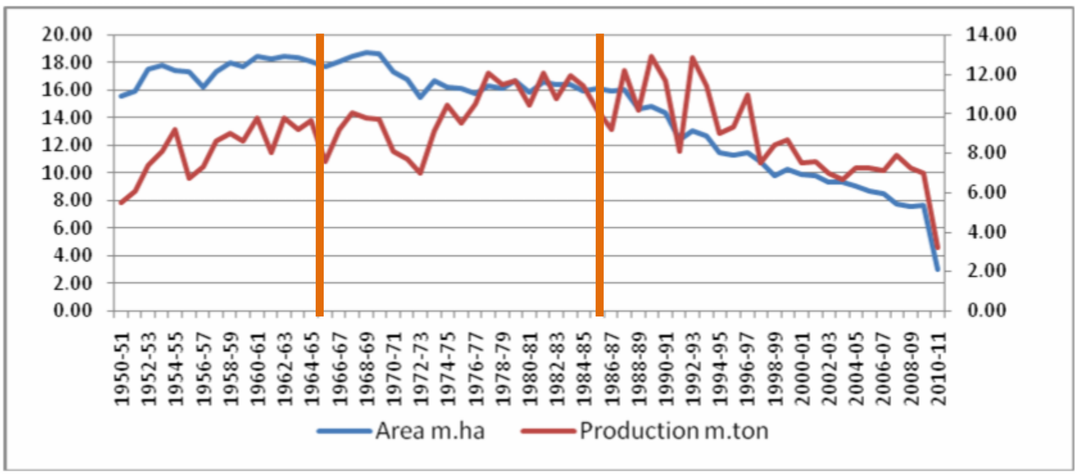
However, based on the decision of 39th AICSIP Annual Group Meetings (AGMs), held at RVSKVV, Indore, 2009 new scheme of national zonation research was developed and being under implementation for better targeting. The details of their characteristics and major centres/states covered under them are summarized above.

So far, hybrid breeding in Indian sorghum has been targeted toward the rainy season; improvement of rabi sorghum did not receive as much emphasis and effort as kharif sorghum until the 1990s. Conventional breeding until now has been unsuccessful in developing higher-yielding sorghum hybrids for the post-rainy season. Consequently, with more area of rainy sorghum is now planted to hybrids and grain yields also much higher in rainy sorghum than post-rainy. Most of the post-rainy areas are still under local land races with lower productivity.

4. Sorghum production and growthin India

Roughly, the fifty years production, area and yield trends in Indian sorghum reveals three different time periods: post-independence (1947-1965); public-supported growth (1965-85); and private sector driven growth (1986 to present)(see fig 4.) 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.

Fig 4: Performance of sorghum in India



Source: Ministry of Agriculture, GOI

The sorghum story is further complicated by a major shift in production, from the rainy season (kharif) to the post-rainy (rabi) 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 45.0 and 55.0 per cent respectively by 2010. The reason for these shifts was poor quality of kharif grains due to rains at the time of harvesting which was fetching lower price. The detailed growth trends in kharif and rabi areas and their production levels were summarized in table 3.Changing consumption preferences among consumers towards wheat and rice rather than coarse grains reduced the demand for both kharif and rabi sorghum (especially rainy season sorghum). The kharif production has declined despite successful crop improvement efforts by public and private sector breeders. However, the yields are steadily increasing and around 1000 kg per ha (Pray and Nagarajan, 2009). The total sorghum area under irrigation was only 8 per cent. Overall, the technology advancement in sorghum has nevertheless kept the production stable, in spiteof decline in area planted.

Table 3:All India area and production growth trends in sorghum

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
2005-09	-8.12	-7.34	-1.68	6.10	-4.33	0.54
1980-2009	-4.44	-3.22	-1.14	0.13	-2.89	-1.95

Source: Directorate of Economics& Statistics)

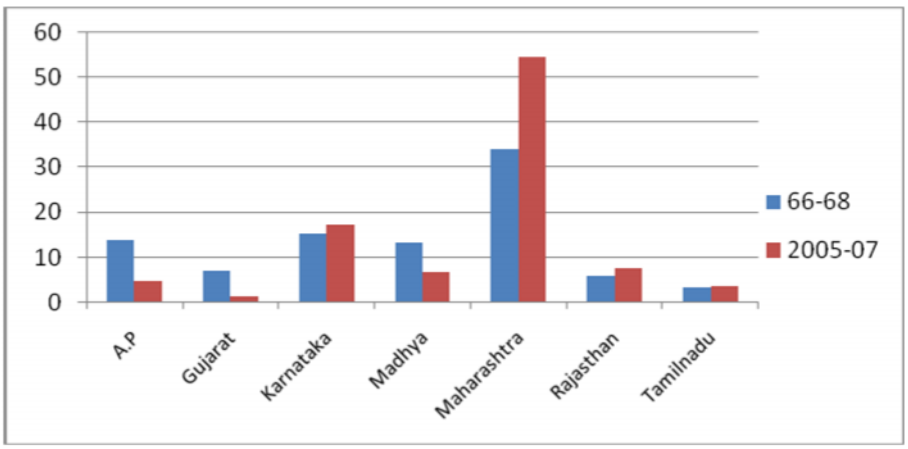
The declined area of nearly 10.3 million hahas been diverted to other commercial crops likegroundnut, sunflower, soybean, pigeonpea, chickpea, maize, castor, cotton and sugar cane in different states. The diversion has been taken place due to availability of irrigation facilities, improved cultivars of other crops and fetching of attractive and more remunerative prices compared to sorghum. Overall, area under sorghum showed an annual growth rate of -2.8% whereas production exhibited -1.9% over last three decades (table 3). This negative trend in production despite the adoption of improved varieties in recent times is due to continuous fall in acreage amid lower yield levels in some states and affect of biotic and abiotic factors etc.

