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Improved sorghum cultivation and value-addition perspectives

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Model training course on improved sorghum cultivation and value addition perspectives

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1. Improved genotypes for rabi sorghum

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Introduction: In India, sorghum is grown both in kharif and rabi seasons. While grain from kharif season, in recent years, has been used primarily for animal feed, that from rabi season sorghum is mostly used for human consumption. The crop residue (stover) after the harvest of kharif and rabi season sorghums is a valuable source of fodder for both milch and draught animals, especially during dry seasons. Sorghum is also an excellent source of green fodder because of its wide adaptation, rapid growth and drought tolerance.

Rabi sorghum is an important dry land crop grown in the Deccan Plateau on 5.0 m ha area in the states of Maharashtra (3.2 m ha), Karnataka (1.4 m ha) and Andhra Pradesh (0.38 m ha). It is the major source of food and fodder and as such it greatly influences the economic well being of the population in the region. It is mostly grown in medium (45 to 90 cm) and deep (>90 cm) black soils of dry semi-arid region under receding moisture conditions. The productivity of the crop in general is low (719 kg/ha). Moisture stress in GS-2 due to a unique situation of growing the crop on receding soil moisture in medium to shallow soils, susceptibility to shoot fly, charcoal rot and low temperature affecting crop growth as well as fertility restoration in hybrids are the major factors responsible for low yield.

Rabi sorghum in different agroclimatic zones across states

Maharashtra: Western Maharashtra plain zone (Zone V), scarce rainfall zone (Zone VI) and central Maharashtra plateau zone (assured rainfall zone) (zone VIII), Eastern Vidarbha zone (Zone IX). The major rabi sorghum districts include Solapur, Sangli, Satara-east, Pune east, Ahmadanagar, parts of Nasik, Dhule, Beed, Aurangabad, Parbhani and Osmanabad.

Karnataka: Northern and central parts of the state consisting of entire Bijapur, Bagalkota, Bellary, Koppal districts, parts of Raichur, Gadag, Dharwad, Belgaum, Bidar and Gulbarga districts.

Andhra Pradesh: Parts of Prakasham, Kurnool, Anantapur, Cuddapah, Ranga Reddy, Medak, Nizamabad, Mahabubnagar, and Adilabad encompassing agro climatic zones of North Telangana,(Zone IV) South Telangana (ZoneV) and scarce rainfall zone (Zone VI).

Tamil Nadu: The major sorghum growing districts include Coimbatore, Dindigal, Thriuchirapalli, Salem, Perambalur, Karur, Dharmapuri, Erode, Vellore, Theni and Namakkal.

Gujarat: Districts of Surat, Bharuch, and Baroda.

Varietal Improvement in rabi sorghum: There are many better varieties for rabi season, besides 5-decade old local variety M35-1, like the recently released national varieties/hybrids (CSV-216R, CSV-18, CSV-22, CSH-15R, CSH-19R, CSV-26, CSV-29R) and state released (Shallow soils-Sel.3, Mauli, Phule Anuradha; medium soils- Mauli, Phule Chitra, Parbhani Moti, Phule Suchitra; deep soils/irrigated conditions-Phule Vasudha, Phule Revati, DSV-4, DSV-5 and PKV Kranti). Although several hybrids have been developed and released for rabi season cultivation, the area covered with hybrids is almost negligible. Lack of appropriate hybrids with acceptable grain quality adapted to different agro-ecological situations of rabi season characterized by terminal drought, low temperatures and biotic stresses like shoot fly infestation is a major constraint for higher productivity (Rao et. al. 1986, Rana et.al. 1997). As most of the rabi sorghums are grown under receding moisture situation without any supplementary irrigation, the heterosis can be exploited to break the yield plateau and enhance national productivity from present levels of 769 kg to 900 kg/ha.

Development of early maturing cultivars helps escape terminal drought in rabi and will ensure higher yield in medium to shallow soils where crop failure is frequent. Incorporating greater levels of resistance to shoot fly, charcoal rot, drought and cold can enhance the stability of the production. Hence, intensive efforts are necessary to develop rabi sorghum varieties/ hybrids incorporating all the above characters including earliness to tackle difficult situation of low productivity under receding soil moisture condition.

Historical aspect: Focused breeding on rabi sorghum was initiated in the early seventies. These breeding efforts led to the central release of varieties like Muguti. Heterosis breeding led to the central release of the hybrids like CSH-7R, CSH-8R and CSH-12R. These cultivars were notable in two respects. First, that none of these cultivars succeeded in gaining consistent acceptability from farmers at a scale to effect a discernible impact. Second, that the breeders came to realise the complexities in the genetic up gradation of yield in rabi sorghum. Following were the lessons learnt out of these programmes,

- The traditional and widely preferred land races are ineffective as donors of favourable gene complexes and as parents in heterosis breeding,
- The kharif genetic diversity though very effective in achieving quick yield increase is bedeviled with low adaptability and grain quality, and
- Critical elements of rabi sorghum adaptability are resistance to shoot fly, charcoal rot, moisture stress and low temperature.

The second phase of rabi sorghum breeding with emphasis on hybrid cultivars was initiated in the late eighties. During the first eight years of this phase, 199 entries were evaluated in the AICSIP Initial Varietal Trials, out of which 43 were proposed to the Advanced Varietal Trials. This resulted in the identification of SPV 839 and its central release as CSV-14R. During this period 250 experimental hybrids were evaluated in the AICSIP Initial Hybrid Trials. These trials resulted in the identification of two hybrids, SPH 504 and SPH 677 for central release as CSH-13R and CSH-15R.Variety CSV-14R has no significant yield advantage over M35-1 and is comparable to the latter in most of the adaptability traits. CSH-13R has significant yield superiority over M35-1 but is highly vulnerable to shoot fly and low temperature and has inferior grain quality. The case of CSH-15R having a rabi based MS line (104A) developed at Mohol Centre is different from CSH-13R has a marginal yield advantage over M35-1. Rabi sorghum hybrids will have a tangible impact only when the MS and R lines having the season adaptability and desired combining ability are developed (Rao, 1986)

Hybrid vs. Variety : This is a continuing dilemma in the minds of rabi sorghum breeders. The hybrid school point to the quantum jump made possible in productivity through yield heterosis and highlights the heterozygote advantage against unfavourable growing conditions. The variety school dismisses the heterozygote advantage theory under rabi growing conditions and illustrates the failure of high yielding hybrids. It is also argued that the adaptability under rabi conditions could be achieved by selectively preserved gene complexes rather than by mere heterozygosity. It is further argued that the traditional rabi land races are notable for their high adaptability across an array of micro and macro-environments under the rabi sorghum farming areas (Nerkar, 1998).

Genetic Improvement: Genetic improvement strategy for increasing productivity of rabi sorghum, therefore, should offer flexibility to develop,

(i) Varieties with adaptability to specific soil depths (shallow, medium and deep) and superiority over the existing land races in one or more agronomic or quality attributes,

(ii) Rabi adapted parental lines capable of breeding high heterotic hybrids significantly superior to varieties under rained management conditions and

(iii) Rabi adapted and high input responsive hybrids for irrigated conditions.

Rabi sorghum has an important role in the food and fodder security in the dry land areas of deccan plateau. Its regional importance as a food crop is as much as that of wheat and rice at national level. The continuing low productivity of the crop and its marginal production system are challenges to the researchers. A long way still remains to reach towards the goal of increasing rabi sorghum yield. The research and technology need a thorough relook and introspection to reset attainable targets with time frame and agenda of vigorous action.

Table 1: Rabi sorghum varieties and hybrids recommended: State-wise

State	Area of adptation	Hybrids	Varieties
Maharashtra	Shallow soils Medium soils Deep soils Irrigated conditions	Nil CSH-15R CSH-15R, CSH-19R, SPH-1666 CSH-15R, CSH-19R, SPH-1666	Se. 3, CSV 26, Mauli, Phule Anuradha M35-1, Mauli, Phule Chitra, Suchitra, Parbhani Moti, CSV14R, DSV 4 and CSH 15R CSV 18, CSV22, CSV 216R(Phule Yashoda), PKV Kranti, CSV 14R, DSV 5, CSV-29R, DSV 4 Phule Vasudha, Phule Revati, CSV 216R (Phule Yashoda), DSV 4, CSV-29R
Karnataka	Dry zones Transitional zones Irrigated zone	CSH-12R,CSH 15R CSH-13R,CSH 15R CSH-12R,CSH-13R,CSH-15R	M 35-1, DSV 5 CSV 8R, CSV 14R DSV 4, CSV-29R DSV5, CSV-29R
Andhra Pradesh	Early rabi of Rayalaseema Normal rabi areas	CSH 13R, CSH 15R CSH-13R,CSH 15R	CSV 8R, CSV 14R, M 35-1, CSV 8R, CSV 14R, CSV-29R
Tamil Nadu	Entire rabi area Summer irrigated areas	CSH 10, K.tall CSH 13R CSH 13R, CSH 15R CSH 3, CSH 5	CO 24, CO 25 CSV 14R CO 26, CO 24, CO 25, CSV 8R, CSV 14R
Gujarat	Entire rabi zone	CSH 13R, CSH 15R	CSV 14R,CSV 8R

Table 2: Salient features of popular rabi sorghum hybrids and varieties

S. No.	Cultivar	Grain yeild kg/acre	Dry fodder yield tones/acre	Plant hieght (cm)	Duration (Days)	Salient features
1	CSH 15R	1278 kg/acre (3194 kg/ha)	2.23 t/acre (5.57t/ha)	180-200 cm	112-115 Days	Suitable for medium to deep soils for rainfed & irrigated areas. Tall, large semi compact panicle. Pearly white round & very bold grain, tolerant to shoot fly & charcoal rot and free threshing
2	Phule Revati	1250 kg/acre (3000-3500 kg/ha	3.0-3.2 t/acre (7.5-8.2 t/ha)	220-240 cm	115-125 Days	Suitable for deep soils & under irrigated conditions. Pearly white round & very bold grain, tolerant to shoot fly & charcoal rot
3	Phule Vasudha	1200-1400 kg/acre (3000-3500 kg/ha)	2.8-3.0 t/acre (7-7.5 t/ha)	180-210 cm	116-120 Days	Suitable for irrigated areas. Pearly white lustrous & Medium bold grain, tolerant to shoot fly & charcoal rot
4	Phule Chitra	800-1000 kg/acre (2000-2500 kg/ha)	2.2-2.6 t/acre (5.5-6.5 t/ha)	200-220 cm	112-115 Days	Suitable for medium soils. Plumpy, lustrous & medium bold grain, good grain & fodder quality, tolerant to shootfly, charcoal rot, drought and non lodging
5	CSV 216R (Phule Yashoda)	800-1000 kg/acre (2000-2500 kg/ha)	2.8-3.2 t/acre (7-8 t/ha)	220-250 cm	120-125 Days	Suitable for medium to deep soils in rainfed & irrigated areas. Pearly white round, lustrous & medium bold grain, Tolerant to shoot fly and drought

S. No.	Cultivar	Grain yeild kg/acre	Dry fodder yield tones/acre	Plant hieght (cm)	Duration (Days)	Salient features
6	M35-1	832 kg/acre (2080 kg/ha)	2.44 t/acre (6.11 t/ha)	170-210 cm	115-118 Days	Suitable for medium to deep soils in rainfed areas. Oval shaped semi compact earheads. Pearly white round, lustrous & medium bold grain, tolerant to shootfly, charcoal rot & drought
7	CSV 18	1400-1520 kg/acre (3500-3800 kg/ha)	3.4-3.6 t/acre (8.7-9.0 t/ha)	220-240 cm	120-126 Dyas	Suitable for irrigated areas. Yellow white & bold grain, tolerant to aphid & non lodging
8	CSV 22	920 kg/acre (2300 kg/ha)	2.84 t/acre (7.1 t/ha)	180-200 cm	116-120 Days	Suitable for medium to deep soils in rainfed & irrigated areas. Pearly white round, lustrous & medium bold grain, tolerant to charcoal rot & shootfly,
9	CSV 26	650-720 kg/acre (1300-1600 kg/ha)	1.8-2.4 t/acre (4.5-6.0 t/ha)	180-200 cm	112-115 Days	Suitable for shallow soils, tolerant to shoot fly, stem borer, charcoal rot and tolerant to drought. Medium bold grain with good fodder quality
10	CSV 14R	908 kg/acre (2270 kg/ha)	2.22 t/acre (5.54 t/ha)	180-200 cm	115-120 Days	Suitable for medium to deep soils in rainfed areas. Pearly white round, bold grain, resistant to shootfly charcoal rot & drought equal to M35-1
11	CSV 8R	1000-1200 kg/acre (2500-3000 kg/ha)	2.2-2.6 t/acre (5.0-6.0 t/ha)	200-230 cm	115-120 Days	Suitable for medium to deep soils. Creamy coloured bold gran tolerant to charcoal rot, shoot fly & drought
12	Parbhani Moti	1280 kg/acre (3200 kg/ha)	2.44 t/acre (6.1 t/ha)	190-200 cm	125-130 Days	Suitable for medium soils in rainfed areas. Pearly white lustrous & bold round grain. Tolerant to shoot fly & charcoal rot. Responsive to fertilizers
13	PKV Kranti	900-1000 kg/acre (3000-3500 kg/ha)	2.5-3.0 t/acre (5.0-7.5 t/ha)	180-200 cm	115-120 Days	Suitable for medium to deep soils and irrigated Pearly white round & very bold grain, tolerant to shoot fly.
14	CSV-29R	800-1000 kg/acre (2500-3000 kg/ha)	2.6-3.2 t/acre (5.0-7.5 t/ha)	180-200 cm	115-120 Days	Suitable for deep soil. Pearly white round & very bold grain, tolerant to shoot fly & charcoal rot
15	Phule Anuradha	600-700 kg/acre (1500-1800 kg/ha)	1.2-1.6 t/acre (3.0-3.5 t/ha)	160-180 cm	100-112 Days	Suitable for shallow soils in rainfed areas. Early Pearly white round and medium grain, tolerant to shoot fly & charcoal rot. Early maturing.
16	Phule Maulee	600-800 kg/acre (1500-2000 kg/ha)	1.8-2.0 t/acre (4.5-5.0 t/ha)	180-210 cm	110-115 Days	Suitable for shallow, medium soils in rainfed areas. Yellow white, lustrous & medium bold grain, tolerant to shoot fly & charcoal rot & drought
17	DSV 5	900-1000 kg/acre (3000-3500 kg/ha)	2.6-3.2 t/acre (3.5-4.5 t/ha)	220-250 cm	120-125 Days	Suitable for deep soils, transitional & irrigated zones in Karnataka. Pearly white round & very bold grain, tolerant to shoot fly.
18	DSV 4	1600-1680 kg/acre (4000-4200 kg/ha)	1.8-2.0 t/acre (4.5-5.0 t/ha)	180-200 cm	115-120 Days	Suitable for dry zones in karnataka. Creamy bold, round grain flat at one side and tolerant to diseases
19	Solapur Dagadi	400-500 kg/care (1000-1250 kg/ha)	1.8-2.2 t/acre (3.5-4.0 t/ha)	180-200 cm	120 Days	Suitable for deep soils and irrigated conditions Pearly white, bold grain, tolerant to shoot fly & charcoal rotdrought.
20	CSH 19R	1181.2 kg/acre (2953 kg/ha)	2.34 t/acre (5.84 t/ha)	225 cm	117-120 Days	Suitable for medium to deep soils for rainfed & irrigated areas. Pearly white,slightly flat, medium sized grain, tolerant to shoot fly & charcoal rot
21	SPH1666	1200 kg/acre (3000-4000 kg/ha)	2.2 t/acre (5.5 to 6.5 t/ha)	200-225 cm	118-122 Days	Suitable for deep soils . Pearly white,slightly flat, medium sized grain, tolerant to shoot fly & charcoal rot
22	Phule Suchitra	1000-1200 kg/acre (2500-3000 kg/ha)	2.2-2.6 t/acre (5.5-6.5 t/ha)	200-220 cm	115 Days	Suitable for medium Pearly white, lustrous & medium bold grain, tolerant to shoot fly & charcoal rot & drought soil.

Table 3.Details on the pedigree and origin of hybrids and varieties

S.No.	Hybrid/Variety	Pedigree	Origin
	Hybrids		
1	CSH-12R	296A xM148-138	Dharwad
2	CSH-13R	296A x RS 29	NRCS
3	CSH-15R	104A x RS-585	NRCS
4	CSH-19R	104A x R 354	Akola
5	SPH-1666		Devgen
	Varieties		
6	M35-1	Selection from Maldandi bulk	Mohol
7	CSV-8R	R24(IS-2954 x M35-1)	NRCS
8	SWATI	SPV-86 x M35-1	Rahuri
9	SEL-3	Selection from Bidar local	Rahuri
10	CSV-14R	M35-1 x (CS2947 x CS2644) x M35-1)	NRCS
11	DSV-4(9-13)	E36-1 x SPV-86	Dharwad
12	DSV-5(GRS-1)	Selection from Natte maldandi of Gulbarga	Dharwad
13	CSV-216R (Phule Yashoda)	Selection from Dhulia germplasm	Rahuri
14	RSLG-262 (Mauli)	Land race selection	Rahuri
15	Parbhani Moti	Selection from GD 31-4-2-3	Parbhani
16	CSV-18 (Parbhani Jyoti)	PVR 579	Parbhani
17	PKV Kranti(AKSV-13R)	SPV-1201 x Ringni	Akola
18	Phule Chitra	SPV-655 x RSLG-112	Rahuri
19	Phule Vasudha	RSLG-206 x SPV-1047	Rahuri
20	Phule Revati	CSV 216 x SPV 1501-1	Rahuri
21	Phule Suchitra		Rahuri
22	Phule Anuradha		Rahuri
23	CSV-22	CSV 216 x RSP 2	Rahuri
24	CSV-26	SPV 655 x SPV 1538	Solapur
25	CSV-29R	[GRS 1 x CSV 216R] x CSV 216R	Bijapur

Conclusion

Rabi sorghum has an important role in the food and fodder security in the dry land areas of deccan plateau. Its regional importance as a food crop is as much as that of wheat and rice at national level. The continuing low productivity of the crop and its marginal production system are challenges to the researchers. The research and technology need a thorough relook and introspection to reset attainable targets with time frame and agenda of vigorous action.

References

Nerkar, Y.S. 1998. Rabi sorghum improvement for food and fodder security: Opportunities and strategies, Special lecture delivered at 29th Workshop of AICSIP, April 23-25,1998 at University of Agricultural Sciences, Dharwad

Prabhakar, M Elangovan and MS Raut. 2010. Stability of new varieties for yield components in rabi sorghum, Indian J. agric, Sci. 80 (2): 106-109.

Rana BS, Swarnlata Kaul and Rao MH. 1997. Impact of genetic improvement on sorghum productivity in India. Pages 142-165 in the Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl millet, 22-27 September 1996, Holiday Inn Plaza, Lubbock, Texas.

Rana, B.S., Jaya Mohan Rao, V., Reddy, B.B., and Rao, N.G.P. 1985. Overcoming present hybrid yield in sorghum. Pages 48-59 In Genetics of heterotic system in crop plants: Proceedings of Precongress Symposium XV International Genetics Congress, 7-9 Dec 1983, Tamil Nadu Agricultural University, Coimbatore, India.

Rao, N.G.P. 1982. Transforming traditional sorghum in India. Pages 39-59 In Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, ICRISAT, India. Vol. 1. Patancheru, Andhra Pradesh 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Rao, N.G.P., Jaya Mohan Rao, V., and Reddy, B.B. 1986. Progress in genetic improvement of rabi sorghums in India. Indian J. Genet. 46(2): 348-354.

Reddy. B.V.S., Ahok Kumar, A., Sanjana Reddy, P. and Elangovan, M. 2008. Sorghum germplasm: diversity and utilization in 'Sorghum Improvement in the New Millennium edited by Reddy Belum VS, Ramesh S, Ashok Kumar A and Gowda CLL, pp153-169.

2. Pests of sorghum and their management

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Sorghum (Jowar), *Sorghum bicolor* (L.) Moench) is an important dry land crop grown with minimum purchased inputs mostly grown in most of the parts of India either for grain or fodder use. It is also the base crop on which many inter- and sequence-cropping systems are built upon. Increasing industrial utilization, greater use as quality forage and as an adjunct in food and feed mixes can enhance the demand for sorghum. However, insect pests in *Kharif* and *Rabi* sorghum remain the major causes for limiting yield and economic losses. The grain yields are generally low (500-800 kg/ha) mainly damages caused by insect pests. Nearly 150 insect pest species have been reported as pests of sorghum of which shoot fly (*Atherigona soccata*, Rondani), spotted stem borers, (*Chilo partellus*,Swinhoe and *Sesamia inferens*), aphids (*Melanaphis sacchari* and *Rhopalosiphum maidis*), shoot bug (*Peregrinus maidis*), sorghum midge (*Stenodiplosis sorghicola* Coquillett), earhead bug (*Calocoris angustatus*), armyworm (*Mythimna separata*, Walker), bollworms (*Helicoverpa armigera* (Hubner), *Eublema* and *Pyroderces*) and spider mites (*Oligonychus spp*.) have been reported as major pests in sorghum in India. The list sorghum pests and their status is given (Table 1).

Table 1: Major pests of sorghum in India

S No	Common name	Scientific name, Family, (Order)	Status
1	Shoot fly	*Atherigona soccata* Muscidae (Diptera)	Major
2	Stem borer	*Chilo partellus,* Crambidae (Lepidoptera)	Major
3	Pink stem borer	*Sesamia inferens,* Noctuidae (Lepidoptera)	Major
4	Shoot bug	*Peregrinus maidis,* Delphacidae (Hemiptera)	Major
5	Aphids	*Rhopalosiphum maidis, Melanaphis sacchari* Aphididae (Hemiptera)	Major
6	Earhead bug	*Calocoris angustatus,* Miridae (Hemiptera)	Major
7	Sorghum midge	*Stenodiplosis sorghicola,* Cecidomyiidae (Diptera)	Occasional
8	Earhead web worm	*Cryptoblabes gnidiella* Pyraustidae (Lepidoptera)	Occasional
9	Gram caterpillar	*Helicoverpa armigera,* Noctuidae (Lepidoptera)	Occasional
10	Stink bug	*Nezara viridula* Pentatomidae (Hemiptera)	Occasional
11	Mirid bug	*Creontiades pallidifer* Miridae (Hemiptera)	Occasional
12	Leaf roller	*Marasmia trapezalis* Pyralidae (Lepidoptera)	Occasional
13	Flea beetle	*Cryptocephalus schestedii, Monolepta signata* Chrysomelidae (Coleoptera)	Occasional
14	Hairy caterpillar	*Amsacta albistriga, A. moorei* Arctiidae (Lepidoptera)	Occasional
15	Semilooper	*Eublemma silicula,* Noctuidae (Lepidoptera)	Occasional
16	Weevils	*Myllocerus maculosus M. discolor,* Curculionidae (Coleoptera)	Occasional
17	Grasshopper	*Colemania sphenaroides,* Acrididae (Orthoptera)	Sporadic
18	Spider mites	*Oligonychus spp.*	Sporadic

The biology, damage symptoms, cultural control, chemical control and integrated management strategies for major pests are discussed below.

I. MAJOR PESTS

1. Sorghum Shoot fly: *Atherigona soccata* (Muscidae: Diptera)

Host range: Maize, ragi, bajra, rice, wheat and grasses

ETL: 10% dead hearts or 1 egg / plant

1.1. Bionomics

Plate 1: Shoot fly-Adult

The adult is a small, grey coloured, female shoot fly which deposits small, white cigar shaped eggs, singly on the under surface of the seedling leaves (Plate 1). After hatching in 2-3 days, the maggot enters the seedling through the whorl and destroys the growing point. The larval period lasts for 8-10 days. Mature larva is yellow and about 6 mm in length. Pupation takes place either at the plant base or in the soil and lasts for 8-10 days. The fly population exhibits considerable variation and normally very low in April to June, tends to increase in July and reaches the peak in August. From September onwards the population gradually declines and remains at a moderate level till March. Its activity is influenced by extreme temperatures (high or low) and also by continuous rains.

1.2. Damage symptoms

It is a seedling pest and normally occurs in the 1st-4th week after germination. Maggot feeds on the growing tip causing wilting of leaf and later drying of central leaf giving a typical appearance of `dead heart' symptoms (Plate 2). If the infestation occurs a little later, damaged plants produce side tiller which again are infested increasing the population build up. To schedule the chemical control, the shoot fly infestation can be monitored by checking the egg-laying on the lower surface of the seedling leaves before the formation of dead hearts.

Plate 2: Shoot fly deadheart

2. Stem borer: *Chilo partellus* (Crambidae: Lepidoptera)

Host range: Maize, sorghum, sugarcane, bajra, rice, *Sorghum halepense*, finger millet
ETL: 10% dead heart

2.1. Bionomics

The female lays nearly 500 eggs in masses of 10-80 on the under surface of the leaf often near the midrib. The eggs hatch in 4-5 days. The larval period lasts from 19 to 27 days. Pupation takes place inside the stem and the adult emerges in 7-10 days. During the dry season, the larva enters into diapauses and survives in harvested stalks/stems as well as stubbles left in the field. As the rainy season starts the diapauses brakes down and pupation takes place. The moth is medium size and straw colored.

2.2. Damage symptoms

It infests the crop from 2nd week till maturity. Initially, the larvae feed on the upper surface of whorl leaves leaving the lower surface intact as transparent windows. As the severity of the feeding increases, blend of punctures and scratches of epidermal feeding appears prominently. Sometimes, `deadhearts' (Plate 3) symptoms also develop in younger plants due to early attack. Subsequently, the larvae bore into the stem resulting in extensive stem tunneling (Plate 4). Peduncle tunneling results in either breakage or complete or partial chaffy panicle.

Plate 3: Stem borer deadheart

Plate 4: Stem infestation

3. Pink stem borer: *Sesamia inferens* (Noctuidae: Lepidoptera)

Host range: Sorghum, maize, rice, wheat, sugarcane, bajra and ragi, barley, guinea grasses.
ETL: 1 larva/whorl

3.1. Bionomics

Plate 5: Pink stem borer-

The adult moth is pale pink colored, with dark brown streaks on the fore wings and white hind wings. The female lays about 150 creamy-white and hemispherical eggs that are arranged in two or three rows between the leaf sheath and the stem of the host plant. Egg period remains till 7 days. The fully grown larvae measures about 25 mm and is pale yellow with a purple pink tinge and a reddish-brown head. The larval period 25 days but in cold months it may be extended to 75 days. Pupation occurs in the larval tunnel in the stem and the adult emerges in 12 days (Plate 5). One generation may take 6-7 weeks. The life cycle is completed in 45-75 days. There are 4-6 generations per year.

3.2. Damage symptoms

The pink larva bores into the stem and damages the central shoot resulting in deadheart. Borer holes are visible on the stem near the nodes. Holes in the stem caused by the larvae tunneling into the stem, deadheart (drying and eventual death of the growing point of the maize), broken due to larvae tunneling in to the stem. Internal feeding causes withering of stem results in formation of deadhearts, Faeces (frass) and empty grains are visible due to damage (Plate 6).

Plate 6: Stem damage-borer

4. Shoot bug: *Peregrinus maidis* (Delphacidae, Hemiptera)

Host range: Sorghum, maize, rice, millets, ETL: 5 nymphs/whorl

4.1. Bionomics

The adult is yellowish brown to dark brown with translucent wings. The brachypterous female is yellowish while macropterous female is yellowish brown and male dark brown (Plate 7). It lays eggs in groups of 1-4 inside the leaf tissue and covered with a white waxy substance. The fecundity of the bug is 97 eggs / female. The egg period lasts for seven days. The nymphal stage undergoes five instars in 16 days. The total life cycle is completed in 18-31 days. Being a sporadic pest, under favourable conditions, it produces several generations and can cause heavy damage to sorghum.

Plate 7: Adult-Shoot

4.2. Damage symptom

Infestation in kharif begins 30 days after germination. However, heavy infestation is seen on the *Rabi* crop, when rain occurs at seedling stage. Both the adult types (Brachypterous and Macropterous) and nymphs suck the plant sap causing reduced plant vigour and yellowing. In severe cases, the younger leaves start drying and gradually extend to older leaves (Plate 8). Sometimes, complete plant death occurs. Heavy infestation at vegetative stage may twist the top leaves and prevent either the formation or emergence of panicles. It is also known to be vector for transmitting stripe disease of maize.

Plate 8: Shoot bug damage

5. Aphids: *Rhopalosiphum maidis, Melanaphis sacchari* (Aphididae: Hemiptera)

Host range: Sorghum, maize, ragi, ETL:10 aphids/leaf (undersurface)

5.1. Bionomics

The corn yellow aphid is dark bluish-green and somewhat ovate. It is 2 mm long, with black legs, cornicles, and antennae. Winged and wingless forms occur. Females give birth to living young without mating and a generation requires only a week or so. During Rabi, the adult is yellow coloured with dark green legs. Female gives birth to young ones and a generation takes 7 days. The colonies are typically found deep inside the plant whorl of the middle leaf on the ventral surface of the leaves, stem and panicle.

5.2. Damage symptom

Rhopalosiphum maidis: Colonies of aphids are seen in central leaf whorl, stems, or in panicles. The young and adults suck the plant juice. This frequently causes yellowish mottling of the leaves and marginal leaf necrosis. The aphid produces an abundance of honeydew on which molds grow. In panicles, honeydew may hinder harvesting. The aphid also transmits maize dwarf mosaic virus.

Melanaphis sacchari: The sugarcane aphid is yellow to buff. Numbers increase rapidly during dry spells or at the end of the rainy season. The female of the wingless form deposits 60- 100 nymphs within its reproductive period of 13-20 days (Plate 9). The winged form produces slightly fewer nymphs. The life cycle is completed in 5.5-7.0 days during the dry season. The honeydew excretion hinders harvesting process and result in poor quality grain (Plate 10). Severe damage was noticed under moisture stress conditions resulting in drying of leaves as well as plant death. Unlike the corn leaf aphid, sugarcane aphid predominantly is a serious pest in rabi and prefers to fed on older leaves and also infest younger leaves including panicle at flowering stage. Adults are yellow to buff colored. Both adults and nymphs such the plant sap and cause stunted growth.

Plate 9: Aphids on leaf

Plate 10: Aphid damage

6. Oriental armyworm, *Mythimna separate* (Noctuidae: Lepidoptera)

Host range: Sorghum, maize, ragi, graminaceous plants; ETL: 1-2 Caterpillars/plant

6.1. Bionomics

Female lays round greenish white eggs in batches. Caterpillars become full grown in 3-4 weeks. Pupal periods last for 8-10 days. The pest is active from June to November. It completes its life cycle in about six weeks. In a year about three generations can be completed. The pupae usually hibernate in the soil (Plate 11).

Plate 11: Caterpillar-armyworm

6.2. Damage symptom

Caterpillars are mostly active in night and hide in leaf whorl or in the soil in day time. The Oriental armyworm, *Mythimna separata* larvae (Plate 12) feed on the leaves, leaving only the midribs, and panicles. Pellated excreta of the larvae are observed either on the leaf or in the whorl. When the larvae are in gregarious phase, they move in a band and feed on the foliage of most of the graminaceous plants they come across. Maximum larval incidence and damage occur during August.

Plate 12: Leaf damage-armyworm

7. Earhead bug: *Calocoris angustatus* (Miridae: Hemiptera)

Host range: Pearl Millet, maize, tenai, sugarcane and grasses, ETL: 1-2 bugs /earhead

7.1. Bionomics

Adult male is green in colour and female is green with a brown margin (Plate 13) Blue cigar shaped eggs are laid under the glumes or into the middle of the florets. Each insect lay between 150 and 200 eggs. The egg period is seven days. Nymphs are

Plate 13: Earhead bug-adult

slender, green in color. First instar is orange in color. The nymphal period is 10 - 14 days. The life cycle from egg to adult occupies less than 3 weeks. At least 2 generations of the bug can feed on the same crop when the panicles do not ripen at the same time.

7.2. Damage symptom

The adults and nymphs damage the earheads by feeding on them. They suck the juice from the grains when they are in the milky stage. The sucked out grains, shrink and turn black in colour and become ill filled (or) chaffy (Plate 14). Older grain shows distinct feeding punctures that reduce grain quality. Extent of damage usually depends on the number of bugs per panicle, duration of infestation and stage of grain development and decreases as the grain develop towards hard dough stage. Grain mold damage is severe in bug affected panicles.

Plate 14: Earhead damage-head

8. Sorghum midge: *Contarinia sorghicola* (Cecidomyiidae: Diptera)

Hosts range: Sorghum cultivated and wild species. ETL: one maggot/earhead

8.1. Bionomics

The adult fly is small, fragile with a bright orange abdomen and a pair of transparent wings. It lays eggs singly in developing florets resulting in pollen shedding (Plate 15). A female lay about 30-35 eggs at the rate of 6-10 in each floret. The incubation period is 3-4 days. The maggot has four instars with duration of 8-10 days. Larvae are colorless, but, when fully grown, they are dark orange. Larval period 9 - 11 days. The larval stage undergoes diapauses in a cocoon during December - January within a spikelet. It pupates beneath the glumes. The pupal period lasts for 3 days. When the adult emerges the white pupal skin remains at the tip of the spikelet. A generation is completed in 14-16 days. The insect's rapid developmental cycle permits 9-12 generations.

Plate 15: Midge

Damage symptoms

A maggot feeds on the developing grains and pupates there. White pupal cases protruding out from the grains and chaffy grains with holes are the damage symptoms (Plate 16). Pupal cases can be seen attached to the glumes of damaged spikelets.

Plate 16: Earhead damage

9. Spider mites (*Oligonychus indicus*)

9.1. Bionomics

Female and immature stages feed on the foliage. It leaves in colonies under a deliberate web on the under surface of the leaves and get disturbed by crawling or by wind. Adults of sorghum spider mite are deep red or maroon and the nymphs are also slightly reddish (Plate 17).

Plate 17: Spider mite-adult

9.2. Damage symptoms

Although found early in the growing season rapid population increases occurs only after the panicle emergence. They such the plant sap first on the under surface of the functional leaves and the infested areas initially are pale yellow, but later turn to reddish (in purple pigmented cultivars) or brownish tan (in tan pigmented plants) on the upper leaf surface. This extends to the entire leaf area which spreads upwards through the plant affecting plant growth and seed development (Plate 18). The underside of the heavily infested leaves have dense deposits of webbing and in severe infestations they may invade and web even the sorghum panicle. It often causes damage to sorghum in prolonged drought situations.

Plate 18: Mite damage

II. MINOR PESTS

The pests like ear head web worm (Cryptoblabes gnidiella), Gram caterpillar (Helicoverpa armigera), Oriental armyworm/cut-worms (Mythimna separata), plant bug (Dolycoris indicus) sting bug (Nezara viridula), Mirid bug (Creontiades pallidifer), leaf roller (Marasmia trapezalis), flea beetle (Cryptocephalus schestedii), Wingless grasshopper (Colemania sphenaroides) and Pyrilla (Pyrilla perpusilla) are minor in nature and infest occasionally.

III. INSECT PEST MANAGEMENT

1. Cultural methods

- Collect and burn stubbles and chaffy earheads, and feed the stalks to cattle before the onset of monsoon rains. This will reduce the carryover of stem borers and midge.
- Deep plough one month before planting will expose immature stages of insects and serve as a food for predators.
- Adopt synchronous and timely/early sowings of cultivars with similar maturity over large areas to reduce the damage by shoot fly, midge, and head bugs.
- Rotate sorghum with cotton, groundnut, or sunflower, to reduce the damage by shoot fly, midge, and head bugs. Intercropping sorghum with pigeonpea, cowpea, or lablab also reduces the damage by stem borers
- Treat seeds with carbofuran (5% a.i.) or imidacloprid (0.165 mg/kg seed) or thiamethoxam (cruiser) 70 WS @ 3 g /1 kg of seeds to improve plant stand, seedling vigor, and reduce the damage by shoot fly and to some extent stem borer and sucking pest.
- Use high seed rates 1.5 times more i.e. @10-12 kg/ha, and delay thinning (to maintain optimum plant stand) to minimize shoot fly damage.

2. Mechanical method

- Set up light traps till mid night to monitor, attract and kill adults of stem borer, grain midge and earhead caterpillars.
- Set up sex pheromone trap at 12/ha to attract male moths *Helicoverpa* sp. from flowering to grain hardening.
- Set up the fishmeal traps having impregnated with Arpocarb insecticides @ 12/ha till the crop is 30 days old.

3. Biorational methods

- Release egg parasitoids: *Telenomus* sp., *Trichogramma chilonis*; Larval parasitoids: *Apanteles flavipes*, *Bracon hebetor*; Pupal parasitoid: *Tetrastichus ayyari*
- Take up two applications of NPV at 10 days interval at 250 LE/ha along with crude sugar 2.5 kg + cotton seed kernel powder 250 g on the ear heads to reduce the larval population of *Helicoverpa* sp
- Neem seed kernel extract (5 kg/ha) or *Bacillus thuringiensis* (*Bt*) formulations can be suggested for the control of stem borers, armyworms, and head caterpillars.
- Apply balanced fertilizers having adequate NPK to promote better plant growth, that results in reduced damage by shoot fly and stem borers.
- Plant sorghum varieties with less susceptibility to insect, e.g., SV 1616, CSV 15, M 35-1, Phule Yashoda, are relatively less damaged by shoot fly and stem borers while ICSV 745 and ICSV 88032 are resistant to sorghum midge.
- Conserve egg parasitoids *viz., Paranagrus optabilis*, *Octetrastichus indicus and* Predators - *Coccinella septumpunctatum, Menochilus sexmaculatus*, *Geocoris* tricolor for shoot bugs and aphids control.

4. Chemical methods

- When the shoot fly damage reaches 5 to 10% of the plants with deadhearts, the crop may be sprayed with cypermethrin 10 EC (750 ml/ha) or quinalphos 25 EC (400 g a.i./ha) or carbofuran granules (5 to 7 granules/plant) may be applied in the leaf whorls
- For stem borers, dusts or granules can be applied in the whorl leaves of damaged plants or the entire field can be sprayed with quinalphos fenvalerate, or cypermethrin.
- For sorghum midge, the crop may be sprayed at the 50% flowering stage (1 midge/panicle) with quinalphos or cypermethrin.
- For earhead bugs (1 to 2 bugs per panicle) and head caterpillars (2 larvae per panicle), the crop may be sprayed at the completion of flowering and at the milk stage with quinalphos or cypermethrin.
- Spraying of sulphur has been most effective in reducing the mite population, in severe cases kelthane (Dicofol) 35 EC or ethion @ 1 lt/ha in 500 ml of water reduces the incidence
- Spraying of Metasystox 35 EC (@1 lt/ha in 500 lt water) or methyl demeton 25 EC 500 ml in 500 L of water per ha effectively controls aphids and shoot bugs.

3. Sorghum for food, feed, fodder and fuel

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Sorghum [*Sorghum bicolor* (L) Moench] is an important cereal crop in semi-arid regions of the world including African and Asian countries. Sorghum is generally a dry land crop and most commonly cultivated by resource poor farmers in marginal farms where this relays on very low inputs. In India sorghum is found primarily on Deccan Plateau and it is the main staple diet of the people of Maharashtra, Karnataka and Andhra Pradesh states. Due to its versatile use, drought hardiness and adaptability over wide range of climates, sorghum has maintained its importance and dependability. Nutritional point of view, it is the main source of dietary energy in central parts of the country contributing nearly 50% of the total cereal intake (75 kg grain per head per year), especially by rural consumers in the inlands of Maharashtra and Karnataka. In terms of nutrient intake, sorghum accounts for about 35% of the total intake of calories, protein, Fe and Zn in the dominant production/ consumption regions. Kharif sorghum area in India is 4.10 m ha while rabi sorghum occupies relatively more acreage of 5.2 m ha. Here we have provided brief information about different uses of sorghum and its importance in changing climatic conditions.