4.1 Sorghum performance across major states

The details of changes in cropped area among major states between 1966-68 and 2005-07 are depicted in fig 5.In India major sorghum producing states are Maharashtra with 54% share in total area followed by Karnataka (17%), Rajasthan (8%), Madhya Pradesh (7%), Andhra Pradesh (5%), Tamil Nadu (4%)and Gujarat (2%) during 2005-07. The sorghum area has increased during 2005-07 significantly in Maharashtra (58.8 %) and Karnataka (13.3%) when compared to 1966-

68. The highest productivity was noticed in Andhra Pradesh (1563 kg/ha) followed by Gujarat (1200 kg/ha), Madhya Pradesh (1193kg/ha) and Karnataka (1180kg/ha). Nearly 50 years of extensive research in sorghum, the mean productivity has increased from 630 kg/ha to 950 kg/ha in India. Even though, sharp decrease in area under sorghum in recent past, the increasing area coverage under improved cultivars (nearly 77%), and application of better management practices resulted in moderate fall in production when compared to area.

Fig 5: State-wise shifts in sorghum cropped area



The details of state-wise growth rates in sorghum area, production and productivity are summarized in table 5. Almost all states have exhibited negative growth in area between 1970 and 2008 period. The highest negative growth rate was observed in case of Gujarat followed by Andhra Pradesh and Madhya Pradesh. Similarly, the decrease in production was also highest for Gujarat (-3.57%) followed by Madhya Pradesh (-3.0%) and Andhra Pradesh (-2.99%). The positive growth in production was observed only in case of Maharashtra for whole period. Interestingly, the productivity growth rates were positive among all states. It was the highest for Gujarat state followed by Andhra Pradesh.

Table 5: State wise growth rates in area, production and productivity

States	Item	1970-79	1980-89	1990-99	2000-2008	1970-2008
Andhra Pradesh	Area	-1.98	-5.63	-5.52	-10.53	-5.42
	prod	3.77	-6.35	-5.78	-5.37	-2.99
	yield	5.87	0.76	-0.28	5.75	2.57
Gujarat	Area	-2.29	-2.96	-11.54	-2.54	-6.33
	prod	5.29	-8.35	-2.51	3.89	-3.57
	yield	7.75	-5.56	10.21	6.63	2.95
Karnataka	Area	-2.26	2.48	-1.55	4.67	-0.85

	prod	0.14	0.65	0.07	6.98	-0.43
	yield	2.46	-1.78	1.64	2.21	0.43
Maharashtra	Area	2.13	-0.31	-2.00	-2.55	-0.96
	prod	17.15	1.52	-1.70	-0.18	0.89
	yield	14.70	1.84	0.31	2.42	1.87
Rajasthan	Area	-4.90	0.51	-5.58	-0.60	-1.54
	prod	-3.76	-1.55	-6.58	12.70	-1.16
	yield	1.20	-2.06	-1.05	13.42	0.39
Tamil Nadu	Area	0.9	0.6	-5.4	-1.8	-2.7
	prod	3.7	5.1	-7.4	-1.0	-2.5
	yield	2.8	4.5	-2.1	0.9	0.2
Madhya Pradesh	Area	-0.8	-2.7	-9.3	-2.8	-4.1
	prod	-1.5	-0.6	-9.7	1.9	-3.0
	yield	-0.7	2.1	-0.4	4.9	1.2

4.2 Intra-state shifts in sorghum areas

Table 4: Performance of sorghum in major growing states

State	Area shares in 1966-68		Area shares in 2005-07		Crop nature	Productivity nature
	Kharif	Rabi	Kharif	Rabi		
A.P	0.47	0.53	0.41	0.59	Both kharif and rabi	Kpdty == Rpdty
Maharashtra	0.43	0.57	0.30	0.70	Rabi dominant	Kpdty>Rpdty
Karnataka	0.43	0.57	0.21	0.79	Rabi dominant	Kpdty>Rpdty
Gujarat	0.87	0.13	0.57	0.43	Kharif dominant	Kpdty>Rpdty
Rajasthan	1.00	0.00	1.00	0.00	Kharif only	N.A
Madhya Pradesh	0.99	0.01	0.99	0.01	Kharif dominant	Kpdty == Rpdty
Tamil Nadu	0.73	0.27	0.71	0.29	Kharif dominant	Kpdty<Rpdty

Kpdty: Kharif productivity **Rpdty**: Rabi productivity

The details of intra-state shifts in sorghum cropped area across major states between1966-68 and 2005-07 are summarized in table 4. The shares of kharif and rabi in total area have significantly changed in case of Maharashtra, Karnataka and Gujarat. In the rest of the states the changes were negligible. Among seven states, Maharashtra and Karnataka sorghum area was dominated by rabi season where as in Gujarat, Rajasthan, Madhya Pradesh and Tamil Nadu it was higher under kharif season. Andhra Pradesh exhibited almost equal shares in both the time periods. In general, the productivity levels were higher during kharif (except Tamil Nadu) than rabi season.

5. Development of sorghum improved cultivars

There was little research on sorghum in the pre-independence period. Even after independence these crops received very little research attention, until the creation and expansion of the All

India Coordinated Crop Improvement Projects. In the early 1960s, the ICAR, with Rockefeller Foundation assistance, initiated research on hybrid sorghum. ICAR then initiated the AICSIP in 1969. The first sorghum hybrid, CSH1 (Coordinated Sorghum Hybrid), was bred in India and officially released for commercial cultivation in 1964. The formation of ICRISAT further stimulated ampleresearch 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 (CSH5 and CSH6 in the mid 1970s and CSH9 in the early 1980s) augmented the spread of sorghum HYVs and open pollinated varieties and boosted productivity. Hybrids CSH1 to CSH25 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, 2006).