Sorghum as a food and feed

Grain sorghum mainly cultivated in two seasons i.e. kharif and rabi. Most of produce from kharif season is used for the industrial uses and also as a feed. Maturity period in kharif season generally coincides with the heavy rains thus affected by grain mold. This produce is used by distilleries to produce alcohol and some part is utilized by feed industry (Dairy and Poultry). Unlike kharif, in rabi season produce will be clean and of high quality. This is mostly used for consumption. Kharif sorghum area is mostly dominated by hydrids which respond better to high moisture and fertilizers. Whereas, varieties are the choice for the rabi season under receding moisture conditions.

Pooped sorghum is very popular snack consumed in several sorghum growing states of India. Popped sorghum grains superior to popped corn as they are tender, have less hull, do not clog in space between teeth and causes less noise while eating. Popping sorghums have a very low germ-endosperm size ratio and the embryo is located at a corner in the hilar region. The germ remains unaffected during popping. The availability of sorghum cultivars whose grains exhibit superior popping quality without any pretreatment should be of significance to food technologists and breeders.

In most of the sorghum growing parts of the India there is a practice of roasting sorghum heads at the dough stage and eating the threshed grain as a delicacy. The cultivars most suitable for roasting have a sweet endosperm that is dimpled at maturity. ***Vani*** sorghums (*durra* group) of India are especially popular in this respect. The panicles were buried in hot coals and ashes for several minutes to be cooked, following which the light green seeds were lightly beaten off the heads and hand winnowed. In Maharashtra this very popular snack is called *Hurda*.

Sorghum as fodder

Sorghum as a forage crop has high demand due to its high quality fodder. It is cultivated in large area in northern states of India. Forage sorghum is a valuable fodder, it is relished by ruminants, it is outstandingly drought resistant and it grows where maize is not able to grow because of high temperatures or dry conditions. Most of the sorghum cultivars grown in India are found to be dual-purpose varieties providing grain for human consumption and fodder for livestock. It has two types, single cut and multi-cut sorghum. Multi-cut sorghum has more advantage as we can get more fodder from the same plant for longer period.

Sorghum as a biofuel

Sorghum genotypes possessing sweet stalks are excellent alternative for production biofuels. Improved cultivars of sorghum are very high in the brix and used for extracting juice and thereafter converted to ethanol. Sorghum grains are also used for the production of ethanol. The main advantage of sweet sorghum is that it requires very less water as compared to the sugarcane. The greatest challenge for large-scale production of sweet sorghum for biofuel is the lack of commercial harvesting equipment. It is hoped that this will change in the near future. Government has also initiated and made it mandatory to blend ethanol in petrol and other commercial fuels. This will bring in private players to commercially exploit the sweet sorghum potential by developing equipments for processing.

Color sorghum

Coloured sorghum is now gaining importance due its high antioxidant content. This sorghum grain contains high amount tannins and phytates. Nonalcoholic porridges of sorghum are made by souring the grain overnight and cooking it in the morning. Such preparations are diluted and consumed as a thin gruel. In the highlands of southern Uganda extending into Rwanda, there is a practice of malting the dark brown sorghums for preparation of ***porridge.*** The coloured sorghum grains are in high demand as feed in eastern countries for pigs and other live stock. It gives a reddish colour to the flesh.

Scented sorghum

There are some sorghum landraces which have a special aroma or scent similar to scented rice. Seedlings were stated to emit scent and also the adult leaves when crumpled. Directorate of Sorghum Research has good collection of scented landraces collected from Bundelkhand region. The efforts are in way to transfer this character in high varieties.

Broomcorn sorghum

Sorghum has multifarious uses such as human food, animal feed, and biofuel. One of the special type’s sorghum is broom corn sorghum. The only reported use of broomcorn sorghum is in the broom industry. Brooms of different sizes, shapes, and purposes based on broomcorn fibers are called corn brooms. This use of sorghum is mainly exploited in South Eastern European countries i.e. Serbia. Here the corn brooms are products of a well–organized niche market. In India even though we have diversity for broomcorn in Uttaranchal and Himalayas, it is not flourished as industry. The local people are manufacturing the brooms for the house hold purpose. The landraces they are using are not of standard qualities which are required for making the good quality brooms.

4. Production technologies of sorghum in rice-fallows

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Under changing climate scenario, sorghum is emerging as a potential alternative feed, fodder and bio-energy besides, food crop. However, the area under kharif sorghum cultivation is decreasing rapidly due to various reasons. The situation demands a search for potential niches for its cultivation in non-traditional areas. Sorghum cultivation in rice-fallows with an average productivity of 6.5 t /ha, which is the highest in the country, is a valuable opportunity.

In recent years, sorghum cultivation in rice-fallows during late-*rabi* is gaining popularity in coastal Andhra Pradesh, especially in Guntur and adjoining Krishna and Prakasham districts due to insufficient water for second crop of rice. The farmers are planting sorghum after harvest of rice in mid-December under zero-tillage to utilize the residual soil moisture. The crop is harvest during first week of April. Usually, farmers grow pulses (greengram and blackgram) in rice-fallows of the Krishna-Godavari zone of Andhra Pradesh as *utera* cropping (broadcasting of seeds in standing crop of rice). This practice helps the farmers to harness the residual moisture (Singh, 2007), and at the same time increasing nitrogen content in soil by biological nitrogen fixation. However, in the recent times, the area under pulses has declined due to late planting of rice and severe attack of viral diseases and parasitic weed *Cuscuta* (Mishra *et al.* 2009). The farmers of the coastal area having assured irrigation facilities have now shifted to maize and those with limited irrigation to sorghum. The area under sorghum in rice-fallows has increased from 2000 ha in 2005-06 to more than 24000 ha during 2012-13 (fig. 1), with an average productivity of 6.5 t/ha, which is the highest in the country. Sorghum also requires fewer inputs such as nutrients and plant protection measures as compared to maize. Farmers of the area are harvesting up to 6-7 t/ha sorghum grains depending up on management practices. Keeping in view the scarcity of irrigation water in future, the area under sorghum is expected to increase.

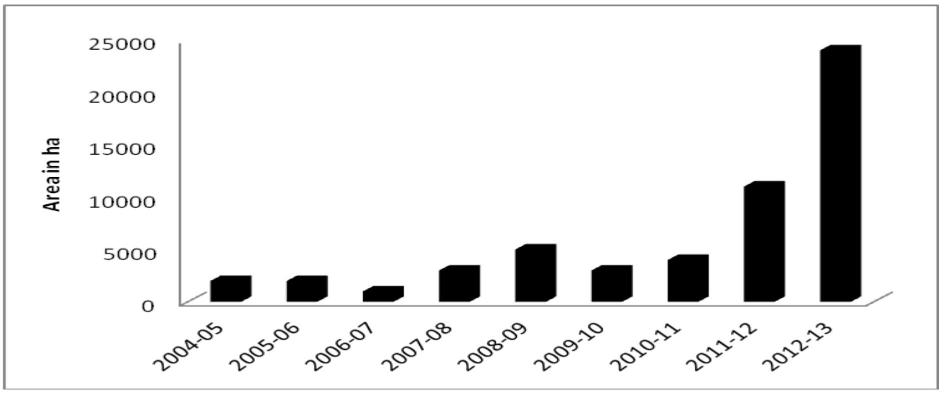

Fig. 1 Sorghum area in rice-fallows in Guntur district of coastal Andhra Pradesh

Production technology

Cultivars: In rice-fallows of coastal Andhra Pradesh, sorghum is grown for grain purpose. The hybrids are preferred over varieties due to their high yields. Mishra et al. (2009) evaluated thirteen sorghum cultivars including hybrids and varieties in rice-fallows under zero tillage at farmer's field in Guntur district of Andhra Pradesh and reported that sorghum hybrids, 'Sudama 333' (8.44 tonnes/ha), 'CSH 16' (7.80 tonnes/ha), 'MJ 4334' (7.37 tonnes/ha) and 'MRS 4094' (7.14 tonnes/ha) were promising. Chapke et al. (2011) demonstrated the performance of sorghum hybrids in rice-fallows at farmer's fields in Guntur district and found that hybrids NSH 27 (7.57 t/ha), CSH 16 (7.43 t/ha), Kaveri 6363 (7.4 t/ha), Mahalaxmi (7.11 t/ha), and SBSH 151 (6.97 t/ha) registered the higher grain yield (Table 1).

Table 1. Plant height, yield and yield attributes of sorghum hybrids in rice-fallows in the farmers' fields in Guntur district

Hybrid	Plant height (cm)	Panicles/ m^2	Panicle length (cm)	Grains/ panicle	Grain weight/ panicle (g)	100-grain weight (g)	Grain yield (t/ha)
NSH 27	163	15.1	29.6	2951	54.7	2.58	7.57
CSH 16	174	18.4	30.7	2471	50.1	2.66	7.43
Kaveri 6363	163	17.4	28.4	2780	52.8	2.46	7.40
Mahalaxmi	146	17.2	28.9	2352	46.9	2.55	7.11
SBSH 151	171	15.8	28.5	2446	49.5	2.88	6.97
CSH 15R	251	16.2	26.7	1948	41.4	2.86	5.95
CSH 23	155	17.9	25.4	2498	36.8	2.41	5.39
CD(P=0.05)	19	3.6	1.9	611.63	8.3	0.36	0.92

Fig.2. Performance of sorghum hybrid CSH 16 in rice-fallows

Time of sowing: The time of sowing of sorghum in rice-fallows depends solely on the time of *kharif* paddy harvesting as the crop is sown on the residual soil moisture. In general, 2nd to 3rd week of December is an ideal time. Delayed sowing in January affects the seed setting and grain filling due to high temperature in March and April. Sometimes unusual rains in coastal areas during April cause heavy damage in sorghum.

Method of sowing and seed rate: The crop is sown in zero tillage after harvesting of paddy. The sowing is done manually in rows (40x15cm apart) at 4-6 cm depth by making a hole with wooden stick and putting 2-3 seeds in each hole (Fig. 13.2). Making holes manually for sowing is however; time consuming back breaking and costly. Therefore manually operated small implement (Fig. 13.2) and tractor operated hole maker (Fig.13.3) have been developed for easy and timely sowing. Around 8-10 kg seed/ha is required for optimum plant population.

Nutrient management: For obtaining high yield of sorghum, 200 kg N, 60 kg phosphorus and 60 kg potassium per hectare is recommended. Mishra *et al.* (2013) obtained maximum sorghum grain yield (8.04 t/ha), nutrient uptake and income benefits with 225 kg N/ha (Table 2 and 3). Grain yield of different sorghum hybrids varied significantly in their response to applied nitrogen (Fig 4). Hybrids

'CSH 23' and 'CSH 15R' were less responsive to higher doses of nitrogen as compared to other hybrids. Being a zero till manually sown crop, no nutrient is applied at sowing. A dose of 100 kg N and full dose of phosphorus is applied at 30 days after sowing (DAS) (just before Ist irrigation). Remaining 100 kg N and 60 kg potassium is applied at 60 DAS (just before 2nd irrigation). Nutrients are applied manually to individual plants by mixing different fertilizers (Fig. 5). In the event of using seed-cum-fertilizer drill, 50% of N and total P and K should be applied at sowing and remaining 50% of N should be applied at 30 DAS.

Seeding with wooden stick

Twine wheel hole maker

Crop sown by tractor drawn hole maker

Tractor-drawn hole maker

Fig. 13.3. Progress in sowing machinery of sorghum in rice-fallows

Table 2 Effect of nitrogen levels and genotypes on growth, yield attributes and yields of sorghum cultivars in rice-fallows

Treatment	Plant height at harvest (cm)	Leaf area index	Panicles /m2	Panicle length (cm)	Grains /panicle	Grain weight /panicle (g)	100-grain weight (g)	Grain yield (t/ha)
Nitrogen levels (kg/ha)								
25	159	2.19	13.1	26.24	1401	38.39	2.63	4.81

75	170	2.29	13.3	26.33	1851	48.10	2.69	5.96
125	177	2.91	12.9	28.19	2225	58.81	2.74	7.38
175	187	3.26	12.4	29.10	2391	65.81	2.78	7.82
225	188	3.94	13.2	29.05	2249	66.35	2.96	8.04
LSD (P=0.05)	12	0.36	1.7	0.85	93	2.79	0.09	0.89

Table 3. Effect of nitrogen levels and genotypes on nutrient content and uptake in sorghum grains

Treatment	Nutrient content (%) in grain			Nutrient uptake (kg/ha) by grain			Protein content (%)	Net returns (₹/ha)	B:C ratio
	N	*P*	*K*	*N*	*P*	*K*			
Nitrogen levels (kg/ha)									
25	1.49	0.46	0.33	72.6	22.1	16.0	9.31	24 625	2.05
75	1.54	0.48	0.34	96.1	29.9	21.1	9.61	35 589	2.48
125	1.55	0.49	0.34	112.3	35.5	24.6	9.69	49 254	3.00
175	1.57	0.49	0.34	120.2	37.6	26.1	9.81	53 060	3.11
225	1.58	0.49	0.35	129.4	40.0	28.8	9.86	54 782	3.13
LSD (P=0.05)	0.03	0.01	0.01	5.3	3.4	2.3	0.26	2 127	0.15

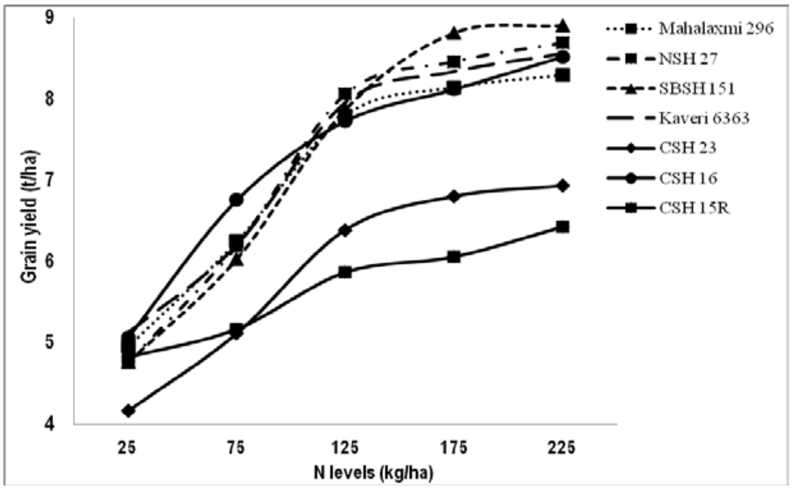

Fig 4. Response of sorghum hybrids to nitrogen in rice-fallows

Fig. 5. Nutrient application at 30 DAS (just before 1st irrigation)

Weed Management: Weeds are major problem in rice-fallows sorghum. As the crop is grown under zero tillage weeds infest the crop heavily due to adequate soil moisture. Moreover, due to moisture and favourable weather conditions, large number of rice ratoons and new rice plants also germinates and compete with sorghum crop for resources. For effective weed control, tank mixed application of paraquat + atrazine (0.50+0.75 kg/ha) should be done one day after sowing. Paraquat controls the rice rations and already emerged vegetations and atrazine checks the emergence of new weeds (Fig. 6).

Severe infestation of weeds

Atrazine + paraquat used as pre-emergence

Fig. 6. Weed management with herbicides

Irrigation: Sorghum in rice-fallows is grown on residual soil moisture, which supports the germination and early establishment of crop. Two irrigations are sufficient to harvest good yield in this area. First irrigation should be applied at 30 days after sowing (DAS) and 2nd irrigation at 60 DAS. Irrigation frequency however, depends on the seasonal rains.

Harvesting and threshing: Crop is harvested manually at 105-110 days after sowing depending upon the genotypes duration. The harvested panicles are left in the field for about a week for drying and thereafter the grains are separated from panicles manually. The panicles are harvested first and remaining plants latter.

Economic analysis: On an average, farmers' expenditure incurred on sorghum cultivation was Rs. 28,000 – 30,000 per ha with net profit of around Rs.35000 /ha. Component-wise cost and benefits are highlighted in Table 4. However, the cost of stover was not included in the net benefit as it is either burnt or incorporated in the soil.

Table 4: Economics of sorghum cultivation in rice-fallows as per the farmer's experience

S. No.	Particular	Cost (Rs. /ha)
1	Sowing and seed cost	3,500
2	Fertilizers' cost + its application	6,000
3	Herbicide cost + its application	1,500
4	Pesticides cost + its application	4,500
5	Irrigation water and labour charges	5,000
6	Harvesting	3,000
7	Threshing	3,000

S. No.	Particular	Cost (Rs. /ha)
8	Drying / Bagging	1,500
10	Total cost of production	28,000
11	Gross returns*	63,000
12	Net returns	35,000
13	Benefit : Cost ratio	2.25:1

Excluding fodder's price, selling price of sorghum grain @Rs. 10000/- per ton.

Fig 7 Sorghum cultivation in rice-fallows

5. Sweet sorghum: An important biofuel crop

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Biofuel and its importance

Owing to drastic increase in the population and their demanding requirements, depletion of natural energy sources is rapid and demand for alternative energy sources is ever increasing worldwide to meet the needs of increased population and to reduce carbon dioxide emissions along with associated risks of climate change, global warming and global oceanic acidification. Environmental sustainability and reduced dependence on fossil fuels (the primary source of transport fuel) require the development of alternate renewable energy sources which also ensures energy security. Renewable energy is a critical source of energy that contributes to energy security, reducing dependence on fossil fuels and emission of greenhouse gases (Vinutha et al, 2014). Biological fuels derived from the crops are the best among the energy sources as they are renewable, holding promise as an alternative to depleting non-renewable sources. Production and use of biofuel will have potential impact on environmental sustainability, and will be the alternate source for declining natural energy source. Use of renewable, easily available, consistent photosynthetic biomass for production of biofuel plays significant contribution in development of environment friendly technologies. Biofuel include fuels derived from biomass conversion, as well as solid biomass, liquid fuels and various biogases (Demirbas, 2009). The biofuel development program especially lignocellulosic bioethanol received highest priority of late considering the long term economic, environmental and social benefits. Use of corn and sugar cane as first generation biofuel crop is limited as their use as biofuel feed stock may lead to food shortage. Sorghum is a promising crop with high biomass and sugars, and offers an option to produce biofuel without great increase in food price. Wider adaptability of sorghum also makes economy of the industries viable.

Sorghum: an alternate biofuel crop

Sorghum (Sorghum bicolor [L.] Moench) biomass is considered as one of the potential renewable sources of energy for economic development and environmental sustainability, owing to its wide adaptability, C4 photosynthetic pathway, and high nitrogen and water use efficiency (Prakasham et al, 2014). Some sorghum genotypes partition large amounts of sugars to their stems like sugar cane and therefore classified as sweet sorghum. Sweet sorghum is a high biomass and sugar yielding crop and is equally competent to sugarcane, maize in its ability to provide feedstock for industries, under water-limited conditions sorghum is reliably more productive than corn, and is more tolerant to drought than other crops. Sweet Sorghum is a promising crop considering its high biomass, economic value to produce a very wide range of renewable industrial commodities like sugar, biofuel and other valuable products. Ethanol is produced from stalk juice similar to molasses based ethanol production process. In recent years, much emphasis is given to the production of ethanol from agricultural wastes/residues which contain cellulose (most abundant on earth) and hemicelluloses, the carbohydrates that can be converted to ethanol by fermentation. Cellulose has earlier been taken into account for chemical/biological saccharification and subsequent biological conversion of the monomeric sugars to ethanol (Chaudhary and Qazi et al, 2011). The convertibility of high biomass lines of sorghum to bioethanol is of special interest as the use of sorghum biomass for biofuel production will not lead to food price increase. According to Agribusiness week (2008) estimated costs for production of 1 gallon of ethanol from sweet sorghum is at $1.74 while it was estimated at $2.12 for producing 1 gallon of ethanol from corn. Sweet and forage sorghums have high yield potential i.e. up to 20-40 ta/ha dry biomass and above 100 t/ha fresh biomass and they are good source of cellulose and hemicelluloses. Some sweet sorghum lines yield juice about 78%

of total plant biomass and contains soluble fermentable sugars from 15 to 23% (by comparison, sugarcane has 14–16%) (Reddy *et al*., 2008). The sugar is composed mainly of sucrose (70–80%), fructose and glucose. Most of the sugars are distributed in the stalk, with about 2% in the leaves and inflorescences (Vietor and Miller, 1990). The large scale cultivation of sweet sorghum can happen if improved cultivars with higher sugar yield with multiple biotic and abiotic stress tolerance are available besides more importantly the policy support from Government of India in terms of both producer and processor incentives materialize.