Table 6 Improved cultivars released by different stakeholders

Released period	ICRISAT (1975-2010)	NARS releases (1964-2010)		
		ICAR*	Other notified varieties**	Total
1961-70	Nr	5	7	12
1971-80	1	12	48	60
1981-90	6	10	49	59
1991-00	16	12	64	76
2001-05	3	7	22	29
2006-10	9	4	18	22
Total	35	50	208	258

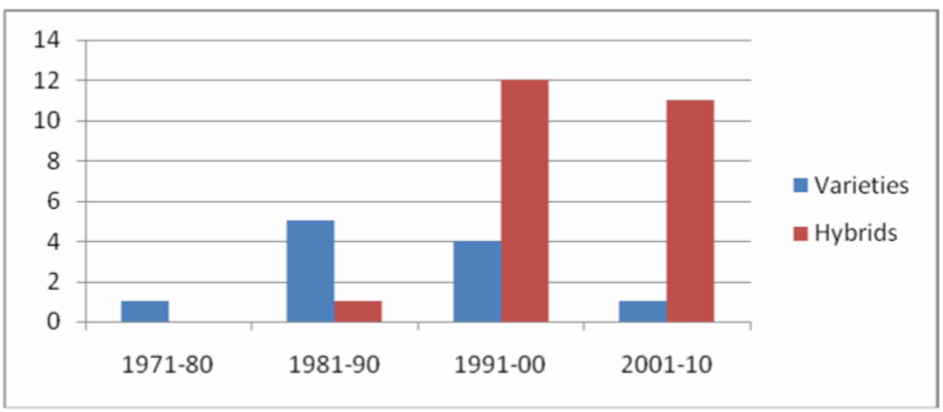
*only hybrids and varieties** Includes state releases and SAU's

Table 6 summarizes the releases of improved cultivars by different stakeholders between 1964 and 2010. ICRISAT has released around 35 improved cultivars in India either by sharing their germplasm or breeding materials to NARS and private seed companies during 1975-2010. Similarly, ICAR has also released 50 improved cultivars nationally for growing in major sorghum states in India between 1964 and 2010. The major sorghum states including their respective state agricultural universities have released around 208 state notified cultivars which have location specific importance during the same period. A total of 258 improved cultivars have been released through NARS in India for sorghum crop improvement. The releases were at their peak during 1990s (76) followed by 1980s (59). In general, the no. of releases in the last decade has declined (51) when compared to earlier two decades.

5.1 ICRISAT releases

The details of ICRISAT releases in India are summarized in Appendix table 2.Since 2001, ICRISAT has been in close collaboration with HPRC members and mostly concentrating in developing the parental lines which would immediately fit in to the NARS as well as private seed companies' research. Among the 35 improved cultivars, there were 11 varieties and 24 hybrids with diversified salient features. The pattern of these releases was furnished in fig 6. Apart from these Indian releases, ICRISAT also released 207 cultivars (except Indian releases)globally for different regions.

Fig 6: ICRISAT releases in India from 1975-2010



5.2 NARS releases

The detailed break-up of national and state releases over a period of 1960 to 2010 are summarized in Fig.7 and Fig.8 respectively. As we can see from the figures, there is a clear contrast between national and state releases over a period. The national releases (see Appendix table 1) were dominated by hybrids where as the state releases were dominated by varieties[4]. Similarly, the details of total notified cultivars across the same period are also furnished in Fig 9. It is clearly conspicuous from diagram that till 1990s mostly dominated by

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

varieties where as the major thrust on hybrids have been started rigorously afterwards. The details of classification of total cultivars based on duration were tabulated in table 7. Nearly 50 per cent of total improved cultivars were targeted on short duration (90-110 days) crop followed medium (43%) and long duration (7%).

Fig 7: Pattern of ICAR National releases in India, 1964-2010

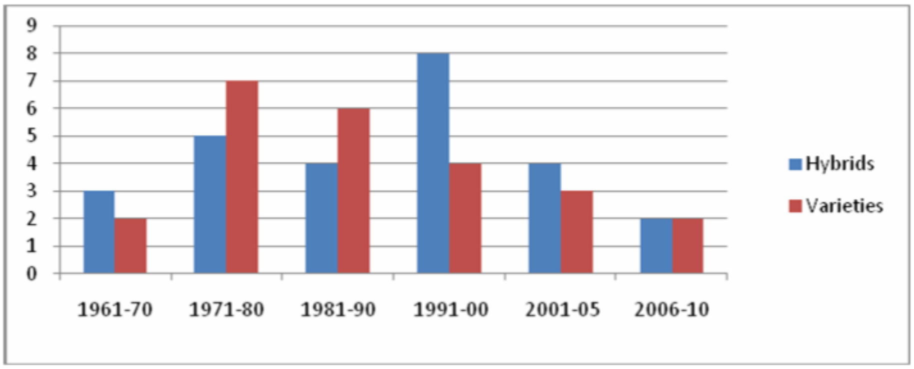


Fig 8: Pattern of state releases including SAUs, 1964-2010

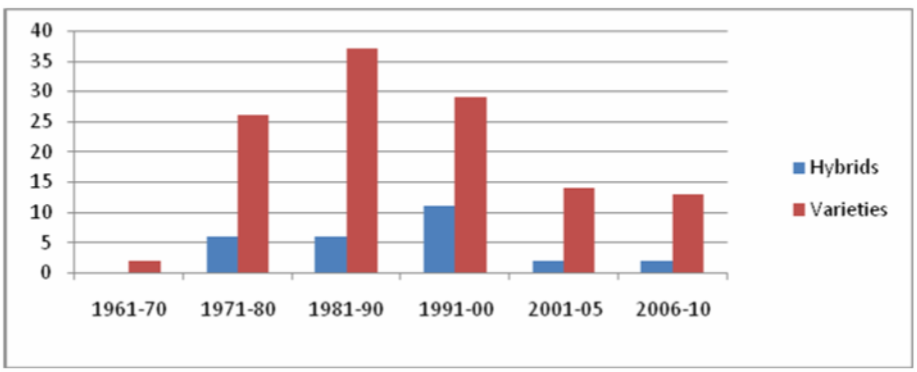


Fig 9: Decadal-wise total notified cultivars, 1964-2010

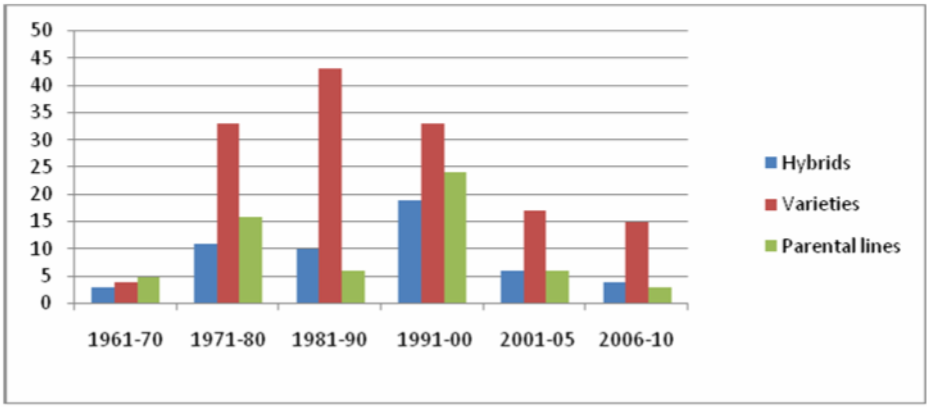


Table 7: Classification of sorghum improved cultivars based on duration (days)

Year	Hybrids						Varieties					
	Central			State			Central			State		
	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	1	4	1	3	4	0	19	2	5
1981-90	1	3	0	4	2	0	1	5	0	14	22	1
1991-00	5	3	0	6	4	1	1	3	0	16	13	0
2001-10	4	2	0	2	0	2	3	2	0	15	10	2
Total	13	12	1	13	10	4	9	15	0	64	48	9

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

6. NARES strength and crop research investments

At ICRISAT, nine sorghum breeders located in Asia and Africa are involved in breeding. Twentyother 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 to 30 sorghum scientists are working for sorghum improvement in private sector. Unlike private sector scientists, the NARS scientists are devoted most of their time on development of sorghum crop improvement. The details of NARS staff involved in sorghum crop improvement in Xth and XIth Five year plans are summarized in table 8. Among the total 279 personnel, 219 are scientific and technical persons where as remaining 60 are support staff. Nearly 36 per cent scientific staff working at DSR, Hyderabad while remaining 64 per cent staff is with AICSIP centres. The sorghum production per crop improvement scientist has gone done from 0.747 to 0.719 lakh tons between the two Five year plans. This may be due to the sharp decline in crop area and production in the country. In terms of the Full Time Equivalent (FTE) of staff specialized in sorghum crop improvement,it came around 179.58 as on 2010 (see table 9). The gap of 39.42 is devoted for other purposes such as teaching, guiding students, training programs, extension etc by the scientific persons. The major junk of FTE is concentrated for sorghum breeding followed by crop management. In terms of their educational qualifications, around 43 per cent of FTE are doctorates, 4 per cent are masters and remaining 53 are graduates (table 10).

Table 8 Total NARS strength (actual)

Category	AICSIP		DSR		Total	
	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

* Other supporting staff # as on 2010-11

Table 9 Full time equivalent (FTE) staff by major specialization on sorghum crop improvement (2010)

Discipline	**Actual staff**			**FTE**
	DSR**	**AICSIP**	**Total**	
Agronomist	8	24	32	26.24
Plant breeder	22	52	74	60.68
Entomologist	10	19	29	23.78
Pathologist	7	18	25	20.50
Physiologist	4	10	14	11.48
Genetic resource specialist	4	4	8	6.56
Social scientist	4	0	4	3.28
Bio chemistry	3	2	5	4.10
Post harvest/ food technology	1	2	3	2.46
Molecular biology	1	1	2	1.64
Seed technology	3	2	5	4.10
Soil science	1	2	3	2.46
Genetics / cytogenetics	5	2	7	5.74
Eco botany	1	0	1	0.82
Computer application	1	0	1	0.82
Bio technology	4	2	6	4.92
Total	79	140	219	179.58

** includes CRS, Solapur

Table 10 Full time equivalent scientific staff by educational degree, 2010

Institution	PhD	MSc	BSc	Total

AICSIP	46.7	4.9	63.1	114.8
DSR	30.3	2.5	32.0	64.8
Total NARS	77.08	7.38	95.12	179.58

Table 11 Variability in annual varietal releases of sorghum in India, 1964-2010

Institutions	Mean annual release rate	Years with zero releases	Standard deviation of releases	Coefficient of variation
ICRISAT (1975-2010)	1.00	20	1.89	189
ICAR* (1964-2010)	1.09	19	1.36	125
Other notified **(1964-2010)	3.22	6	2.54	79
NARS (1964-2010)	4.30	2	2.80	65
India (1964-2010)#	5.07	2	3.76	74

* includes Hybrids and varieties** includes state releases and SAU's# NARS and ICRISAT releases together

Table 11 summarizes the variability in annual varietal releases by different stakeholders in India between 1964 and 2010. The highest coefficient of variation (C.V) was observed in case of ICRISAT followed by ICAR and other notified releases. The mean annual release rate in case of ICRISAT was 1.00, but years with zero releases were 20 between 1975 and 2010 time period. In case of ICAR, the mean annual release rate was slightly higher and years with zero releases were 19 between 1964 and 2010. Since the state releases including SAUs were higher than ICAR and ICRISAT, the coefficient of variation was relatively low. Both ICAR and state together (NARS) increased the mean annual release rate and reduced the C.V. to 65 per cent. After we combine the total NARS and ICRISAT releases in India, the mean annual release rate was gone up to 5.07 and years with zero releases gone down to 2. But, the C.V has slightly increased from 65 to 74 per cent.

Table 12 NARS research allocation during X and XI Five Year Plan (Rs in lakhs)

Year plan	DSR		AICSIP		Total NARS	Expenditure per scientist
	Plan	Non -plan	Plan	Non -plan		
2002-2007	729.58	1767.93	1439.68	Nil	3937.19	41.4
2007-12	1772.70	3675.00	3212.68	Nil	8660.38	84.1

Source: DSR, Hyderabad

Table 12 summarizes the NARS research allocation 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. It was almost doubled than the previous FY allocations. The available research expenditure per each individual scientist working in sorghum crop improvement was calculated. It was around Rs.41.44 lakhs during Xth FY plan. It has increased up to 84.1 lakh during the XIth FY plan. It clearly indicates that ICAR presently is giving more emphasis on sorghum crop improvement through high resource allocations.