R& D efforts on sweet sorghum breeding

Early R & D efforts were made at Nimbkar Agricultural Research Institute (NARI), Phaltan, Maharashtra to develop improved sweet sorghum cultivars by crossing locals with exotic lines that resulted in the identification of superior types with high cane yield, high brix content and moderate grain yield (Rajavanshi and Nimbkar 1996). At International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, major attempts were made to evaluate and identify useful sweet sorghum high biomass germplasm from world collections (Seetharama et al. 1987). Sweet sorghum research in India is being carried out at Directorate of Sorghum Research (DSR), Hyderabad, and at other All India Coordinated Sorghum Improvement Project (AICSIP) centers in Rahuri, Phaltan, Parbhani, Akola, Coimbatore and other places. DSR has been engaged in sweet sorghum research since 1989 and the sweet sorghum varieties and hybrids bred have the ability to produce extremely high stalk yields of up to 50 t ha-1, with juice Brix reading between 18% and 22% and 1.5 to 2.5 t ha-1 grain.

Concerted research efforts during last two decades at DSR and its cooperating centres in different State Agricultural Universities and at ICRISAT have resulted in excellent sweet sorghum varieties for use in ethanol production by the sugar industries/alcohol distilleries and for use as green/dry fodder. Sweet sorghum improvement programs at AICSIP centers have resulted in the identification of several promising sweet sorghum varieties such as SSV 96, GSSV 148, SR 350-3, SSV 74, HES 13, HES 4, SSV 119 and SSV 12611 for TSS% and juice yield, GSSV 148 for cane sugar, NSS 104 and HES 4 for green cane yield, juice yield, juice extraction and total sugar content, and RSSV 48 for better alcohol yield.

Promising nationally released varieties/hybrids were SSV 84 (high brix), CSV 19SS (High stalk yield, shoot fly tolerance), CSV 24SS (High stalk and sugar yields) and hybrid CSH 22 SS (High stalk and sugar yields). The productivity ranged between 40 and 50 t ha-1 (AICSIP 2004, 2005, 2006, 2007 and 2008). The performance of nationally released cultivars (Fig. 1) during kharif season across AICSIP locations is given in Table 1. The yields may vary according to the location, date of planting, soil type, season (Kharif or Rabi), rainfall distribution etc. Stalk yields obtainable during Rabi will be 30-35% less with reduced sugar content than kharif and summer grown crops because of prevailing low night temperatures and shorter day lengths and their interaction with planting time.

Table 1. Performance of nationally released cultivars

Entry	Year of release	Pedigree	Days to flower	Days to maturity	Fresh stalk yield (t ha-1)	Brix	Juice yield (L ha-1)	Cal. ethanol yield (L/ha)
SSV 84	1992	Selection from IS 23568	84	124	35-40	17-18	12000-14000	1000-1100
CSV 19SS	2005	RSSV 2 x SPV 462	78	120	35-40	17-18	12000-14000	1000
CSH 22SS	2005	ICSA 38 x SSV 84	82	119	44-52	17-18	14000-18000	1100-1300
CSV24SS	2011	NSS 1005B x (SSV 84 x 401B)	81	119	35-40	17-18	14000-15000	1100-1200

CSV 24 SS

Fig.1. Sweet sorghum cultivars released at national level

Important features of Sweet sorghum

Characteristics that make sweet sorghum as a candidate crop for biofuel production:

- High biomass productivity (45–80 t ha−1).
- High Brix (soluble sugars) % (16–20%).
- Thick stems and juicy internodes with maintenance of stem juiciness until maturity.
- Photo- and thermo-insensitivity so that it can be grown throughout the year and fit into diversified cropping systems.
- Tolerance to shoot-pests and diseases.
- Good digestibility of residues when used as forage or for lignocellulosic ethanol production.
- Tolerance to mid-season and terminal drought.
- High water and nitrogen-use efficiencies.

- Suitability for specific conversion technologies (*bmr*).
- Grain yield (3.0 – 5.0 t ha−1).

Current efforts in sweet sorghum breeding

Breeding methods that are used for self pollinated and cross pollinated crops can be used in sweet sorghum breeding to develop pure line varieties and hybrids. The most commonly used programmes in sweet sorghum improvement are short term programmes (pedigree method and backcross) and long term programmes (population improvement methods). Sweet sorghum breeding and improvement leads to the development of hybrids and parents that are useful as first and second generation (lignocellulosic) biofuel feed stock. Efforts are underway to breed and develop sweet sorghum hybrids and varieties with high biomass, rich in soluble sugars, which are highly advantageous and promising for the sugar and biofuel industry. The evaluation of four promising sweet sorghum lines ('Keller', 'BJ 248', 'Wray' and 'NSSH 104' ('CSH 22SS') along with the check 'SSV 84' indicated substantial genotypic differences for extractable juice, total sugar content, fermentation efficiency and alcohol production (Ratnavathi *et al*., 2003). The sweet sorghum variety, keller, gained attention as a potential alternative feedstock for the renewable energy due to its high sugar content and biomass yields (Jaisil. 2007). Genetic improvement should focus on stalk sugar, biomass quantity and quality and general agronomic traits (such as water and nutrient use efficiency) and, in particular, adaptation of sweet sorghum to colder, arid saline, and alkaline conditions. Further improvement in soluble sugar %, stalk yield and juice volume should be targeted in sweet sorghum to help improve the benefits to the industry and farmers without effecting grain yield. Improvement of population offers better opportunities for breaking the desired and undesired traits, which consequently provides scope for increased utilization of stress resistance (both biotic and abiotic). Population improvement of sorghum provides long term breeding strategy to develop superior varieties and hybrid parents. While population improvement programs are not the most common in sorghum breeding, they are an important source of genetic variation and improved traits (Rooney and Smith 2000). Brown mid rib (bmr) sorghum mutants have been identified, which give high biomass and have lower lignin in their cell walls compared to normal sorghum. Introgression of *bmr* into high biomass and stay green lines can be done as different bmr mutants are characterized (Vermerris et al. 2007), and most of the bmr mutants resulted in increased yields of fermentable sugars followed enzymatic saccharification (Saballos et al. 2008).

Brown midrib (bmr) sorghum

Currently, bio fuels are mainly generated from starch and sugarcane sucrose; however, the bulk of plant biomass is in the form of cell walls, which promise to be the most abundant renewable source of biofuels. Recent research efforts within the area of lignocellulosic ethanol production have focused heavily on identifying genes involved in secondary cell wall synthesis in an attempt to change the overall composition of the plant (Sarath et el, 2008). Another advantageous feature of sorghum for bioenergy is the presence of brown midrib (*bmr*) mutations that can reduce lignin content and increase forage digestibility in animals (Gerhardt et al, 1994: Bucholtz et al, 1980). Increased forage digestibility is negatively correlated with lignin content in a number of grass species, including potential bioenergy crops such as switchgrass, sorghum, and reed canary grass (Gerhardt et al, 1994: Miron et al, 2006: Vermerris et al, 2007: Casler et al, 2002). Lowered lignin also has been shown to increase conversion efficiency of biomass into ethanol (Casler et al, 2006: Dien et al, 2006). Lignin is a major factor negatively affecting the lignocellulose to ethanol conversion process (Chen et al, 2007).

Beyond the use of brown midrib mutants to increase forage digestibility, there has been significant interest in the impact potential these mutants may have on lignocellulosic bioenergy. Lignocellulosic bioenergy conversion requires decomposition of the cell wall polysaccharides cellulose and hemicellulose into monomeric sugars prior to their conversion into ethanol or alternative biofuels. Lignin negatively impacts lignocellulosic conversion because it can block the enzymatic liberation of sugars from cell wall polysaccharide moieties, releases aromatic compounds that can inhibit microbes used for fermenting sugars to fuels, and adheres to hydrolytic enzymes. Therefore brown midrib feedstocks, which have reduced lignin content and altered lignin composition, would likely have increased conversion efficiency over their wild-type counterparts (Pedersen et al, 2008).

In a study on allelic relationship between bmr mutants, (Vogler et al, 2009) observed that the percent NDF and ADF across bmr and normal genotypes were significantly higher in panicle tissues followed by the leaf sheath (Table 2). Differences between individual bmr mutants and their respective wild-type counterparts were in most cases significant. The bmr-12 mutant had significantly higher NDF compared to its wild-type isoline in all tissues except the panicle. There were significant differences in IVDMD among different tissues in both bmr and normal genotypes. In the bmr-12 mutant, the degree of reduction in lignin content is paralleled with an increase in cellulose and hemicellulose contents which are favourable for biofuel production.
Hence, *bmr* sorghums meet many of the general criteria (Pedersen et al, 2005) laid out in selecting a bioenergy crop species:

1. High suitability for genetic improvement
2. High biomass accumulation
3. High harvest index
4. High fraction of biofuel in harvested biomass
5. Being able to be grown on marginal lands
6. Harvested material able to be stored in the field
7. High bulk density
8. High water use efficiency
9. High N use efficiency
10. Low potential as a weed
11. High coproduct potential
12. Optimal biomass composition
13. Large-scale potential production
14. Low processing costs including harvesting

In a study on the enzymatic saccharification efficiency of sorghum bmr2, bmr6 and bmr12 stover, it was observed increases of up to 17%, 20% and 21%, respectively, relative to wild-type (Dien et al, 2009). Brown midrib forage sorghum stover had highest hexose yield (79% for maximum) following enzymatic hydrolysis as compared to non-bmr stover that yielded 43% and 48% of this maximum (Saballos et al, 2008). Bmr6 and bmr12 forage sorghum stover had higher hexose yield (79% and 77% for maximum, respectively) following enzymatic hydrolysis compared to wild-type stover that yielded 65% of the maximum while the highest hexose yield (90% of maximum) was observed in bmr6 bmr12 double mutant stover (Chen et al, 2007). The reduced lignin in bmr6, bmr12 and the bmr6 bmr12 double mutant stovers increased ethanol conversion efficiency (44%, 46%, 57%, respectively) compared to wild-type (38%). Within this isogenic forage sorghum background, lignin (Klason) content had a strong negative correlation with ethanol conversion efficiency (r = _0.943). Together these studies establish that brown midrib mutants can increase hexose yield in enzymatic saccharification, which will translate into higher ethanol conversion efficiencies (Pedersen et al, 2008). Pyramiding of bmr genes into genotypes will help in reducing lignin content and increase the conversion efficiency of bmr sorghum for meeting the needs of animal feed and bioenergy. It is possible to further reduce lignin content in a high yielding hybrid background by stacking bmr6 and bmr12 without a substantial reduction in either grain or lignocellulosic tissue yield.

In a study on near-isogenic grain sorghum hybrids involving bmr 6, bmr 12 and bmr6 bmr12 double mutant (stacked), the soluble sugars were fairly similar among the hybrids except for bmr12, which had significantly higher levels of arabinose and soluble glucose (Table 3) relative to those of the WT or bmr6 hybrids. Soluble glucose levels were 28% higher in bmr12 tissue than in the WT. Likewise, sugars liberated by dilute acid treatment from glucuronoarabinoxylan (hemicellulose) were fairly similar for all of the hybrids except for bmr12, which contained 21% higher levels of arabinose than the WT. The stacked hybrid has the potential to further reduce Acid Detergent Lignin by 33%and 22% relative to that of bmr6 or bmr12, which is strongly negatively correlated with both ruminant animal performance and lignocellulosic ethanol conversion efficiency. Using standard equations to predict theoretical ethanol yields using both hexose and pentose sugars, the predicted lignocellulosic ethanol yields of bmr12, WT, bmr6, and stacked hybrids were 389, 357, 355, and 346 L T-1 respectively. The higher carbohydrate levels and modified lignocellulosic tissue composition associated with bmr12 could explain the higher IVDMD and higher theoretical ethanol yields associated with bmr12 (Corredor et al, 2009).

By virtue of low lignin in the bmr plants, the cost and duration of pre-treatments can be reduced thereby decreasing the energy requirement for processing. Sweet sorghum stover also serves as an excellent feedstock for ethanol production. Introgression of bmr genes into sweet sorghums will result in the ideal feed stock for production of second generation biofuels.

The introduction of the *bmr* trait into high biomass sorghums would result in a dual-purpose bioenergy crop that supplies fodder and fermentable sugars from the lignocellulosic biomass. At Directorate of Sorghum Research, work on *bmr* sorghums was initiated way back in 2003-04 and currently advanced *bmr* breeding stocks in dual-purpose background are available while introgression of brown midrib trait into elite sweet sorghum and high biomass lines is in progress. The promising bmr lines were evaluated during kharif 2008 and 2009 under All India Coordinated Sorghum Improvement Project trials and lines viz., (CSV 15 x IS-21891)-6-1-1-1 , (CSV 15 x IS-21891)-1-1-1-1, (Palem2 X IS 21891)-2-1-2-1 and (PC5 X IS 21888)-5-1-1-1 were found promising with low lignin (4.2-5.4%) and higher digestibility values (IVDMD %) in the range of 50-54 % as compared to the All India checks CSV 15 and CSV 23 (Lignin-5-6% and IVDMD-48-49%). These lines offer promise for increased yield of fermentable sugars owing to their low lignin content and higher *invitro* drymatter digestibility.

Table 2. Percent cell wall and in vitro dry matter digestibility (IVDMD) of normal and brown midrib sorghum genotypes[a]

Tissue	NDF	ADF	Lignin	Hemicellulose	Cellulose	IVDMD
Across genotypes						
Whole plant	58.1 c	31.8 c	4.8 c	26.2 c	27.4 c	59.2 b
Stem	55.0 d	31.8 c	4.9c	23.1 d	27.6 c	59.8 ab
Sheath	64.5 b	36.3 b	5.4 b	28.2 b	31.0 b	56.2 c
Blade	53.9 e	27.6 d	3.9 d	26.3 c	23.9 d	61.3 a
Panicle	75.7 a	37.3 a	5.8 a	38.3 a	31.8 a	51.9 d
Bmr genotypes						
Whole plant	58.0 c	31.4 d	4.3 c	26.6 c	27.7 d	59.5 ab
Stem	57.5 c	32.8 c	4.2 c	24.7 d	29.1 c	56.7 bc
Sheath	65.5 b	35.8 b	4.7 b	29.7 b	31.3 b	57.0 bc
Blade	55.0 d	28.3 e	3.8 d	26.7 c	24.8 e	61.9 a
Panicle	75.9 a	36.9 a	5.4 a	39.0 a	31.8 a	54.2 c

Normal genotypes						
Whole plant	58.2 c	32.4 c	5.6 b	25.7 b	27.0 c	58.6 b
Stem	51.1 e	30.3 d	6.0 ab	20.7 c	25.4 d	64.4 a
Sheath	63.1 b	37.0 b	6.5 a	26.0 b	30.6 b	55.0 c
Blade	52.3 d	26.5 e	4.0 c	25.7 b	22.4 e	60.4 b
Panicle	75.2 a	38.0 a	6.5 a	37.2 a	31.7 a	48.5 d

Means followed by the same letter in a column are not significantly different. NDF – neutral detergent fiber; ADF - acid detergent fiber; IVDMD in vitro dry matter digestibility.

[a] *Adapted from Vogler et al (2009).*

Table 3. Effects of Brown Midrib (bmr) Genes on Lignocellulose carbohydrate composition (Dry basis) in the Grain Sorghum Hybrid AWheatland x RTx430[a]

	bmr6	*bmr12*	stacked	WT	SEM
soluble glucose (gkg -1)	12.7 b	11.4 b	15.4 a	13.0 ab	4
soluble fructose (gkg -1)	26.4	25.3	28.2	27.3	5.6
soluble sucrose (gkg -1)	56.3	58.5	64.9	59.3	7.1
arabinose (gkg -1)	15.3 b	16.0 b	19.6 a	17.1 ab	2.4
xylose (gkg -1)	175.8	179.8	192	174	11.3
dilute acid glucose (gkg -1)	87.7	91.2	81.7	83.7	10.8
conc. acid glucose (gkg -1)	172.5 b	163.3 b	196.5 a	161.0 b	6.1

[a] Means in rows with differing letters differ at P = 0.05 using an F-protected LSD.

[a] Adapted from Sattler et al (2010).

Way forward

In order to meet the increased demand for energy, there is a need to develop renewable energy sources such as high energy sorghum which produce high stalk yield per unit time, input energy, photo-and thermo-insensitive with inbuilt desired levels of resistance/ tolerance to various stresses and with different maturities, ensuring a continuous supply of feedstock to the biofuel industry. Genetically developed brown mid-rib (*bmr*) sorghums having reduced lignin content have paved a better path to increase cellulosic ethanol production as compared with other sorghum cultivars and improve process economics targeting higher conversion efficiency. Future research should address the optimization of sorghum as an energy crop through breeding for enhanced productivity under limited available resources and adaptation to colder, arid, saline, and alkaline conditions. Sweet sorghum parental line research needs urgent attention for enhancing genetic potential for high sugar content. To develop superior varieties and hybrids, long term breeding strategy is useful.

References

Bucholtz DL, Cantrell RP, Axtell JD and Lechtenberg VL.1980. Lignin biochemistry of normal and brown midrib mutant sorghum. J Agric Food Chem 28: 1239–1241.

Casler MD, Buxton DR and Vogel KP. 2002. Genetic modification of lignin concentration aVects Wtness of perennial herbaceous plants. Theor Appl Genet 104:127–131.

Casler MD and Jung HJG. 2006. Relationships of Wbre, lignin, and phenolics to in vitro Wbre digestibility in three perennial grasses. Anim Feed Sci Technol 125:151–161.

Chen F and Dixon RA. 2007. Lignin modiWcation improves fermentable sugar yields for biofuel production. Nat Biotechnol 25:759–761.

Corredor DY, Salazar JM, Hohn KL, Bean S, Bean B, Wang D. 2009. Evaluation and characterization of forage sorghum as feedstock for fermentable sugar production, Appl. Biochem. Biotechnol. 158:164–179.

Demirbas, A. (2009). "Political, economic and environmental impacts of biofuels: A review". *Applied Energy* 86: S108–S117.

Dien BS, Jung HG, Vogel KP, Casler MD, Lamb JFS, Weimer PJ, Iten L, Mitchell RB, Sarath G. 2006. Chemical composition and response to dilute-acid pretreatment and enzymatic saccharification of alfalfa, reed canarygrass, and switchgrass. Biomass Bioener 30:880–891.

Dien BS, Sarath G, Pedersen JF, Sattler SE, Chen H, Funnell-Harris D, Nichols NN, Cotta MA. 2009. Improved sugar conversion and ethanol yield for forage sorghum (Sorghum bicolor L. Moench) lines with reduced lignin contents, BioEnergy Res. 2:153–164.

Gerhardt R.L, Fritz J O, Moore K J and Jaster E H. 1994. Digestion kinetics and composition of normal and brownmidrib sorghum morphological components. Crop Sci. 34:1353–1361.

Jaisil P. Feasibility study on sweet sorghum production as raw materials for commercial ethanol production. Proceedings of the International conference on Agricultural, Food and Biological Engineering & Post Harvest/ ProductionTechnology. Khon Kaen, Thailand, 21–24 January 2007.

Miron, J., Soloman, R., Adin, G., Nir, U., Nikbachat, M., Yosef, E., Carmi, A.,Weinberg, Z.G., Kipnis, T., Zuckerman, E., 2006. Effects of harvest stage and re-growth on yield, composition, ensilage and in vitro digestibility of new forage sorghum varieties. J. Sci. Food Agric. 86, 140–147.

Naureen Chaudhary and Javed Iqbal Qazi, 2011. Lignocellulose for ethanol production: A review of issues relating to bagasse as a source material. African Journal of Biotechnology Vol. 10(8), pp. 1270-1274.

Pedersen, J.F., Vogel, K.P., Funnell, D.L., 2005. Impact of reduced lignin on plant fitness. Crop Sci. 45, 812–819.

Pedersen JF, Toy J J, Funnell DL, Sattler S E, Oliver AL, Grant RA. 2008. Registration of BN611, AN612, BN612, and RN613 Sorghum genetic stocks with stacked bmr-6 and bmr-12 genes, J. Plant Registrations 2: 258–262.