Table 13Research expenditure over the last four years (Rs lakhs)

Year	DSR	AICSIP	Total	Allocation per scientist FTE*	Sorghum Production (lakh tons)	Research cost per ton (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	N.A	N.A

***** Considered scientist FTE onlySource: DSR Annual Report, 2010-11

Table 13 furnishes the information about annual research allocations to sorghum crop improvement during XIth FY plan. Over the period of time the research allocations were almost in increasing trend. The research allocations per each FTE scientist have gone up significantly between 2007 and 2008 years. After 2007-08, this share has gone up further and slightly decreased during 2010-11. However, sorghum production in the country is decreasing in trend during the same period. The research costs per ton of sorghum production in the country are going up during the study period.

Table 14 State-wise research expenditure allocations, 2010 (Rs lakh)

	Actual			FTE#	Research expenditure (2009-10)	Allocation per scientist FTE
	Technical	Scientific	Total			
Maharashtra	25	18	43	36.68	137.15	3.7
Andhra Pradesh	7	6	13	10.45	40.93	3.9
Madhya Pradesh	5	6	11	9.35	25.5	2.7
Tamil Nadu	6	5	11	9.00	44.43	4.9
Rajasthan	6	4	10	8.10	55.08	6.8
Haryana	2	3	5	3.95	28.37	7.2
Gujarat	3	9	12	9.35	58.68	6.3
Karnataka	12	8	20	16.60	84.5	5.1
Others states	11	4	15	12.35	158.91	12.9
DSR	39	40	79	63.15	1683.00	26.7
Total	116	103	219	178.98	2316.55	12.9

includes both scientists and technical staff

Table 14 shows the state-wise break-upin research allocations during 2009-10 for sorghum crop improvement. The state-wise actual and Full-Time Equivalent (FTE) staff working for sorghum crop improvement are calculated and summarized in the table. Among the total FTE of 178.98, nearly 20 per cent scientific staff working in Maharashtra alone followed by 10 per cent in Karnataka state. Almost 6 per cent of the total research allocations are going to Maharashtra followed by 3.6 per cent for Karnataka. The research allocation per each scientist FTE was the highest in case of Haryana followed by Rajasthan and Gujarat states.

7. Diffusion of improved cultivars

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 practices to increase yield and 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 the Department of Agriculture, GOI estimates the area under improved cultivars are increasing over period of time (see fig 10) in India. 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 increasing trend.

Fig 10: Sorghum area and area under modern varieties in India

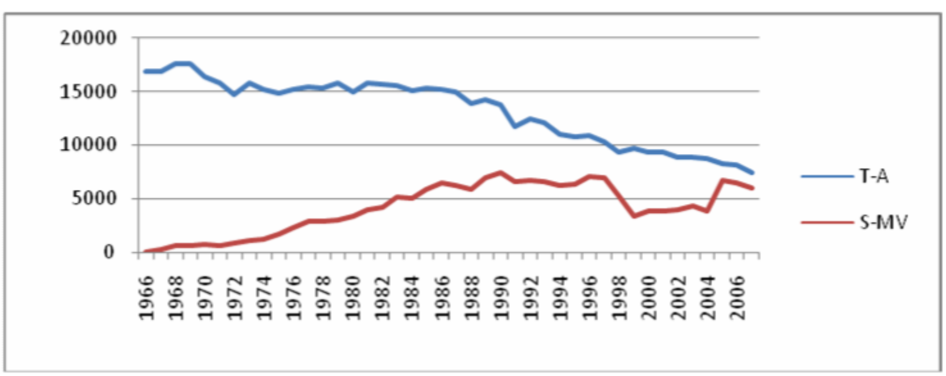


Table 15 Diffusion of improved cultivars in major states (per cent area)

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

Table 16 Distribution of districts based on sorghum area under improved cultivars, 1977-07 (no.)

States	Per cent total sorghum area under improved cultivars			
	< = 25 %	26-50 %	51-75 %	76-100 %
	1977-79			
Andhra Pradesh (18)	17	1	0	0
Gujarat (16)	14	2	0	0
Karnataka (13)	5	4	4	0
Madhya Pradesh (34)	24	8	2	0
Maharashtra (21)	8	9	3	1
Rajasthan (22)	22	0	0	0
Tamil Nadu (8)	5	2	1	0
All India (132)	95	26	10	1
	1991-93			
Andhra Pradesh (18)	0	8	6	4
Gujarat (16)	6	7	2	1
Karnataka (13)	2	5	5	1
Madhya Pradesh (34)	12	3	12	7
Maharashtra (21)	1	2	4	14
Rajasthan (22)	20	1	0	1
Tamil Nadu (8)	0	3	3	2
All India (132)	41	29	32	30
	2005-2007			
Andhra Pradesh (18)	5	5	6	2
Gujarat (16)	5	6	3	2
Karnataka (13)	2	2	3	6
Madhya Pradesh (34)	12	5	5	12
Maharashtra (21)	0	0	0	21
Rajasthan (22)	15	1	2	4
Tamil Nadu (8)	0	0	0	8
All India (132)	39	19	19	55

Note: Figures in the parenthesis indicates no.of districts

In India, the rate of adoption of improved sorghum cultivars in different states is presented in table 15. Based on 2006-08 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 (-54.4%) in area under improved cultivars during the same period. Overall, all India level the area share has gone up and registered a growth of 19.4 per cent.

Table 16 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.

7.1 Cultivar specific adoption estimates in major states

The cultivar specific adoption estimatesof improved varieties and hybrids are summarized in this section for major sorghum growing states. For conduct of expert elicitations in India, ICRISAT has collaborated with National Agricultural Research System (NARS). Specifically, ICRISAT was joined hands with Directorate of that crop (in case of sorghum, DSR) as well as All India Coordinated Program (in case of sorghum, AICSIP). After thorough discussions with DSR and AICSIP scientists, 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 is one of the fastest methods of updating cultivar specific adoption information.