Ratnavathi, C.V., Dayakar Rao, B. and Seetharama, N. (2003) Sweet sorghum stalk: a suitable raw material for fuel alcohol production. DSR/NRCS Report Number 12/2003. NATP (DSR) Series No. 1, National Research Center for Sorghum (NRCS), Rajendranagar, Hyderabad, Andhra Pradesh, India, 8 pp.

Reddy Shetty Prakasham, Darmarapu Nagaiah, Kanaganahalli S Vinutha, Addepally Uma,Thulluri Chiranjeevi, Akula V Umakanth, Pinnamaneni Srinivasa Rao & Ning Yan. Sorghum biomass: a novel renewable carbon source for industrial bioproducts. Biofuels (2014) 5(2), 159–174.

Reddy, B.V.S., Ramesh, S., Ashok Kumar, A., Wani, S.P., Ortiz, R. *et al*. (2008) Biofuel crops research for energy security and rural development in developing countries. *Bioenergy Research* 1, 248–258.

Rooney, WL. & CW Smith. 2000. Techniques for developing new cultivars. Pages 329– 347 *in* Sorghum: Origin, History, Technology and Production (Smith CW and Frederiksen, eds.). Wiley, New York.

Saballos A, Vermerris W, Rivera L, Ejeta G (2008) Allelic association, chemical characterization and saccharification properties of *brown midrib* mutants of sorghum (*Sorghum bicolor* (L.) Moench). BioEnergy Research 2: 193-204.

Sarath G, Mitchell RB, Sattler SE, Funnell D, Pedersen JF, Graybosch RA, Vogel KP. 2008. Opportunities and roadblocks in utilizing forages and small grains for liquid fuels. J Ind Microbiol Biotechnol.doi:10.1007/s10295-007-0296-3.

Sattler S E, Funnel-Harris D L, Pedersen J F. 2010. Efficacy of Singular and Stacked brown midrib 6 and 12 in the Modification of Lignocellulose and Grain Chemistry. J. Agric. Food Chem. 2010, 58, 3611–3616.

Sattler SE, Funnell-Harris, D L, Pedersen J F. 2010. Brown midrib mutations and their importance to the utilization of maize, sorghum, and pearl millet lignocellulosic tissues. Plant Science 178: 229–238.

Vermerris W, Saballos A, Ejeta G, Mosier NS, Ladisch MR and Carpita NC.2007. Molecular breeding to enhance ethanol production from corn and sorghum stover. Crop Science 47(Supplement3) S142–S153.

Vietor, D. and Miller, F. (1990) Assimilation, partitioning, and nonstructural carbohydrates in sweet compared with grain sorghum. *Crop Science* 30, 1109–1115.

Vinutha, K S and Rayaprolu, L and Yadagiri, K and Umakanth, A V and Srinivasa Rao, P. 2014. Sweet Sorghum Research and Development in India: Status and Prospects. Sugar Tech, 16 (2). pp. 133-143.

Vogler RK, Tesso TT, Johnson K D and Ejeta G. 2009. The effect of allelic variation on forage quality of brown midrib sorghum mutants with reduced caffeic acid Omethyl transferase activity. African Jl of Biochem Res.3:070-076

6. Sorghum: An important forage crop

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Sorghum for green forage is popularly grown over 2.6 m ha area in Western Uttar Pradesh, Punjab, Haryana, Delhi, Gujarat, Rajasthan and is also popular with farmers in other states. Almost 60-70% of total forage demand in kharif is met from sorghum. Multi cut sorghum under irrigation in summer and single cut as rainfed crop in kharif are popular. Its quick growth, high yielding ability, high dry matter content, leafiness, wider adaptability and drought resistance make sorghum an ideal forage crop. Sorghum is suitable for silage and hay making and thus supplement the nutritious supply in lean season.

CROP IMPROVEMENT

Development of improved varieties / hybrids and production technology has led to an average yield of 500q/ha in single cut forage sorghum and up to 700 q/ha in multi cut hybrids. A number of forage sorghum varieties have been released in our country. The list of single and multi cut sorghum cultivars is presented in Tables 1 and 2.

The good quality fodder should have good palatability, higher intake, high protein content and better digestibility. Usually the characters which determine the quality are softness of stalk, high leaf: stem ration, protein content, low NDF and high dry matter digestibility in stover. The softness and thinness of stem is more amenable for feeding by livestock. The characters which may contribute to softness is the pithy type with less silica content. The varieties with stay green trait and resistance to leaf diseases and stem borer keep the leaf activity for longer period up to maturity and thus have better quality than others.

The protein content in dual purpose / single cut fodder varieties ranges from 6.54 / 7.39% and the IVDMD (*In Vitro* Dry Matter Digestibility) from 45 – 54% with an average of 50% in released varieties. This may give about 65 – 70 q/ha DDM (Digestible Dry Matter).

CROP MANAGEMENT

Sorghum gave maximum yield when it was preceded by crops like berseem, senji and metha. The protein, silica and IVDMD percentage and green fodder yield q/ha increase under irrigated conditions. The leaf diseases (*Helminthosporium, Cercospora, Ramulispora* and *Gloeocercospora*) and stem borer reduce the protein content, zinc content and IVDMD.

a) Field preparation and sowing time

In general 2-3 harrowings followed by planting is sufficient for most of the soil types to prepare the field for sowing of forage sorghum. In unirrigated areas, sorghum for fodder should be sown immediately after onset of monsoon.

b) Cultivation practices for multi cut forage sorghum:

Seed rate	:	10 kg/ha
Spacing	:	45 cm between rows
Time of sowing	:	April – Mid May
Fertilizers	:	60 kg N/ha and 60 kg P_2O_5/ha as basal. Top dressing with 40 kg N/ha after each cut

Irrigation as and when required or at 7 to 10 days interval in summer season.

c) Cultivation practice of single cut forage sorghum:

Seed rate	:	25 kg/ha
Spacing	:	30 cm between rows
Intercropping	:	Intercropping of sorghum with Cowpea in 2 : 1
Time of sowing	:	June (with onset of monsoon)
Fertilizers	:	80 kg N in 2 split doses + 40 kg P_2O_5/ha

d) Agronomic Management

The suitable cultural practices for forage production are:

i) Sowing time: The single cut and two cut varieties may be planted between 15 June to 30 June, with onset of monsoon. In Tarai region of Uttar Pradesh, the best time of sowing is from last week of May to first fortnight of June. This helps in avoidance of major pests. The multi cut varieties / hybrids can be planted early under irrigation as a summer crop.

ii) Seed rate and method of sowing: Depending on seed size 25 kg seed/ha in small seeded varieties and 40 kg/ha in bold seeded varieties is recommended. The row to row spacing of 30 cm is optimum for higher fodder yield and better quality.

iii) Fertilizer: Sorghum being a cereal and high biomass crop requires balanced fertilizer application to get high yields. In case of single cut varieties 80 Kg N per ha in two split doses is optimum under irrigated condition. First half as basal at the time of last ploughing or at the time of sowing and remaining half after 35-40 days after sowing when there is adequate moisture in the soil. In rainfed areas, 40 kg N/ha as basal is preferred. In multi cut varieties, 100-120 kg N per has is recommended in three split doses. First, one-third of it should be applied at the time of sowing. The second dose of 1/3 is given after the first cut and remaining 1/3 after second cut. These split doses should be given when there is an adequate moisture in the soil.

iv) Irrigation: In summer season the crop should be irrigated 3-4 times at the interval of 10-15 days to get better fodder yields. During kharif season, irrigation is adjusted according to rainfall distribution and 1-2 irrigation may be given during long dry spells.

v) Weed control: Weeds are a major problem in initial stage of crop growth and compete for water and nutrients. Summer ploughing to keep field weed free, 1-2 hand weeding after 15-20 days of crop sowing reduce weeds considerably. The per-emergence spray of Atrazine @ 0.5 kg a.i/ha effectively control the weeds. The soil surface need to be moist. Spray of weedicide should be taken immediately after sorghum sowing.

vi) Mixed cropping: The planting of fodder legumes like cowpea and guar along with sowing in 2 : 1 ratio increases fodder yield and quality. In low rainfall or less irrigated areas mixed cropping of sorghum and guar is desirable. In irrigated or high rainfall areas, mix cropping with cowpea gives high greed fodder yield. The erect variety of fodder cowpea is preferred.

vii) Crop rotation: The yield of sorghum is high when planted after taking the leguminous crop like berseem, senji and metha. It saves nitrogen application to sorghum crop. The crop rotation of fodder sorghum – wheat; fodder sorghum – Bengal gram or pea are popular. Thus, early flowering variety or early planting is useful to get higher yields of forage sorghum as well as rabi corp.

viii) Harvesting:

Single cut varieties: Such varieties are harvested from 50% flowering to full flowering.

Multi cut varieties: In multi cut varieties first cut taken 60 days after sowing gave significantly higher yield of green fodder, where as dry matter production was more when crop was harvested at 70 days after sowing. Subsequent cut at 40 days interval was invariably found to be the best as it gave the highest green as well as dry matter production. Harvesting of sudan grass, 5 cm above the ground level produced significantly higher forage yield over 10 cm stubble height. The variety HC 136 may give two cuts where first cut can be taken at 75 days and second cut at 90 days of first cut.

ix) Management of HCN poisoning: HCN is maximum at early stages up to 35 – 40 days stage of crop growth. It decreases gradually with the growth of the crop. The HCN in excess of 200 ppm is toxic. HCN content increases under moisture stress. In most of sorghum varieties, HCN decreases below toxic level after 40 days of the crop growth. In summer, crop should be irrigated 2-3 days before harvesting or else it is safer to harvest crop after flowering.

x) Seed production: Maximum seed yield of single cut forage types was obtained when 25 kg seed/ha was used with 45 cm row spacing and 10-15 cm spacing between plant to plant. Application of 50 kg P_2O_5/ha found to increase seed yield in forage sorghum. However, in dual purpose variety, the seed rate 8-10 kg/ha is optimum.

Strategies for improving fodder quality: The quality of sorghum fodder can be improved nutritionally by various means, such as mixing with berseem, or groundnut cakes + maize or urea + molasses. Berseem or groundnut cake has associative effect towards the better utilization of dry matter due to increase in the activity of cellulytic microflora of rumen. Similarly the supplementation with uera + molasses or concentrates also increases dry matter digestibility.

Table 1: Single cut varieties of forage sorghum

S. No.	Variety	Fodder Yield (q/ha)		Characteristics
		Green	Dry	
1	HC-308	415	128	Tall, leafy and medium maturity, stem is sweet and juicy, highly resistant to all foliar diseases, midrib green, panicle semi compact.
2	HC 171	410	122	Its stem is sweet and juicy and leaves have green midrib. Panicles are semi compact with small and creamy white seeds. It is highly resistant to most of the foliar diseases being tan pigmented. It is highly resistant to mites.
3	CSV 15	440	110	Tall, juicy, sweet stem, resistant to leaf spot diseases; Grown for fodder +grain purpose in Gujarat, Rajasthan, Northern MP and Bundelkhand
4	HJ-513	470	119	This variety was developed by CCS HAU, Hisar and released in 2004 for north-west zone of the country. It is a derivative of S-305 (PJ-7R × SPV- 80) × HC-136. The variety is recommended for cultivation in Haryana under timely sown/ normal fertility/irrigated conditions. The plant height is 245–260 cm. It is tolerant to major foliar diseases
5	Pusa Chari-6	440	165	It flowers in 85-90 days. Stem is medium thick, non-sweet, pithy and nonjuicy. Leaves are medium long and broad with white midrib. Panicle is semi-compact. Seeds are medium bold and white. It matures for seed in 135-140 days and gives 8-9 q/ha seed.
6	GFS-5	380	135	This is an early maturing variety developed by GAU, Surat and was released for cultivation during Kharif season in arid and semi-arid areas of Gujarat state. Average plant height is 276 cm with thin stem. It is resistant to most of the leaf spot diseases and grain mold.

Table 2: Multi cut cultivars of forage sorghum

S. No.	Variety / Hybrid	Fodder Yield (q/ha)		Characteristics
		Green	Dry	
1	CSH 24 MF (hybrid)	914	232	This hybrid was released in 2009 with the parentage of ICSA 467 x Pant Chari 6. Plant height at first cut is 200-210 cm. Has high digestibility (55-58% IVDMD), high protein (7.5-8.0%) and low HCN (80-95 ppm). The stem is thick, juicy and semi-sweet with 2-3 tillers. This hybrids is resistant to major foliar diseases and amenable for 3-4 cuttings. The female parent has good hybrid seed yielding ability. This hybrid is recommended for cultivation in multi-cut hybrid growing areas of India for irrigation-protected summer season.
2	CSH 20MF (hybrid)			This variety was developed by GBPUA&T, Pantnagar by inter-specific hybridization (2219 A × Pant Chari 6). This variety was notified for cultivation in medium irrigated summer and rainfed conditions of Uttar Pradesh, Uttarakhand, Haryana, Rajasthan, Punjab, Bihar and Gujarat. It has low HCN content and is highly resistant to foliar diseases and lodging under natural conditions. It is tolerant to drought and water logging. It is tall (215 cm), tan and has medium thick juicy stem with many basal tillers and long and medium broad semi-erect, stay-green leaves. This hybrid shows fast regeneration after cutting
3	M.P. Chari	300	95	Tall, thin stemmed, leaves medium long and narrow with white midrib. Non-sweet, non tan, non-juicy and pithy. Takes 65-70 days to become ready for fodder. Panicles are erect and lax with purple or black glumes. Grains brown coloured. Better generation and for two cuttings. Crop matures for seed in about 110 days. Leaf spot disease susceptible.
2	SSG 59-3	570	138	A popular multicut sudan grass, this variety is suitable for 4 cuts for green fodder during the crop season. It is thin stemmed, sweet with profuse tillering early flower in 55-60 days. Tolerant to drought and water logging. Panicle is laxed with profuse lateral spikes. Seeds purple red coloured with glumes adhered to them. Matures in 95-100 days and yields 10-12 q/ha seed.
4	Pusa Chari 23	550	160	A multicut variety with thin stem, sudan type non-sweet and non-juicy. Leaves narrow with white midrib. Plants have narrow leaves with white midrib. Plants have lateral branches. Seed yield 14 q/ha under North Indian conditions.
6	Punjab Sudex (Hybrid)	592	170	Multicut hybrid 3-4 cuts, 8-10 tillers under irrigation, takes 60-64 days for flowering, 10 leaves, profuse tillering habit, quick regeneration, thin stem, non-juicy, non-tan and palatable. It is recommended for Punjab state.
7	PCH 106 (Hybrid)	640	180	Multicut forage hybrid (Pedigree 2219 A x PC 23), suitable for 3-4 cuts, profuse tillering, quick regeneration, thin stem, non-tan, flowers in 60-63 days. Recommended for all sorghum growing areas in the country.
8	PCH 109 (Hybrid)	820	210	It is a multi-cut hybrid developed by IARI, New Delhi and recommended for cultivation during early summer and normal kharif under timely sown irrigated/ rainfed areas in Delhi. The plants are 225 cm tall, semi-erect, stay green type, leafy (13/plant) with juicy stem. Its leaves are long (83 cm), broad (6.5 cm) with dull green mid rib. The panicles are semi-loose, the grains are creamy white. It attains 50% flowering in 61 days and matures in 101 days. The variety is tolerant to major foliar diseases, shoot fly and stem borer.
9	Pant Chari-6	800-1000	250-350	This variety was developed from selection in Zimbabwe germplasm line EC-438401 by GBPUA&T, Pantnagar. The variety has been recommended for cultivation in Uttarakhand state under rainfed conditions during kharif season and under irrigated conditions in summer season. It reaches mid bloom in 65–70 days and matures in 105–110 days. The plants are tall, erect, tan pigmented and stem is sweet and juicy (TSS-6– 7%). The seed is red, semi-bold and circular in shape. It is resistant to major foliar diseases namely, zonate leaf spot, downy mildew, gray leaf spot and moderately resistant to anthracnose and sooty stripe under natural field conditions.

7. Value addition in sorghum-Potential of sorghum for industrial uses in India and entrepreneurship development

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Abstract

Much less is known about the industrial utilization of the sorghum and its market opportunities; this presents for poor sorghum producers.The prospects of sorghum in industrial sectors lie in animal feed, alcohol distilleries, and starch industries. Only rainy-season sorghum is used for industrial purposes. Postrainy-sorghum is a highly valued foodgrain, and thus too expensive to be used as industrial raw material, which is therefore used solely for food purposes. However in recent past, the processing intervention in sorghum has created a wide scope to enter them in food industry, which ultimately encourages entrepreneurship development for optimum utilization and higher revenue from the produce.

1.0 Introduction

Sorghum (Jowar) is one of the most important cereal crops in the world and is one of the four major food grains of our country. It is a staple food for millions of poor rural people in Asian and African countries. Besides being a major source of staple food for human beings, it also serves as an important source of fodder, animal feed and industrial raw material. *Jowar* (common name of sorghum in India) is grown in semi-arid climate where other crops do not stand well. The crops withstand in drought condition.

Normally sorghum is mainly cultivated by resource poor farmers to meet household requirements of food and fodder and a small surplus for the market. After harvest, sorghum grain may be retained on farm, to be used for home consumption or as seed or for payment in kind. The surplus grain is sold either in a regulated market through commission agents in the markets or through a broker (middleman) at the village. In general sorghum marketable surplus is not huge but because it is one of the main food staples, it is reported that the movement of sorghum from surplus areas to deficit areas and between rural markets within each state is common. Sorghum was found in all the rural and urban markets. However, it was observed that sorghum supply is very limited in all the rural markets as well as in the urban markets.

Although significant amount of sorghum is traded, markets are not well developed, value added and ready to use products need to popularize sorghum as a food. While, industrial liasoning and understanding the market players behaviour and channels for promotion of alternate uses like syrup, industrial products and jaggery from sweet sorghum, sorghum grain for potable alcohol and sweet stalks for fuel alcohol can auger good prospects for sorghum. Grain sorghum marketing fits no ordinary marketing model. Traditionally, only 8 to 9% of the crop carries over to the next marketing year. However, gradual commercialization of Indian agriculture and integration with the world markets on one hand, and decreasing consumption as food, and slow increasing demand for Sorghum on the other, marketing of sorghum, an erstwhile subsistence crop, assumes great importance.

1.1 Alternative Uses of Sorghum

Sorghum grain is primarily grown for direct food uses and fodder for animal.However, with the advance in technology and processing intervention, sorghum grain produced during *rabi*has found to have dedicated food uses while its counterpart kharif sorghum grain has found niche in alternate uses which is elaborated below.

The utilization of kharif sorghum grain as a raw material in various industries is increasing, given the limited prospects of rainy season (kharif) sorghum for human consumption (Table 1)). The main industries currently using sorghum in India are the poultry feed, animal feed and potable alcohol distilleries. At present poultry feed sector is using approximately 2.0 million tonnes sorghum annually; animal feed sector uses about 0.60 million tonnes sorghum followed by alcohol distillers (about 0.49 million tonnes). Sorghum is used when maize is in short supply and priced up to 20% higher than sorghum.

The estimated utilization in 2013-14 shows that poultry feed industry is going to be the major industry which will absorb huge quantity of sorghum (3.18 million tonnes), followed by dairy feed industry (1.3 million tonnes). This estimate is made with the current trends, but if government policy on allocating food grain to potable alcohol making is implemented, 4 million tonnes of sorghum may be needed for brewing industry alone.

Table1. Estimates on various uses of Sorghum grain

Utilization patterns	Type	Estimated utilization in 2013-14 *(million tonnes)*
Direct use/human consumption	a. Rabi b. Kharif (partly)	3.5 0.7
Other uses 1. Poultry feed 2. Animal feed 3. Alcohol	 Kharif Kharif Kharif	 3.18 1.30 2.50
Total		11.18

2.0 Industrial utilization of sorghum

Poultry feed/ Animal Feed: Poultry feed industry in the country is progressing well. Several independent feeding trials conducted on layer and broiler birds could conclusively demonstrate that sorghum is as good as maize although, the latter is marginally superior in total energy value. Sorghum based feed in layer birds has to be supplemented with carotene to ensure yellow colour to egg yolk. With the current price advantage over maize, sorghum is used more and more in poultry feed. Demand for grain from poultry and animal feed industry is rising. While maize is the preferred coarse grain by this industry, sorghum has potential to emerge as a major feed grain with favourable pricing till recent years and with demonstration that it could largely serve the role of maize in feed. In the case of cattle, sorghum based feed is found satisfactory. Molded kharif grain is found as an acceptable grain component in the feed of goat and swine too.

Starch: Sorghum is rarely used by the starch industry in view of processing problem and starch yield as the starch extraction machineries are adapted to the bigger grain size of maize. While there is scope to improve starch recovery from sorghum by modified extraction, selective breeding and use of specifically suited machineries, starch production from the present sorghum cultivars be economically viable only if the grain price is 20% lesser than that of maize. Sorghum grain is found more suitable for production of glucose and liquid glucose.

Potable alcohol: Molded kharif grain which fetches lower market value is a cheap raw material for production of potable or industrial alcohol. Much often this grain is available at prices lower than the minimum support price. It is found to produce good quality potable alcohol which could be exported for blending purpose. Sorghum is the second best grain, after barley, for malting.

Malt: Another potential area could be the use of sorghum malt and as an adjunct in brewing industry. Malted sorghum is used for brewing beer in Ghana and Nigeria. Sorghum's comparative advantage would be its low output price, especially in production regions of rainy sorghum in India over that of existing raw material.

Sorghum for bio-energy harvest (bio-fuel production)

Sweet stalked and high energy sorghum has the potential to emerge as a major bio-energy crop for production of industrial alcohol, gasohol and even electricity. While the national trials on sweet sorghum had shown its potential productivity as 50-60 t stalk and 2-3 t grain/ha in 125-130 days, reports from China indicate a far high productivity to the tune of 90 t stalk and 6 t grain/ha from the crop in 140-150 days. This productivity potential places the crop at an undoubtable advantage over sugarcane or molasses at their ruling prices for ethanol production. As a bio-energy crop sweet sorghum is more efficient than sugarcane because of its high productivity with relatively low levels of fertilisation and irrigation. Sweet sorghum, in this context, could be effectively exploited as an energy crop. However, government policy support in declaring high ethanol pricing will determine its current utilization andfuture demand

Production of jaggery and brown or colourless syrup or high fructose syrup are other opportunities from sweet sorghum. These diversifications could be done at village or farm level as small scale enterprises.

3.0 Diversified food uses of Sorghum

Post-rainy season sorghum is a highly valued food grain, and too expensive to be used as industrial raw material. Due to inconveniences attached with direct food use of sorghum, there was an increasing need for processing interventions which are not attempted in the past. Through processing there are efforts made to revive demand for sorghum. Processing interventions provide wider consumer choices, consumer acceptability through increased shelf life and marketability. In addition, discovering many new potential health benefits from sorghum, such as high levels of anti-oxidants, improved cholesterol profiles of the consumer, and as a source of safe food for persons with celiac disease has gain wide momentum from the consumers' point of view. Sorghum grain has high fibre content, moderate digestibility and rich mineral content compared to other cereals such as rice and wheat. Therefore, sorghum foods are recommended for diabetic and for fighting obesity. Being free from gluten, sorghum is the ideal food for celiac patients and other life style diseases

3.1 Sorghum in food industry

So far sorghum foods are not significantly exploited to commercialize their importance as health or prophylactic food, despite offering well-balanced composition of carbohydrates, proteins and minerals together with high dietary fibre. Sorghum possesses unique nutritional and functional properties that can lead itself to the development of healthy and nutritious foods at low costs. It is gluten-free, have unique phenolic compounds, which are being identified as antioxidants. It contains proteins and starch characteristics that lend itself as functional foods. Sorghum can be used in similar fashion with slight modifications, as with other cereals through processing technologies that are currently available for rice, wheat and maize. . Utilization of sorghum can be increased by various processing treatments including blanching, malting, dry heating, acid treatments, popping. All these treatments decrease the level of anti-nutrients, improve digestibility and increase in shelf-life.

Traditional techniques that are commonly used include decorticating (usually by pounding followed by winnowing or sometimes sifting), malting, fermentation, roasting, flaking and grinding. These methods are mostly labour intensive and give a poor-quality product. Sorghum would probably be more widely used if processing were improved and if sufficient good-quality flour were made available to meet the demand (Eastman, 1980). Therefore to some extent, methods have been developed to make traditional foods to suit local tastes and are appropriate for these purposes.

There was declined direct Sorghum consumption and other millets over the past three decades. Sorghum monthly per capita consumption was declined from 1.2 kg to 0.33 kg in rural, whereas in urban areas from 0.6 kg to 0.22 kg during 1987-88 to 2005-06. In 2011-12 monthly consumption of Sorghum declined to 0.32 kg in rural and 0.21 kg in urban areas. The reason for the decrease in Sorghum consumption is laborious and time-consuming process in preparation of food and also the policy of the Government to supply fine cereals at subsidized prices. However, of late the importance of millets in health and nutritional security has been realized in wake of many surge in lifestyle diseases in the country. This calls for change in food habits and shift towards nutritional millets. This is expected to revive demand of sorghum cultivation for the benefit of dryland sorghum farmers. It has become necessary to reorientation the efforts on Sorghum to generate demand through value-addition of processed foods, feed and industrial products.

To create demand for millets, DSR has worked on identification of suitable genotypes for improved cultivation and production of sorghum in *rabi* and *kharif* seasons. A set of 51 lines including parental lines, released varieties, germplasm lines and breeding lines were evaluated for protein digestibility, an important nutritional trait which enhances the nutritive value of sorghum. End-specific improved cultivars CSH-14, CSH-16, CSH-23, CSV-20 and SPH-1148 in *kharif* and M 35-1, CSV 216 R (*Phule Yashoda*) & SPV 1411 (*Parbhani Moti*), *Phule Vasudha* and *Phule Revati* in *rabi* were identified for production of sorghum foods. The end-product specific on-farm production was facilitated on the lines of successful models of ITC's *e-choupal*. In this model, farmers were given market buy-back assurance for (Fairly Accepted Quality) FAQ grain (In case if they do not find a market or appropriate price, ITC will procure and is aggregated from small holder's marketed surplus). ITC-ABD facilitated integrated farm extension services in private-public partnership (PPP) mode on procurement, extension, dissemination of knowledge and information including daily market prices in various markets through the computers placed in *e-choupal sanchalak's* (village representative) house which is accessible to all the participating farmers in the village. The procurement of participating farmers' produced through buy-back mechanism, and sharing the knowledge are either facilitated or undertaken directly by ITC Ltd. The assurance of buyback gave motivation to the participating farmers to employ gainful crop management practices which led to higher income. In fact, the income of those participating farmers whose produce was procured, increased by 44 per cent over the baseline income, while those whose produce was not procured, income increased by 36 per cent. From the study we could infer that sorghum when cultivated on an intensive scale with backstopping of technology and farm extension services impacted yield and income levels. The end-product specific production also had another advantage of linking up with entrepreneurs who actually bought the identity preserved produce which was procured and aggregated for engaging in small-scale production of specific sorghum products.

Processing technologies for the production of sorghum foods were developed at DSR, CFTRI, Mysore and ANGRAU. More than 50 technologies were developed using different methods such as soaking, malting, germination, dehulling, parboiling, milling, baking, flaking, fermentation, and extrusion cooking. Sorghum foods such as dehulled sorghum, malted sorghum, sorghum flour, multi grain flour , coarse, medium and fine semolina, parboiled semolina, flakes, roasted flakes, vermicelli and pasta, biscuits, protein rich snacks, cakes, fermented foods such as lassi, Instant foods, tastemakers and technologies for utilization of byproducts of sorghum. With DSR, taking the key role in value addition, more than 35 sorghum recipes were standardized. Studies were conducted for the extension of shelf life of millet foods (sorghum & pearl millet) using different packaging materials and suitable packaging material has been used for commercialization. Nutritional evaluation of sorghum foods were done at NIN, Hyderabad. Results from various studies such as organoleptic evaluation, glycemic index and glycemic load, evaluation of sorghum foods in diabetic patients and school children and protein digestibility in animals proved that sorghum can be used as a safe food in for all age groups and benefits can be attained on inclusion of sorghum in the diet.

Creation of awareness about millets has been done successfully through various possible mediums such as pamphlets, leaflets, newspapers, books, jingles, participating in various road shows, campaigns, exhibitions, TV shows, radio talks, seminars, conferences, workshops and conducting training programs for entrepreneurs and farmers. With the launching of DSR brand 'EATRITE' and already partnered 17 entrepreneurs with whom the DSR has entered into MoUs, the DSR has started building a wide network of sorghum products marketing by involving government agencies, more entrepreneurs, wholesalers and retailers by making Hyderabad as the main centre and also the main market while also targeting the national capital and later in different parts of the country. Branding, labeling with nutritional profile, recipes, mandatory information and packing was unique in sorghum as there were no products available in the market. This has huge impact on consumer perception on product diversification and flagging of nutritional superiority. The interventions also sensitized policy makers about the importance of sorghum and millets for potentiality of uplifting the living standards of dry-land farmers. Line departments of government are sensitized in state governments so that they may also take up millets in public distribution schemes. This has resulted to implementation of millets in Mid-Day Meal programme on the pilot scale by the 3 states of Karnataka, Andhra Pradesh and Maharashtra. Lastly it is coincidence that Govt of India heeded to include sorghum and millets in PDS.

In order to find out the consumer acceptability, feasibility and sustainability of newly developed sorghum RTE and RTC products under the DSR brand name 'Eatrite' in the market, the study was conducted in traditional sorghum consuming city of Hyderabad and Pune, and non-traditional Delhi during 2013. The techno-economic feasibility of sorghum-processed products viz., Jowar rich multigrain atta, Jowar rawa, Jowar vermicelli, Jowar pasta, Jowar biscuits, Jowar flakes was conducted. The result shows feasibility and profitability of sorghum processing with respect to cost incurred and market demand.

3.2 Techno-Economic feasibility of sorghum foods processing

Besides laudable efforts of various government agencies viz., Directorate of Sorghum (DSR), ICRISAT, ANGARU, NIN etc in terms of preparation of various recipes from Jowar, developed technologies for incubating entrepreneurship in Jowar based foods going a long way in commercialization of Jowar based foods. However, technology related to production of Jowar based production is still in the evolutions stage. Besides the government agencies viz., DSR, there other numerous private agencies and small entrepreneurs are working with various technologies for production of jowar based products. Owing to which taking a bench mark technology and price becomes difficult.

Nevertheless, an attempt has been made to analyse the specified jowar based products from various financial parameters. The following table depicts the summary of few parameters on which all the products are evaluated.

Product	Recovery %	V Cost	F Cost (dep.)	Net returns/sku	Cost/SKU	Price /SKU MRP	Competitor's Price (Bambino)	Price Advantage
Jowar Rich Multigrain Atta	95	3196	3.11	13.33	33.67	47	50	-3
Jowar Flakes	60	1730	2.27	1.14	28.86	30	100 (jowar)	-70
Jowar Rawa	70 +30 (flour)	977	3.74	1.99	28.01	30	55 (jowar)	-25
Jowar Pasta	90	1448	87.15	12.54	5.46	18	16	+2
Jowar Vermicelli	90	1448	87.15	17.54	5.46	23	13	+10
Jowar Biscuits	85	518	23.81	4.37	10.63	15	18	-3

These value added products are not available in the market. Efforts can be made to popularize sorghum products low cost, high protein and energy rich products among urban population across the country through ongoing nutritional intervention programs. The preparation and production of such products at home and commercial level would initiate the production units and small scale in rural and urban areas to raise the income level of housewives. The developed value added baked, supplementary and health foods in spite of being in expensive, acceptable and nutritionally superior are not taken up by industries for commercialization as people are not aware about the production technology and health benefits. There is a scope for commercialization of various products from health and cost point of view. Industrial linkages for development and commercialization of these food products will secure market for sorghum. Not the least, there is a need to create awareness about the technical know-how of the processing and product development.

4.0 Entrepreneurship Development

In order to keep up the momentum and the sustainability of commercialization process, Entrepreneurship development of the stakeholders is necessitated through interventions in food processing and product development and nutritional evaluation. Creating sustainable value chain has been one of the greatest challenges for the social scientists and research institutions at large. Therefore the ultimate goal of entrepreneurship development programmes is to disseminate thorough knowledge of post-harvest management which includes linkage of farmers with market, processing, nutritional importance of sorghum, and how to promote and market the value added products.

5.0 Future prospects of sorghum

The future prospects of sorghum lie in developing and commercializing various nutritive and consumer friendly food products in the market. With the advance of modern technology, it has become possible to retrofit the processing machineries for sorghum processing. However, for full operation of sorghum processing and commercialization, industry will require consistent supply of required quantity and quality of grain. Rabi sorghum grains are almost all good for human consumption and therefore suitable for food processing, whereas kharif sorghum are inferior for human consumption due to their poor quality and prone to pest and mould. Hence, promoting alternative uses of kharif sorghum grain is the best solution in this regard. Studies have found the prospects of kharif sorghum for production of ethanol, beer, animal feed, etc. Sorghum can make good malt as an adjunct in brewing industry. Sorghum beer is popular world over, but India is yet to catch-up with big possibility.

In this context of increasing demand for Sorghum, value-addition has acquired a great importance which will have a striking impact on socio-economic conditions of dry-land. The efforts of DSR and partner institutes in creating industrial linkages for development and commercialization of Sorghum products is seeing positive aspects with more entrepreneurs coming forward to tie up in any kind of intervention as per business plans made by the DSR. Very shortly, M/s Britannia Industries Ltd is also going to launch sorghum-rich biscuit, which is a positive outcome of the initiative made by DSR in creating demand of sorghum and millets in the country. The successful PPP (public private partnership) model of NAIP-Millets Value Chain model is being replicated for promotion of millets at national level through NFSM (initially under INSIMP) by the DAC, Ministry of Agriculture, Government of India which is seen to be the ideal model of uplifting the dry-land farmers of India which in fact constituted 60 percent of the farming area in India. It also encouraged entrepreneurs dealing with food products to include Sorghum in their business exclusively or in combination with other millets.

5.1 Challenges

The ultimate challenge today is to provide technologies that will enable transformation of subsistence sorghum farming into a commercial and profitable production system that can compete at global level. This can be realized through realistic reassessment of crop research needs in terms of current and future demand, resolving specific production constraints, development of post-harvest processing and value-addition technologies, marketing strategies and policies that may result in additional income and employment without sacrificing overall goal of attaining sustainable food and nutritional security, especially of the sorghum farmers in dry regions and the urban poor.

8. Post harvest management of grain sorghum

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Sorghum is one of the important staple food crops of India. It is cultivated in about 7.7 million hectares of land with a production of 6.98 million tons during 2009-2010. If we look closely the *Rabi* accounts for nearly 60% of the total area and production. The kharif production is mostly utilized for industrial purpose because of its inferior quality (mold infected) whiles the *Rabi* production goes for human consumption. Sorghum crop is mostly grown by small and marginal farmers with limited resources who cannot afford to store it in scientific way to avoid storage losses. The four million tones grain sorghum of Rabi production and seed requirements of farmers which accounts to about a lakh tons needs proper storage to avoid the storage losses.

In India, about 12 to 16 million tons of food grains lost due to poor storage techniques as per the world bank report, 1996. If we put this in monetary terms, it amounts to huge Rs 50,000 crores annual foodgrain losses (www.indiawaterportal.org). The government of India spent Rs.46,456 crores towards food subsidies during 2009-10. In other words whatever, the amount government is giving for food subsidies is being lost in storage due to improper storage methods, defeating the basic purpose of food security of the union government. Though the Food Corporation of India (FCI) has the storage capacity of about 30.5 million tones with a network of 1800 plus storage godowns, it doesn't store sorghum in its godowns. A traditional estimate of about 80% of the grain produced is retained by the farmers and is stored at farm level only 20% is traded in the market. Grain sorghum and millets are important staple foods for the rural poor in India and African countries in arid and semi-arid tropical regions.

During storage, either at household, rural or trader level, the commodities are attacked by several species of insect pests including *Sitophilus oryzae, Rhyzopertha dominica Tribolium castaneum* and *Sitotroga cerealella* resulting in loss in quantity and nutritional quality. Research studies on stored sorghum and millets are mainly concerned about the susceptibility of different cultivars to insect pest damage, physicochemical changes in the produce due to infestation and germinability of infested grains. Studies on pest control methods in grain sorghum or millets are rather limited. In developing countries, traditional control measures like sun-drying and use of local plant materials like neem (Azadirachta indica) leaves are still popular (Rajendran and Chayakumari, 2003). Traditional storage methods carried out by farmers in Africa are well anchored in the culture of local people, though they are ineffective in containing the heavy losses caused by pest infestations (Trematerra *et al*., 2003).

Storage pests are categorized into two types viz., primary and secondary storage pests based upon the type of material infested by them. Insects that can damage sound, whole grains are called as Primary storage pests. (Eg: Rice weevil, lesser grain borer, Angoumois grain moth, Rice moth). Secondary storage pest damage broken or already damaged grains (Eg. Red flour beetle, Saw-toothed beetle etc.)

Storage insects of sorghum

Storage pests are categorized into two types viz., primary and secondary storage pests based upon the type of material infested by them.

Primary storage pests

Insects that can damage sound, whole grains are called as Primary storage pests. (Eg: Rice weevil, lesser grain borer, Angoumois grain moth, Rice moth).

Secondary storage pests

Insects that damage broken or already damaged grains (Eg. Red flour beetle, Saw-toothed beetle etc.) The details of pest biology are summarized in Table 1.

Table 1 : Storage pests of sorghum and their life cycle

Insect	Host range	Nature of damage	Egg	Larvae/grub	Pupa	Adult
Primary pest						
Rice weevil: *Sitophilus oryzae,* Curculionidae, Coleoptera	Wheat, rice, maize, sorghum, paddy	Grubs and adults hollow out kernels and reduce it to mere powder. Attack starts in the field itself cutting circular holes. Heating takes place during heavy infestation, which is known as 'dry heating'.	Translucent white, plugs the egg hole with gelatinous secretion, laid singly.	White with yellowish brown head, apodous, fleshy, curved, remains within the grain.	Pupates inside the grain.	Small, reddish brown to chocolate coloured with characteristic snout, elbowed antennae slightly clubbed. Hindwings present.
Lesser grain borer: *Rhyzopertha dominica*, Bostrychidae, Coleoptera	Paddy, wheat, maize and sorghum	Heating is very common. Infestation is confined to a small area. Grubs and adults are voracious feeders reducing the grain kernels to mere frass. Grubs eat their way into the grain or feed on the grain dust or starchy material and are capable of attacking grain externally.	Eggs are laid on the surface or on the interstices of grains singly or in clusters.	White, apodous with brown head, free living up to third instar.	Grubs enter the grain after third instar for pupation	Brown to blackish, head deflexed downwards below the prothorax. There is a prominent constriction between prothorax and elytra. Antenna clubbed with large three loose segments.
Angoumois grain moth: *Sitotroga cerealella*, Gelechiidae, Lepidoptera	Paddy, maize, sorghum, barley and wheat (rarely)	Only larvae damage grains, adults are harmless. Grains are hollowed out. It attacks both in fields and stores. In bulk grain, infestation remains confined to upper 30 cms only. Caterpillar enters the grain through crack or abrasion on grain. It feeds inside and remains in a single grain only.	White eggs are laid on the surface of damp grains in stores or fields.	White coloured with yellow head.	Pupates in cocoon inside the grain.	Dirty yellowish brown moth with narrow pointed wings folded over back in a sloping manner.
Secondary pest						
Rust red flour beetle: *Tribolium castaneum*, Tenebrionidae, Coleoptera	Broken, damaged grains, germ portion and milled products of all cereals.	Grubs feed on milled products. They are secondary pests of all grains and primary pests of flour and other milled products. In grains, embryo or germ portion is preferred. They construct tunnels as they move through flour and granular food products. Heavy infestation causes	White, translucent, sticky, slender and cylindrical.	Worm like, whitish cream coloured with faint stripes. Two spine like appendages are present at the end of terminal segment.	Pupa remains loosely lying in the grain and is naked.	Oblong, flat, brown in colour. Antennae have a clear 3-segmented club.