Overall, ICRISAT has planned to conduct the expert elicitations in two rounds for sorghum crop. The information tabulated below was obtained from the first round of expert elicitations with scientistsof respective AICSIP centres located in that state. A total of 19 expert elicitations (first round) were conducted in sorghum (at least one elicitation per each AICSIP centre). In most cases, two AICSIP centres are located in each major state. Normally, each expert elicitation was consists of at least 4 to 5 scientists who are based at that AICSIP centre. Always the elicitation group 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 is currently planning to conduct the second round of elicitation with state/national level experts in sorghum crop. In general, the initial results are comparable with secondary information collected from respective state agricultural departments. However, some slight deviations were noticed which needs to be clarified during the second round of expert consultations with state/national experts. 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.

Maharashtra – Kharif -2010		**Maharashtra – Rabi -2010**	
Variety	Adoption (% area)	Variety	Adoption (% area)
CSH-9	30%	M35-1	30%
CSH-14	4%	PhuleVasudha	5%
CSH-9-MS-296A	8%	ParbhaniMoti	3%
M 296	8%	RSLG-262Maulee	3%
CSH-16	5%	PhuleYashoda	3%
MAHABEEJ-7-7A(SPH-981)	5%	PhuleChitra	3%
Pro 8340	3%	CSV-18	3%
PRO AGRO CHARI (SSG-988)	4%	**All MVs**	**50%**
CSV-15	3%		
PVK801(SPV-1333)	2%		
Others	23%		
All MVs	**95%**		

Karnataka – Kharif -2010		**Karnataka – Rabi -2010**	
Variety	Adoption (% area)	Variety	Adoption (% area)
CSH-14	40%	M35-1	60%
CSH-16	10%	Others	10%
CSV-216	7%	**All MVs**	**70%**
Jowar-5-4-1	5%		
Others	18%		
All MVs	**80%**		
Gujarat – Kharif -2010		**Rajasthan – Kharif -2010**	
Variety	Adoption (% area)	Variety	Adoption (% area)
GJ -42	9%	CSV 15	6
GJ -38	6%	CSV 17	4
GJ-39	6%	CSV 23	4
GFS 5	6%	CSV 20	4
GJ 40	3%	MSH 51	2
GJ -41	3%	JKSH 22	2
BP 53	18%	Others	18%
Others	9%	**All MVs**	**40%**
All MVs	**60%**		
Andhra Pradesh – Kharif -2010		**Andhra Pradesh –Rabi -2010**	
Variety	Adoption (% area)	Variety	Adoption (% area)
SPV-462	40%	M35-1	30%
JK-22	10%	CSV-216R	10%
JK-234	5%	NTJ-2	5%
NTJ-2	10%	PhuleVasudha	5%
All MVs	**65%**	**All MVs**	**50%**
Tamil Nadu – Kharif -2010		**Tamil Nadu –Rabi -2010**	
Variety	Adoption (% area)	Variety	Adoption (% area)
Co(s) 28	40%	K 8	20%
Co 26	10%	K 11	18%
Co 30	8%	Others	12%
Co FS 29	7%	**All MVs**	**50%**
Others	10%		
All MVs	**75%**		

Nevertheless, conduct of expert elicitations was quick and fastest way of generating the cultivar-specific varietal adoption information. This method has its own advantages and disadvantages as well. The main advantages are rapid, low-cost, less time consuming and reliable provided the group has good knowledge and exposure towards the crop. The major limitations in this approach are: if none of the group members doesn't havegood comprehension about the farm-level adoption in that locality, insufficient information about different cultivars, biasness in their judgments and sometimes poor knowledge about crop seed chains or seed channels etc. The interest of scientists who participate in the expert elicitation process is the key for its outcome. Sometimes, timing of conduct of expert elicitation also plays a crucial role in its quality. Ultimately, the process of conducting expert elicitation is not cumbersome procedure. However, we should not cent percent rely on those estimates provided by the group. We always need to validate this information through above mentioned secondary sources. Especially, in future, collaborating with respective state agricultural departments (seed/input division) and thorough interactions withat least five major private seed companies of that particular crop would generate quick and high quality information.

8. Impact of modern cultivars on yield growth and variability

In general, impacts of crop improvement research 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 yield. 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[5]. Nevertheless, 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.

Data sources

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

[5] Also refer Evenson R.E and Gollin D. (2003) and Joshi P.K *et al.,* (2005)

yield and stability gains. All these districts together accounted for about 99% of total sorghum area and 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.

Table 17Percentage distribution of districts according to the growth rates in yield of sorghum

States	Percentage of districts in the category of			
	A: High growth (5.0% or above)	B: Moderate growth (>1.0 to< 5.0%)	C: Slow growth (Upto 1.0%)	D: Negative growth
1996/97 to 2007/08				
Andhra Pradesh (18)	50	28	6	16
Gujarat (16)	56	32	6	6
Karnataka (13)	0	23	15	62
Madhya Pradesh (34)	21	59	8	12
Maharashtra (21)	0	24	5	71
Rajasthan (22)	32	50	0	18
Tamil Nadu (8)	0	0	25	75
Over all (132)	24.2 (32)	37.1(49)	7.6(10)	31.1(41)
1966/67 to 2007/08				
Andhra Pradesh (18)	0	72	17	11
Gujarat (16)	7	31	19	43
Karnataka (13)	0	31	15	54
Madhya Pradesh (34)	0	53	44	3
Maharashtra (21)	0	86	14	0
Rajasthan (22)	23	59	14	4
Tamil Nadu (8)	0	24	38	38
Over all (132)	4.5(6)	55.3(73)	24.3(32)	15.9(21)

Note: Figures in the parenthesis indicates no.of districts

Table 17summarizes the yield growth in different districts during the last decade as well as during last 42 years. During 1996-97 to 2007-08, around one quarter of districts exhibited yield growth of greater than 5 per cent. Nearly 37 per cent of districts showed moderate growth rate (between 1 to 5%) during the same period. Slow growth in yields was observed in case of 8 per cent of total districts. Negative growth in yields was noticed in 31 of per cent of districts. Overall, 69 per cent of districts displayed positive growth rate in yields during the last decade. The main concern during this period was high shares of districts under states like Maharashtra, Karnataka and Tamil Nadu showed negative growth in yields. But, the trends have slightly changed when we observe the long term (1966-2007) trends in yield growth rates. Only 16 per cent districts come under negative growth category where as 84 per cent districts revealed positive growth rates.