Primary pest						
Insect	Host range	Nature of damage	Egg	Larvae/grub	Pupa	Adult
		stinking odour in flour affecting the dough quality.				
Saw toothed grain beetle: *Oryzaephilus surinamensis*, Silvanidae, Coleoptera	Rice, wheat, maize, sorghum, oil seeds and dry fruits	Adults and grub cause roughening of grain surface and off odour. Grains with higher percentage of broken, dockage and foreign matter sustain heavy infestation, which leads to heating of grain.	Whitish eggs laid loosely in cracks of storage receptacles.	Grub is slender, pale cream with two slightly darker patches on each segment.	Matured grub makes cocoon like covering with sticky secretion.	Narrow, flattened, thorax bears six teeth like serrations on each side. Antenna clubbed. Elytra cover abdomen completely.

Storage losses

In India, post-harvest losses caused by the unscientific storage, insects, rodents, micro-organisms etc., account for about 10 per cent of total food grains (Anonymous, 1971). Reported storage losses vary widely between 5 and 50 % (Swaminathan, 1977). Adults and larvae of *Sitophilus oryzae* feed on sorghum grain causing 2-21% losses for improved cultivars in India. The major economic loss caused by grain infesting insects is not always on account of the actual material they consume, but also on the amount contaminated by them and their excreta which makes food unfit for human consumption. Reduction of weight losses in bulk storage of grain and grain deterioration in storage is caused mainly through (a) bio-deterioration, (b) insects and pests, and (c) moulds and fungi. Bio-deterioration is due to the activity of enzymes present in the seed. The extent of deterioration depends upon the level of enzyme activity, which in turn is determined by moisture and temperature.

According to one estimate, the harvest and post harvest losses are as follows:

Sl. No.	Losses (during and other causes)	Percentage (of Losses)
1.	Threshing	1.0
2.	Transport	0.5
3.	Processing	-
4.	Rodents	2.50
5.	Birds	0.5
6.	Insect	3.0
7.	Moisture	0.5
	Total	8.00

(Source : Report of the Committee on Post Harvest Losses of Food grains In India, Ministry of Food and Agriculture, GOI, 1971.)

It has been estimated that about 2.20 percent of jowar is lost at farmers' level during harvesting, threshing, winnowing, transportation and storage. Estimated post-harvest losses at producers' level are given in the following Table.

Estimated post- harvest losses of jowar at producers' level

Sl. No	Operations	Losses (% to total production)
1.	Losses in transport from field to threshing floor	0.68
2.	Losses in threshing	0.65
3.	Losses in winnowing	0.32

4.	Losses in transport from Threshing floor to storage	0.21
5.	Losses in storage at farmers' level	0.34
Total		2.20

(Source: Marketable Surplus and Post Harvest Losses of Jowar in India, 2002, Directorate of Marketing & Inspection, Nagpur.)

To minimize post harvest losses, the following measures should be followed.

- The crop should be harvested on attaining physiological maturity and moisture brought down to below 9 5 moisture.
- Use strong, and clean packaging material for storage and transport.
- Use pest control measures (fumigation) before storage.
- Provide aeration to stored grain and stir grain bulk occasionally.
- Seed should not be exposed to direct sunlight.
- Seed should be inspected at fortnightly interval.
- Use proper techniques while handling (loading & unloading), to avoid losses during transport.

Food Corporation of India Grade Standards:

The Jowar shall be dried and matured grains shall have uniform size, shape and colour. It shall be in sound merchantable condition and also conforming to PFA standards.

Jowar shall be sweet, hard, clean, wholesome and free from *Argemone mexicana* and *Lathyrus sativus* (khesari) in any form, coloring matter, moulds, weevils, obnoxious smell, admixture of deleterious substances and all other impurities except to the extent indicated in the schedule below:

SCHEDULE OF SPECIFICATION

S.No.	Refractions Maximum Limits (%)
1.	Foreign matter *
2.	Other foodgrains
3.	Damaged grains
4.	Slightly damaged & discoloured grains
5.	Shrivelled & Immature grains
6	Weevilled grains
7.	Moisture content

**Not more than 0.25% by weight shall be mineral matter and not more than 0.10% by weight shall be impurities of animal origin.*

N.B.:

1. The definition of the above refractions and method of analysis are to be followed as given in Bureau of India 'Standard "Method of Analysis for foodgrains" Nos. IS: 4333 (Part-I): 1996 and IS:4333 (Part-II):2002 and "Terminology for food grains" IS : 2813-1995 as amended from time to time.
2. The method of sampling is to be followed as given in Bureau of Indian Standard `Method of sampling of Cereals and Pulses ` No. IS : 14818-2000 as amended from time to time.
3. Within the overall limit of 1.0% for "Foreign Matter" the poisonous seeds shall not exceed 0.5% of which Dhatura and Akra seeds (Vicia species) not to exceed 0.25% and 0.2% respectively.
4. Kernels with glumes will not be treated as unsound grains. During physical analysis the glumes will be removed and treated as organic foreign matter.

The Codex Alimentarius Commission has established global standards for sorghum grains under Codex Standard 172-1989. However, individual producing countries have their own standards for internal procurement from farmers or by import. In commercial trading the quality standard for sorghum is agreed between buyer and seller and is usually associated with the intended use of the crop. Nevertheless, the principles of the Codex standard may be included within the specifications.

Summary of Codex Standard 172-1989: The standard applies to sorghum for direct human consumption.

- Grains shall not have abnormal odour or taste.
- Grains may be white, pink, red, brown orange or yellow or may be a mixture of grains.
- Grains must be sound, clean and free from living insects.
- Moisture content will not exceed 14.5 percentage
- Ash not more than 1.5 percentage on dry matter
- Protein (N x 6.25) not less than 7 percentage on dry matter basis
- Tannins: For whole grains - not to exceed 0.5 percentage on dry matter.

Hygiene

Grain should be prepared in accordance with the Recommended International Code of Practice, General Principles of Food Hygiene (CAP / RCP 1-1969, Rev. 2, 1985).

Free from micro-organisms, substances originating from micro-organisms, or other poisonous substances in amounts which may represent a hazard to health.

Packaging

Packed in containers (including sacks) which will safeguard the hygienic, nutritional and technological qualities of the grain. A summary of general tolerances for grain defects is given in Table 2

Table 2. Tolerances for defects in sorghum

Defect	Limit	Definition
Blemished grains including diseased grains	3.0% 0.5%	Insect or vermin damaged. Sprouted, diseased, frost damaged or other. Evidence of decay, mould or bacterial decomposition.
Broken kernels	5.0%	Pieces which pass through a screen with round holes 1.8 mm in diameter
Other grains	1.0%	Non-sorghum - legumes, pulses, other edible cereals.
Foreign matter including inorganic matter	2.0% 0.55% (inorganic matter)	All organic and inorganic material which is not sorghum, broken kernels, other grains and filth. Includes loose sorghum seedcoats.
Filth	0.1%	Impurities of animal origin.
Toxic or noxious seeds		Free from amounts which may be a hazard to health.
Contaminants		Free from heavy metals in amounts hazardous to health.

Requirements for safe and scientific storage: Following requirements should be considered for safe and scientific storage of jowar:

- Selection of site: The storage structure should be located on a raised well drained site. It should be easily accessible. The site should be free from water logging, dampness, excessive heat, insects, rodents, termites etc.
- Selection of storage structure: The storage structure should be selected according to the quantity of jowar to be stored and the period of storage. In godowns sufficient space should be provided between two stacks, between stacks and walls, so that proper aeration can be available.
- Cleaning and fumigation: Before, storage of jowar, godown/structure should be properly cleaned and fumigated. There should be no cracks, holes or crevices in the structure.
- Drying and cleaning grains: Before storage jowar grains should be properly dried and cleaned to avoid quality deterioration.

- Cleaning of bags: Always use new gunny bag. In case of second hand gunny bags, it should be disinfested by boiling in one percent Malathion Solution for 3 to 4 minutes and fully dried.
- Separate storage of new and old stock: To prevent contamination from the old stock to new stock, it is advised to store them separately.
- Use of dunnage : Bag of jowar should be kept on wooden crates or bamboo mats along with cover of polythene sheet to avoid absorption of moisture from the floor.
- Proper aeration: Proper aeration should be provided during dry and clean weather but care should be taken to avoid aeration in rainy season to protect the stock from moisture.
- Cleaning of vehicles: The vehicles used for transportation of jowar should be cleaned by phenyl to avoid infestation.
- Regular inspection: To maintain proper health and hygiene of stock regular inspection of stored jowar is necessary. Periodic fumigation should be carried out in case of long term storage.

Management of insect pests

Physical control measures: The infestation of stored grains by insect pests largely depends on the three factors temperature, moisture content of grain, availability of oxygen. All these factors are required for normal development and multiplication of insects. Hence, they have to be properly manipulated through design and construction of storage structures/godowns and storage practices so as to create physical conditions unfavorable for attack by insects.

i. Use of low and high Temperatures: The insects can be controlled either by increasing or decreasing storage temperature. Optimal temperature for most of the storage insects is between 25 and 33^0 C. Temperatures between 13 and 25^0 C will slow development. High temperatures of 35^o C and above will stop development. Refrigerated aeration of grains stored in bins gave results on par with insecticide treatment in Australia, USA and Israel in controlling storage pests (Navarro and Calderon, 1982). High temperature disinfestations using heated air grain driers, fluidized beds, spouted beds, pneumatic conveyors, a counter flow heat exchanger, high frequency waves, microwaves, infra red waves and solar radiations have been satisfactorily used for in disinfesting grains.

ii. Irradiation: Low dose irradiation completely kills or sterilizes the common grain pests, and even the eggs deposited inside the grains. Moreover, only a single radiation exposure of grains is sufficient for disinfestations. This, therefore, is ideally suited for large-scale operations, thereby offering substantial economic benefits. Irradiation can also serve as an effective process for disinfestations of certain prepacked cereal products like atta, soji (rava) and premixes. Low dose applications (Less Than 1kGy) has been found useful for Insect disinfestation in stored grain, pulses and products

iii. Use of controlled atmosphere: In grain storage, insects can be controlled by decreasing O_2 or increasing CO_2 or N_2 concentration in the atmosphere thereby interfering with the normal respiration of insects. This is achieved by modified atmospheric storage, controlled atmospheric storage or airtight storage. In case of modified atmosphere, the storage atmosphere is modified by introducing CO_2 or N_2 replacing O_2. Controlled atmosphere is precisely maintaining the composition of selected gases such as CO_2, O_2 and N_2 at specified concentration under normal pressures or under partial vacuum.
Airtight or hermetic storage of grains/seeds lead to decrease in available O_2 and increase in CO_2 due to respiration and metabolism of the seeds.

b. Use of plant products: The powders of leaves of Neem, and Nochi, Vitex negundo when mixed with grains gives protection from insects. Experimental results show that the fresh leaves of Begunia mixed with paddy at the rate of 2% w/ protected the grains from insect attack for 9 months. Neem leaf powder, turmeric powder, Sweet Flag (Vasambu) Rhizome powder all at 10g /kg have been found to be effective against storage pests.

c. Chemical control measures: Amongst the present methods of insect control, chemical control is the most popular and perhaps most effective one. They may be used for both types of treatments.

a. Prophylactic treatment
b. Curative treatment

a. Prophylactic treatment

1. If the produce is meant for seed purpose, mix 1 kg of activated kaolin or malathion 5% D for every/100 kg of seed and store/pack in gunny or polythene lined bags.
2. Apply one of the following pesticides at the specified dosage over the bags. Malathion 50 EC : 10 ml per litre of water and 3 litres of spray solution per 100 sq.m. (or) DDVP 76% SC : 7 ml per litre of water and 3 litres of spray solution per 100 sq.m.
3. Air charge alleyways or gang ways with one of the following chemicals. Malathion 50 EC : 10 ml/litre of water (or) DDVP 76% SC : 7 ml/litre of water. Apply one litre of spray solution for every 270 cu.m. or 10,000 cu. feet. Spray the chemicals on the walls and floors and repeat the treatment based on the extent of flying and crawling insects.
4. Gunny bag impregnation: Empty bags are soaked in 0.1% malathion emulsion for 10 minutes and dried before using for seed storage.

b. Curative treatment

1. Draw samples of seeds or grains at fortnightly intervals and classify the infestation as follows. When there is no pest - nil infestation. Up to 2 insects -mild infestation More than 2 insects -severe infestation

2. Decide the need for shed fumigation (entire store house or godown) or cover fumigation (only selected blocks of bags)
3. Choose the fumigant and work out the requirement on the following guidelines.

   i. Aluminium phosphide: The dosage of Aluminium phosphide for cover fumigation is 3 tablets of 3 grams each per ton of grain and for shed fumigation is 21 tablets of 3 grams each for 28 cu. Metres. The period of fumigation is 5 days.

   ii. Methyl bromide (MB): MB which has been widely used in temperate regions of the world has been found unsuitable for Indian conditions as it affected seed germination drastically at temperature above 20°C. Among the above three chemicals, Aluminium phosphide is most commonly used. In case of cover fumigation, mix clay or red earth with water and make it into a paste form and keep it ready for plastering all round the fumigation cover or keep ready sand-snakes. Insert the required number of aluminum phosphide tablets in between the bags in different layers. Cover the bags immediately with fumigation cover. Plaster the edges of cover all round with wet red earth or clay plaster or use sand-snakes to make leak proof. Keep the bags for a period of 5 – 7 days under fumigation Remove the mud plaster after specified fumigation period and lift cover in the corner to allow the residual gas to escape. Allow aeration and lift cover after a few hours. Follow similar steps in case of shed fumigation also.

"GRAIN SAVED IS GRAIN PRODUCED"

9. Disease management in sorghum and sweet sorghum

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Introduction

Diseases of sorghum affect productivity, production of quality grain and fodder in sorghum, and sugar yield in sweet sorghum. In grain sorghum grain mold, downy mildew, anthracnose and ergot are major diseases during *kharif* whereas; root and stalk rot and chlorotic stripe virus are common during *rabi* season. Other diseases like leaf spots and smuts occur sporadically and assume economic significance under specific environments depending on relative humidity and temperature in a particular season.

Foliar diseases are important mainly for forage sorghum which are grown in northern part of India. Diseases like zonate leaf spot, anthracnose, sooty stripes, leaf blight and rust are of economic significance and reduce yield and quality of forage. Others like virus diseases (maize stripe virus), sugary disease (ergot) and head mold (grain mold) assume significance under specific environments. Leaf diseases destroy active leaf area required for photosynthesis, adversely affect accumulation of sugar in stalk and thus interfere with the quantity and quality of fodder. Management approaches are mostly concentrated towards the use of genetic resistance with limited use of agrochemicals.

Sweet sorghum or high energy sorghum has immense potential as bio-energy producer and has great relevance in the national renewable energy security. Most of the diseases of grain sorghum also occur in sweet sorghum depending on growing conditions and environment. Leaf anthracnose, red stalk rot, leaf blight, downy mildew, rust, sugary disease, head mold and virus diseases are common in sweet sorghum. Leaf diseases cause destruction or reduction of active leaf area for photosynthesis, and thus adversely affect accumulation of sugar in stalk. As sweet sorghum is a crop having commercial value, cost intensive management practices can be advocated for such crop.

The word 'management' conveys the concept of a continuous process. It implies that diseases are inherent component of an agro-ecosystem that must be dealt with a continuous knowledge based input. Approaches of management may be directed to a single disease or planning for overall health of a crop (IDM). Three major component of disease management are management of host (achieved by improving genetic resistance, nutritional status or by protecting plant with chemical), pathogen (reduction and eradication of pathogen or preventing inoculum from coming in contact with the plant), and environment (management of soil, water and crop). In sorghum, diseases management approaches are concentrated mostly towards the use of genetic resistance with limited use of agrochemicals. Though there are more than a dozen of foliar diseases are reported in sorghum only few are important. Economic importance and management of major diseases are described in the following sections.

Panicle diseases

Grain mold

Grain mold causes a kind of total damage to grain, reduces seed germination, market price and contaminates grain with hazardous mycotoxins. Loss in grain yield up to 50% and reduction in grain price around 20% are common for grain mold. Many fungi are involved in mold development and most of them are saprophytes which grow on grain mostly after physiological maturity of grain.

Among the pathogenic fungi *Fusarium moniliforme Curvularia lunata* and *Alternaria alternata* are predominant which can grow even on immature grain. *F moniliforme* produces mycotoxin fumonisin in fresh as well as stored grain and such grains are harmful for animal and poultry bird.

Avoidance is the best option for grain mold management. Adjust sowing time; if possible, in such a way that crop may not be caught in rain during maturity. Photosensitive sorghum generally escapes grain mold because they flower near the end of the rainy season. Use of tolerant cultivars reduces development of pathogenic mold before physiological maturity. Harvesting of genotypes at physiological maturity and quick drying in a community dryer to bring down the moisture content to less than 12% protects from saprophytic mold development. Need base spray with fungicide (Tilt 25% EC @ 0.2%) and bioagents (fluorescent *Pseudomonas*) reduce mold and significantly improve grain and seed quality. Spray is useful especially for high value crop like nucleus and breeder seed production, sweet sorghum etc.

Sugary disease

After grain mold sugary disease (*Sphacelia sorghi*) or ergot is the next important disease among the panicle diseases. The pathogen damages ovary, interfere with grain formation and thus reduces grain yield. The disease may become serious under favorable conditions (minimum temperature 18-20^{o}C, RH 67-84% and cloudy weather). It is a major problem in hybrid seed production plots especially when there is lack of synchrony in flowering between parental lines. Yield losses ranging from 10-80% is common in seed crop. The ergot produced by the pathogen has potential to create health hazard in livestock.

Early sowing avoids the occurrence of the sugary disease. Removal of collateral host plants (*Penniseum typhoides, Ischaemum pilosum* and *Panicum maximum*) from the field bunds helps to reduce pathogen inoculum and disease. Mechanical removal of sclerotia from seeds, by washing in 30% salt water followed by 3 rinsing in plain water before sowing reduces seed contaminated infection. In seed production plots, ensuring synchrony of flowering between A and R lines avoids the occurrence of disease. Spraying panicles with fungicides (0.1% Bavistin/ 0.2% Tilt/ 0.2% Mancozeb) minimizes disease and its subsequent spread. First spray should be done at 50% flowering stage and rest two sprays at 10 days interval.

Smuts

There are 4 types of smut in sorghum of which 3 are seed-borne. In covered smut, sori are formed in the place of healthy grains. Most of the grains of an infected ear are replaced by smut sori. The membrane like structure covering the spore masses generally persist up to threshing. In loose smut, the affected plants are stunted, produce thinner stalks, more tillers and earlier to flower than the healthy plants. All the spikelets of an infected earhead get malformed and hypertrophied. The membrane like structure covering the spore masses generally ruptures soon after head emergence. In head smut, a sorus fully covered with a grayish-white membrane emerges from the boot leaf in place of normal inflorescence. When fully emerged the fungal membrane ruptures releasing spore masses in the air leaving filamentous vascular tissues of the host. In long smut, the sorus is covered by a whitish to dull yellow, fairly thick membrane and is much longer (about 4.0 cm) than those of the other two smuts.

Loose and covered smuts are externally seed-borne and easily controlled by seed dressing with sulphur (@ 4g kg^{-1} seed). Since head smut is only sporadic and of minor importance, no serious attempts have been made to work out the control measures. However, collecting smutted heads in cloth bags and dipping in boiling water to kill the pathogen will reduce the inoculum potential for the next year's crop. Long smut is air-borne and difficult to control. Adjusting sowing dates seems to help in avoiding the disease.

Foliar diseases

Downy mildew

Sorghum downy mildew (*Peronosclerospora sorghi*) (SDM) is serious problem in *kharif* sorghum particularly in southern states such as Tamil Nadu, Karnataka and Andhra Pradesh. Recently the disease is occurring during *rabi* season too. SDM is one of the potentially destructive diseases that can reach epiphytotic proportions under favorable conditions. It poses possible quarantine risk in grain export. Grain yield loss varies from 6-86% depending on incidence level, and host resistance. The fungus produced numerous conidia on the under surface of infected leaf and are borne on conidiophores protruding through stomata. The infected leaf shows chlorosis on the lower part of the lamina, which further grows to cover larger part of the leaf. As the plant grows, new emerging leaves exhibit parallel stripes of green and white tissue; the white interveinal tissue dies and leaf shredding occurs.