Table 18Average yield and relative variability in yield of sorghum in different districts

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 18 analyzes the average yield and relative variability in yield of sorghum in different districts 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. Overall, 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 relatively higher when compared with other states in all the three periods. The growth in productivity was also consistent but there is 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 19 reveals the association between yield and instability in the yield of sorghum in different 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 sample districts showed increased yield 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 per cent of districts displayed decrease in yield variability while the remaining noticed with increase in variability. On the whole, nearly 60 per cent of study districts expressed increase in variability in their yields. Except Maharashtra and Gujarat, the variability in yields was increasing in all the remaining states during the study period. More in-depth analysis is required to further probe the root causes for variability in yields in these districts.

Table 19Association between yield and instability in yield of sorghum in different districts between 1986-95 and 1996-2007 (per cent)

States	Types of Association			
	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 (18)	0	67	11	22
Gujarat (16)	43	19	38	0
Karnataka (13)	0	8	23	69
Madhya Pradesh (34)	15	62	15	8
Maharashtra (21)	5	0	67	28
Rajasthan (22)	9	37	27	27
Tamil Nadu (8)	25	0	25	50
Over all (132)	12.8(17)	34.2(45)	28.8(38)	24.2(32)

Note: Figures in the parenthesis indicates no.of districts

Table 20Instability in yield of sorghum in different districts, 1966-2007 (per cent)

States	Instability in yield (C.V per cent)			
	< = 25 per cent	26-50 per cent	51-75 per cent	>75 per cent
Andhra Pradesh (18)	11	56	22	11
Gujarat (16)	0	44	25	31
Karnataka (13)	15	85	0	0
Madhya Pradesh (34)	29	71	0	0
Maharashtra (21)	0	100	0	0
Rajasthan (22)	0	32	45	23
Tamil Nadu (8)	0	100	0	0
All India (132)	10.6 (14)	66.6 (88)	13.7 (18)	9.1(12)

Note: Figures in the parenthesis indicates no.of districts

Table 20summarizes 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.

8.1 Impact on unit cost 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[6] reportsin major sorghum growing states showed that real cost per quintal of sorghum production decreased to some extent but after some time it has increased (table 21). The data was collected from 1986-87 to 2007-08 and then the prices were converted in to 1993 real prices. We can conclude from the table that the unit cost reduction was almost perceived up to early 2000s from 1986-87. But, during the late 2000s the unit of production has gone up significantly when compared to 1986-87. The same trend was noticed in all the states. This may be the reason that the farmers are moving out of sorghum crop in many states. Outbreak of biotic and abiotic stresses was also other reasons for diversifying from sorghum to other cash crops.

Year	A.P	Karnataka	Madhya	Maharashtra	T.N	Rajasthan

Table 21 Impact of improved cultivars on unit cost reductions (Rs per qtl) (1993 base)

[6] Commission on Agricultural Costs and Prices (CACP)

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	4.00	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	4.50	3.47	3.59	3.64	3.00	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	2.50	2.59	-	-
2005-08 avg	4.6	4.16	3.47	3.44	4.18	3.70
% Change	38.1%	48.0%	38.8%	32.8%	-	-

8.2 Determinants of inter-district differences in sorghum yield

To probe further, a regression equation was fitted to examine the determinants of inter-district differences in sorghum yield for the period 2005-08 (triennium average). 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 rabisorghum area and with state dummies (table 22). 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.

Table 22 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 per cent level

The R-square value of the regression 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 state 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 byDeb *et al.,* 1999.

8.3 Determinants of variability in sorghum yield

Another regression equation was fitted to analyze the determinants of variability in sorghum district level yields. For this purpose, the coefficient of variation was calculated for all the study district 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 (table 23). A total of 132 observations was generated and fitted in the equation.

Table 23 Determinants of variability in sorghum yields

Variables	Unstandardized Coefficients	Std. Error	t	Sig.
(Constant)	50.734	4.002	12.678	.000*
% area under MV	-4.965E-02	.021	-2.397	.018*
Yield	-1.899E-02	.004	-4.597	.000*
Deviation in RF	4.003E-03	.007	.572	.569
R –square	0.177			
N	132			

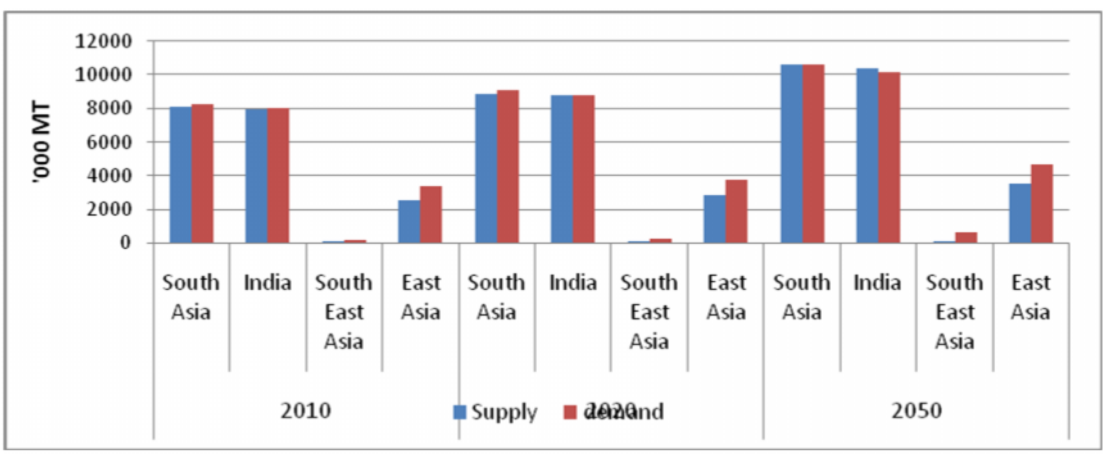
* Significant at one per cent level

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.

9. Supply and demand projections for sorghum

The supply and demand projections for sorghum in Asia were estimated using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) Model developed by IFPRI. The model used 2000 year data as a base and projected for next fifty years for Asia. The results were summarized in fig: 11.

Fig 11: Supply and demand projection for sorghum in Asia ('000 MT)



*Note: Countries included in each group (**South Asia** - Afghanistan, Bangladesh, Bhutan, India, Iran, Nepal, Pakistan and Sri Lanka;**South East Asia** – Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam and Papua New Guinea; **East Asia** – China, North Korea, Mongolia, and South Korea)*

In general, the changes in food preferences and rising income levels have reduced per capita consumption of dryland cereals, but not sufficiently the total aggregate demand. The reasons are increase usage of sorghum in non-food purposes like feed, poultry, bio-fuels and alcohol etc. According to FAO estimates 2008-09, global sorghum utilization was distributed as food (41%), feed and fodder (43%) and for industrial use (10%). The results showed the positive trends in supply and demand of sorghum in all regions of Asia. Especially in case of India, the supply and demand are consistent over the projected period. However, the supply would be slightly higher than the demand by 2050 in India. This may be due to decrease in consumption or increase in production of sorghum. But, in case of East Asia the demand was significantly higher than the supply in all the three periods.

10. Conclusions

The sorghum cropped area in India has declined appreciably(48%) from 1960s to till now. Nevertheless, the production was also decreased marginally (28%) due to increasedadoption of improved cultivars (up to 80%).The mean productivity levels in the country have gone up (71%) significantly during the same period. All the stakeholders such as NARS, ICRISAT and private seed companies have played a major role in sorghum improvement in the last fifty years. A total of 35 ICRISAT and 258 NARS (50 ICAR + 208 state and SAUs) cultivars were made available to farmers for their location specific needs in India. However, ICRISAT also released around 207 cultivars globally especially targeting SSA, America, Asia and ROW. Except states like Maharashtra, Karnataka and Rajasthan; all the remaining major states are losing their area under sorghum. Nearly 180 Full-Time Equivalent (FTE) scientists from NARS are working on sorghum crop improvement and research allocations from ICAR were increased substantially between Xth and XIth Five year plans. The state-level improved cultivars adoption was the highest in case of Maharashtra followed by Madhya Pradesh and Tamil Nadu. The lowest figures were noticed in Rajasthan followed by Andhra Pradesh. In general, the initial estimates from expert elicitationswere comparable with respective state agricultural department estimates. The analysis of secondary data has revealed that nearly 85 per cent of the study districts exhibited positive growth rate in yields with slight increase in variability between 1966 and 2007. The exploration of unit costs of production data showed that reduction in unit costs was observed until early 2000s. The regression results have concluded that increase in area under modern cultivars not only increased the yields but also reduced the variability between districts/states. However, further probe in the analysis is required to deeply understand the other reasons for increase in the variability in yields.

Implications for future priorities for 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 or heart tolerant cultivars by using modern biotechnology tools. Similarly, high emphasis would be given for improvement of post-rainy vintages for increasing the adoption rates. The emerging areas of sorghum research are development of high yielding sweet stalks, fodderquality and increase the density of grain micronutrient traits. Equally, adequate research focus is needed in exploring the preferred traits of non-conventional users / end-users for meeting their demands.

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Appendix Tables

Table 1: National (ICAR) releases during 2000-2010

hybrid/variety	pedigree	season	year	duration
CSV 216 (PhuleYashoda) (SPV-1359)	A Selection from land race	Rabi	2000	120-125
CSV 17 (SPV-1489)	SPV 946 X SPV 772	rabi	2002	95-100
CSV 19SS	RSSV 2 X SPV 462	Kharif	2004	115-120
CSV 18	Selection From CR 4 X IS 18370	rabi	2005	120-126
CSV 20 (SPV-1489)	SPV 946 X kh 89-246		2006	109
CSV 21F	GSSV 148 X SR 897		2006	110
CSH 19R	104AXR354	Rabi	2000	117
CSH 20MF (UPMCH-1101)	2219AXUPMC503	Kharif	2005	100-105
CSH 22SS (NSSH-104)	ICSA 38 X SSV 84	Kharif	2005	115-125

CSH 23 (SPH-1290)	MS 7A X RS 627	kharif	2005	105
CSH21	MLSA 848 X MLR 34	Kharif	2005	N.A
CSH 25	PMS28AXC43	Kharif	2007	110-115
CSH 24MF (UTMCH-1302)	ICSA467Xpant chari		2008	105-110

Table 2 ICRISAT cultivars released in India during 2000-2010

ICRISAT Name	V/H	Released Name	Year of release	Salient features
Parent Source	H	SPH 840	2000	White grain dual purpose hybrid - released stage
GD 34553	V	PVK 801 (Parbhaniswetha)	2000	Grain mold resistant white grain variety released for all India
GD 31-4-2-3	V	ParbhaniMoti (SPV 1411)	2002	Released variety by MAU, Parbhani for Maharashtra suitable for rabi in AP, Karn
Parent Source	H	JK Jyothi	2003	
Parent Source	H	CSH 20/NSSH 104	2005	Sweet sorghum hybrid released for India
Parent Source	H	Bayer 8320	2007	Kharif hybrid for grain & fodder
Parent Source	H	Bayer 8340	2007	Kharif hybrid for grain & fodder
Parent Source	H	Bayer 8562	2007	Kharif hybrid for grain & fodder
Parent Source	H	Bayer 8568	2007	Kharif hybrid for grain & fodder
Parent Source	H	Bayer 8712	2007	Rabi hybrid for grain & fodder similar to Maldandi
Parent Source	H	CSH 25/ParbhaniSainath	2007	Dual purpose sorghum hybrid released in Maharashtra for all India
Parent Source	H	PAC 501	2007	Kharif hybrid for grain & fodder
Parent Source	H	PAC 537	2007	Kharif hybrid for grain & fodder
Parent Source	H	SPH 2ab	2007	Kharif hybrid for grain & fodder