Management of SDM is focused mainly by using combination of host plant resistance and fungicides, but emphasis is obviously on host resistance. Seed dressing or seed dressing + spray with different formulation of Metalaxyl effectively control downy mildew in sorghum. Seed treated at 1.0 or 2.0g a.i./kg, could be preserved at room conditions for 9 months without affecting seed germination. Foliar spray with systemic fungicide (Metalaxyl) can manage the disease but there is risk of resistance development in pathogen. A large-scale screening technique for SDM resistance has been standardized. Good amount of resistance is available in present day cultivars. Some of the resistant varieties are; QL3, IS 3547, CSV4, CSH5, SPH196.

Anthracnose

Anthracnose (*Colletotrichum sublineolum*) is an important disease causing substantial economic losses to grain, forage and sweet sorghum. It is prevalent and severe in warm and humid environments. The disease appears on several plant parts causing seedling blight, leaf blight, stalk rot, and head blight. Among these, leaf anthracnose is the most pronounced and devastating. Anthracnose may defoliate plants markedly, reducing growth and further development. Red rot symptoms are seen on mature plants. Yield losses of 50% or more can occur under severe conditions. The sugar content of sweet sorghums is severely affected.

Use of clean seed, destroying plant refuse, crop rotation and removal of susceptible weeds such as Sudan grass and Johnson grass are some of the practices that reduce field incidence of the disease. Use of resistant genotypes has often met limited success because of the large genetic variation in the pathogen population. IS 3547, SPV 386 and ICSV 247 are sources having resistance to anthracnose.

Zonate leaf spot

Many types of leaf spots are reported in sorghum. But all are not economically important. Zonate leaf spot, Gray leaf spot, Target leaf spots and Sooty stripes are frequently observed on forage cultivars in India. Disease incidence is more on purple or red pigment genotypes and relatively less on tan cultivars. Zonate spot is identified by circular lesions with concentric banding formed out of fungal growth. In gray leaf spot spread of the oval to rectangular lesion becomes limited by the veins. Sooty stripe is characterized by small, circular to elongated reddish brown spots on leaf with distinct yellow haloes.

These pathogens mainly survive in crop residues and weed hosts. Incidence of such diseases can be minimized by use of clean seed, clean cultivation practice and use of tan pigmented lines. Need based fungicide application will help check the disease and its spread to healthy plants within the field.

Leaf blight

Leaf blight (*Exserohilum turcicum*) is an economically important and widespread disease of sorghum in highly humid areas. In susceptible cultivars, grain yield losses of up to 50% may occur, if infection starts early in the growth stage. However, disease development in mature plants is slow and yield losses are minimal. In older plants, the typical symptoms are long elliptical necrotic lesions, straw colored in the centre with dark margins. Very long lesions may develop and coalesce destroying large areas of leaf tissue giving the crop a distinctly burnt or blasted appearance. The disease is considered more important in fodder and sweet sorghums than in grain sorghum.

Use of disease free clean seed and destruction of plant refuse reduce field incidence of the disease. Use of resistant varieties is recommended for disease prone areas.

Rust

Rust (*Puccinia purpurea*) is important in a year of high rainfall and humidity. Rust has the potential to damage the whole crop under favorable conditions. Reddish brown rust pustules appear first on both the surfaces of the lower leaves, the upper half being more severely affected than the lower half. As the disease advances the infection spreads to the younger leaves. The rust sori are minute, round to elliptical and 1.0 to 2.0 mm in diameter. Several sori may coalesce to form large patch on leaves and the infected leaves die prematurely giving the plants an unhealthy appearance which becomes visible from a distance.
Use of resistant cultivars is the best known control measure for sorghum rust as is true in other cereal rusts too. Foliar spray of Mancozeb @ 0.2% effectively controls rust.

Viral diseases

Twenty-three viruses are reported as pathogens on sorghum in nature and among them nine viruses are distributed in Asian countries. In India virus diseases on sorghum are distributed in all sorghum growing regions. Maize stripe virus (MStV), maize mosaic virus (MMV), sugarcane mosaic virus (SCMV), maize dwarf mosaic virus (MDMV), johnson grass mosaic virus (JGMV) and red stripe disease (SRSD) are economically important on sorghum in India. In recent times there is an increasing trend in incidence of these viruses on sorghum. Studies suggested substantial loss in grain and fodder yields due to these viruses.

Sorghum stripe disease, caused by a strain of maize stripe tenuivirus (MStV-sorg) is assuming economic significance particularly in *kharif* and irrigated *rabi* crops. Disease incidence ranged from 1-14%. The disease is characterized by chlorotic stripes and bands along the veins of the infected leaves and stunted growth of the plant. First visible symptom can occur on any leaf starting from 4^{th} to 11^{th} leaf. Symptom expression frequency increase from 4^{th} to 7^{th} leaf, reach peak on 7^{th} or on 8^{th} leaf and thereafter gradually decrease on subsequent upper leaves. The growth stages between 36 to 65 DAE are highly susceptible for this disease development. Early infected plants did not produce any ear head and die prematurely, whereas plants infected later in the growth stages produce either poor or no panicle. Reduction of plant height, ear head weight and thousand grain weights to the extent of 73, 93 and 25 per cent respectively have been reported in the variety CSV15. Yield losses are, however, different when infection occurs at different growth stages.

The disease is transmitted by an insect vector, *Peregrinus maidis* which itself is a major pest on sorghum in India. The disease can be managed or its incidence can be reduced by practices like clean cultivation, vector control and adjustment of sowing time. The practice of uprooting and burning of the infected plants help to reduce source of inoculum for the vector and thus reduce spread of the disease in the field. Spraying of Endosulfan 35% EC @1.5 ml l^{-1} of water effectively reduces vector population and the disease. Disease incidence is greatly reduced as sowing of *rabi* sorghum is shifted from September to October. When sowing is delayed from 1st week of September to 1st or 3rd week of October disease incidence is reduced by 40 and 65 per cent respectively. Therefore, early sowing of *rabi* sorghum should be avoided to reduce crop loss by this viral disease.

Root and stalk diseases

Charcoal rot

Root and stalk rot is a complex disease often associated with several fungi of which *Macrophomina* and *Fusarium* are dominant component. The disease is characterized by root rot, seedling blight during early stage and stalk rot (charcoal rot) and lodging in the later stage. Charcoal rot is a serious problem and occurs every year on *rabi* crop. The disease becomes severe in hybrids and high yielding varieties. The disease is not only important for the loss it incur in sorghum productivity but also for its potential role in creating animal health hazard which may be created due to feeding of intoxicated (charcoal rotted) stover to domestic animals. However, major losses occur due to rotting of stalk tissue followed by lodging of the diseased. Lodging up to 100 per cent and grain yield losses up to 64 per cent has been reported in CSH-6. Lodging at flowering stage severely affects grain filling and causes loss in seed weight.

Most of the efforts for management of charcoal rot is and has been oriented towards developments and use of resistant cultivars. However, resistance is low in high yielding cultivars with desired grain type. Incidence of the disease can be reduced by cultural practices like clean cultivation, use of less nitrogenous fertilizer, less plant density, or growing sorghum in mixed cropping. Chemical control measures have also been tried but results are not encouraging. Drought stress predisposes sorghum to charcoal rot and lodging. Preventing drought stress to occur (irrigating crop at flowering stage where water is available) and escaping terminal drought (growing early maturing varieties) are few other viable strategies for charcoal rot management. Recent studies showed that seed treatment with selected strains of fluorescent *Pseudomonas* (*P chlororaphis* strain SRB127) reduce charcoal rot and increase 1000 grain weight in high yielding cultivar.

Reference

Aruna C, Bhat BV, Umakanth AV, Shyam Prasad G, Das IK and Patil JV. 2011. Forage sorghum. Directorate of Sorghum Research, Rajendranagar, Hyderabad 500030, Andhra Pradesh, India. 52pp. ISBN: 81-89-335-36-7.

Audilakshmi S, Aruna C, Garud T B, Nayakar N Y, Atale S B, Veerabadhiran P, Dayakar Rao B, Ratnavathi C V and Indira S. 2005. A technique to enhance the quality and market value of rainy season sorghum grain. Crop Protection 24: 251-58.

Das, I. K., Audilakshmi, S., Annapurna, A., Kannababu, N., and Patil, J.V. 2012. Relationship among seed germination and other characters associated with Fusarium grain mold disease in sorghum (*Sorghum bicolor* L. Moench) using path coefficient analysis. Canadian Journal of Plant Pathology, 34(2): 203–212.

Das I. K., Audilakshmi, S. and Patil, J. V. 2012. Fusarium Grain Mold: The Major Component of Grain Mold in Sorghum (Sorghum bicolor L. Moench). The European Journal of Plant Science and Biotechnology, 6: (Special Issue 1): 45-55.

Das, I. K., Indira, S., Annapurna, A., Prabhakar and Seetharama, N. 2008. Biocontrol of charcoal rot in sorghum by fluorescent pseudomonads associated with rhizosphere. Crop Protection 27 (11): 1407-1414.

Frederiksen RA. 1986. Compendium of sorghum diseases. The American Phytopathological Society and Depertment of Plant Pathology and Microbiology, Texas A&M University, Texas, 82pp

Narayana YD, Das IK, Bhagwat VR, Vilas A Tonapi and Patil JV. 2011. Viral disease of sorghum in India. Directorate of Sorghum Research, Rajendranagar, Hyderabad 500030, Andhra Pradesh, India. 30pp. ISBN: 81-89-335-35-9.

Peterschmitt, M., A.S. Ratna, W.R. Sacks, D.V.R. Reddy and L.K. Mughogho. 1991. Occurrence of an isolate of maize stripe virus on sorghum in India. Ann. Appl. Biol. 118: 57-70.

Ratnavathi, C.V., Komala, V.V., Vijaykumar, B.S., Das, I.K. and Patil, J.V. 2012. Natural occurrence of aflatoxin B1 in sorghum grown at different geographical regions of India. Journal of the Science of Food and Agriculture, 92:2416-2420.

Thakur, RP, Reddy, BVS and Mathur, K. 2007. Screening techniques for sorghum diseases. Information Bulletin No. 76. Patancheru 502 324, Andhra Pradesh, India: *ICRISAT*. 92pp. ISBN 978-92-9066-504-5.

10. Field demonstrations on improved sorghum technologies and its impact

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ABSTRACT

Frontline demonstrations (FLDs) programme is one of the approaches for disseminating farm technologies generated by research system. The programme which started with the conduct of 220 ha demonstrations in both *kharif* and *rabi* season during 1996-97, now they enhanced to more than 5000 ha, seeing the success of the programme in terms of adoption of recently released hybrids and varieties by the farmers. The results revealed that with the exploitation of the currently available sorghum production technologies, farmers could realize additional yield more than 50 per cent over the prevailing farmer's practices under wide range of agro-ecological sorghum growing regions.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is the fourth largest crop after wheat, rice and maize which is being cultivated by resource poor, small and marginal farmers in semi-arid regions of the country. The efforts made by the Directorate of Sorghum Research (DSR), All India Coordinated Sorghum Improvement Project (AICSIP) and State Agricultural Universities since its inception, has led to technologies for enhancing production and productivity to meet requirement of food, fodder, feed and fuel.

In spite of its multiple uses, the area under grain sorghum in India has declined from 18.61 m. ha in 1969-70 to 5.75 m. ha in 2013-14. However, because of significant improvements made in research and development, its productivity has increased from 522 kg /ha to 912 kg /ha during the same period. There is a wide gap between average national productivity and yield potential of the improved sorghum technologies developed from the research institutes. The project aimed to involve the scientists who developed the technologies in demonstration of their product to the farmers (user of the technologies) and to have first hand feedback on its performance and problems for its further refinement. This programme is being organized by the DSR since its inception which was financially sponsored by the Ministry of Agriculture (Table 3).

Thus, FLD is one of the important programmes to evaluate and demonstrate the production potential of recently released sorghum cultivars in the farmers' fields. Besides, building confidence of the farmers to adopt the latest technologies, it gave valuable feedback to modify the research programme based on experience gained during the programme. Now-a-days, the farmers preference is for dual purpose cultivars to meet the requirement of both fodder and food. The farmers' choice is also varies at locations to locations. Keeping these in view, FLDs on sorghum were organized and is being organized at different locations with the help of AICSIP centres. The results of the *kharif* FLDs organized during 2009-10 are highlighted in this articles to projects its implementation and impact.

Guidelines for frontline demonstrations

Including in the guidelines given by the Ministry of Agriculture, Department of Agriculture and Cooperation (DAC), the following guidelines are revised for implementing the FLD programme in different sorghum growing regions of the country.

Selection of the farmers: Farmers from the different categories including SC and ST, who are interested, cooperative and responsive, should be selected. The farmers should be within limit, as 20-25 numbers maximum from a single village or from a cluster with one technical field assistance.

Site selection: FLD sites should preferably be selected on road sides of the village in order to get exposure to the maximum numbers of farmers including non-beneficiaries.

Field layout: The field layout should be included farmer's practice. The component demonstration and total package demonstration need to be conducted separately. The field for FLD should be minimum of 0.4 ha.

Field boards and labels: The trials should be labeled with field boards and plates showing name of latest cultivars, date of sowing and fertilizers (NPK) dose, etc.

Technology for demonstration

a. Package demonstrations: Details of practices used should be listed out under demonstrations and made available to the farmers at the beginning. The farmers' practices are also need to be enlisted at the beginning of the programme.

b. Demonstrations on high yielding cultivars: The demonstrations should include the cultivars developed within the last five years period. Their performance should be compared with local cultivars. All the management practices except the cultivars should be same.

Literature distribution: Handouts or leaflets on the demonstrated technologies in local language should be distributed to the farmers along with critical inputs as a subscription.

Field book maintenance: The field book having farmer's details, layout design, date-wise operations, component-wise cost incurred, labour requirement, yield attributes, yield data, etc., along with the farmers' practice (as a check) must be maintained.

Data support: Data need to be generated or collected on physico-chemical properties of soil, annual rainfall and district-wise area, production and yield (APY) in addition to the FLDs' data.

Contact with line departments: These demonstrations should be focused on adoption of critical technological gaps. The Strategic Research and Extension Plans (SREPs) prepared by ATMAs have identified such technological gaps for major crops of the district. While preparing plan for the FLDs, the SREP of the district may be consulted by the concerned scientist of implementing centres.

Latest approach: Farm Field Schools are being setup at Block / Village level by the ATMA official on the field of progressive farmers, who may be linked in organizing FLDs on sorghum.

Technology dissemination: Conduct extension activity like, farmers' day, field days and field visits and explain superiority of the demonstrated technologies over their own practices involving maximum number of farmers of the village and surrounding areas.

FLD monitoring: The monitoring team of experts should assess the trials on different parameters including utilization of funds, crop management, field layout, literature distribution, etc.

1. Frontline demonstrations on *kharif* sorghum

In total, 254 frontline demonstrations (FLDs) on sorghum were organized during the year under report in 29 districts across the 7 different sorghum growing states viz., Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, Gujrat and Tamil Nadu. Latest sorghum cultivars (SPSH 1148, CSV 20, CSV 23, CSH 23 and CSV 17) were commonly undertaken and compared with farmers' cultivar as local check to evaluate and demonstrate their performance in farmers' fields at different locations.

Highlight of the results

The demonstrated improved sorghum cultivars irrespective of the agro-ecological regions yielded better by obtaining 12 to 67% higher grain yield and 1% to 64% more fodder yield than the local check. It was also proved more economical than the local checks. On an average, the demonstrated cultivars could earn net returns of Rs.17,955/- per ha, which was 56.21 per cent more than the local check (Rs.11,494/- per ha). It was also resulted in to 0.45 more B:C ratio from them. However, the rate of increase varied at different locations. The higher increase in grain yield 368% was obtained in *Mevad* region of the Rajsthan and lowest 12% was in *Vidharbha* region of the Maharashtra. Similar trend was observed in case of fodder yields, except in the *Mevad* region (yield increased 1%) because the local cultivars were also performed better (Table 2).

Yield gaps

The results show that the grain yield of sorghum was lower under farmer's practice (1.52 t. ha^{-1}) as compared to FLD's (2.20 t. ha^{-1}) indicating a wider gap (45%). However, comparatively lower yield gap (21.53%) was found in case of stover yield (Table 4 and Fig. 1). The cultivars could bridge the yield gap in grain (45%) and stover (21.53%) through improved sorghum technologies, *kharif* sorghum farmers could able to produce the maximum grain and stover yields. Since, the demonstrated sorghum cultivars shows potential to increase the yields and profits over local one at almost all the locations, FLDs may be conducted systematically in small area under control with location-specific sorghum technologies to build up confidence of the farmers for its wide adoption.

Table 1 Economics of *kharif* sorghum cultivation under FLDs

S. No.	FLD Centre	Economic					
		Cost of cultivation ($Rs.ha^{-1}$)		Net return ($Rs.ha^{-1}$)		B:C ratio	
		FLD	FP	FLD	FP	FLD	Local check
1	Palem	10900	9125	25162	16830	3.29	2.83
2	Udaipur	8500	7700	16950	7160	2.74	1.85
3	Surat	15038	14310	20215	12812	1.34	0.90
4	Indore	8064	6787	17818	12695	3.21	2.91
5	Akola	14109	15501	20321	17298	1.44	1.11
6	Coimbatore	9211	7643	7264	2170	1.70	1.45
	Mean	10970	10178	17955	11494	2.29	1.84

Table 2 State-wise yield gap between FLDs and farmer's practice (FP)

S. No.	State	Grain yield (t. ha^{-1})			Stover yield (t. ha^{-1})		
		FLD	FP	Yield gap (%)	FLD	FP	Yield gap (%)
1	Andhra Pradesh	3.5	2.45	42	8.6	6.25	38
2	Rajsthan	1.64	0.35	368	7.82	7.73	01
3	Gujrat	2.16	1.63	33	6.19	5.02	23
4	Madhya Pradesh	2.33	1.86	25	7.10	5.26	35
5	Maharashtra	2.36	2.10	12	8.50	8.08	05
6	Tamil Nadu	1.22	0.73	67	7.20	4.40	64
	Mean	2.20	1.52	91.17	7.57	6.12	27.67

Table 3 Details of frontline demonstrations conducted since 2006

Year	Varieties/hybrids demonstrated	Area covered (ha)	Demos	States/locations
2013-14	CSV 22R, CSV 18R, Phule Vasuda, Phule Suchitra, Phule Revati, Phule Anuradha, PKV Kranti, Parbhani Moti, CSV 26R and CSV 29R	152	341	Maharashtra, Karnataka and Andhra Pradesh
2012-13	CSV 22R, CSV 18R, Phule Vasuda, Phule Suchitra, Phule Revati, PKV Kranti, Parbhani Moti and CSV 26R	156	280	Maharashtra, Karnataka and Andhra Pradesh
2011-12	CSH 16 (in rice-fallows)	50	126	Guntur district of Andhra Pradesh
2010-11	CSH 23, CSV 23, CSV 20, CSV 17, SPH 1148, CSH 25, SU 1080, CoS 30, CSV 22, Phule Yashodha, Phule Vasudha and CSV 18	250	431 (125K+306R)	Maharashtra, Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Rajsthan, Gujarat
2009-10	CSH 23, CSV 23, CSV 20, CSV 17, SPH 1148, CSH25, PJ1430, SU 1080, JJ 1022, Co (s)28, PKV-kranti, CSV 22R and CSV18R	283	471 (254K+217R)	Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Rajsthan, Gujarat, Uttar Pradesh
2008-09	CSH 23, CSV 23, SPV 1616, CSV 17, SPV 1753, PJ 1430, SU 1080, JJ 1041, and JJ 1022	47.20	90	Karnataka, Madhya Pradesh, Rajsthan
2007-08	CSV13, CSV17, CSV19SS, SPV1616, SPV1430, NSV13, ICSV745, SSV84, GJ40, JJ1041, PVK400, PVK801, PVK809	312	479	Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Rajsthan, Gujarat, Uttarakhand, Jharkhand, J&K, Uttaranchal
2006-07	SPV1616, CSV17 and state released cultivars	271	498	Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Rajsthan, Gujarat, Uttar Pradesh, Jharkhand, Uttaranchal

(Source: Report on frontline demonstrations on sorghum, National Research Centre for Sorghum, Hyderabad)

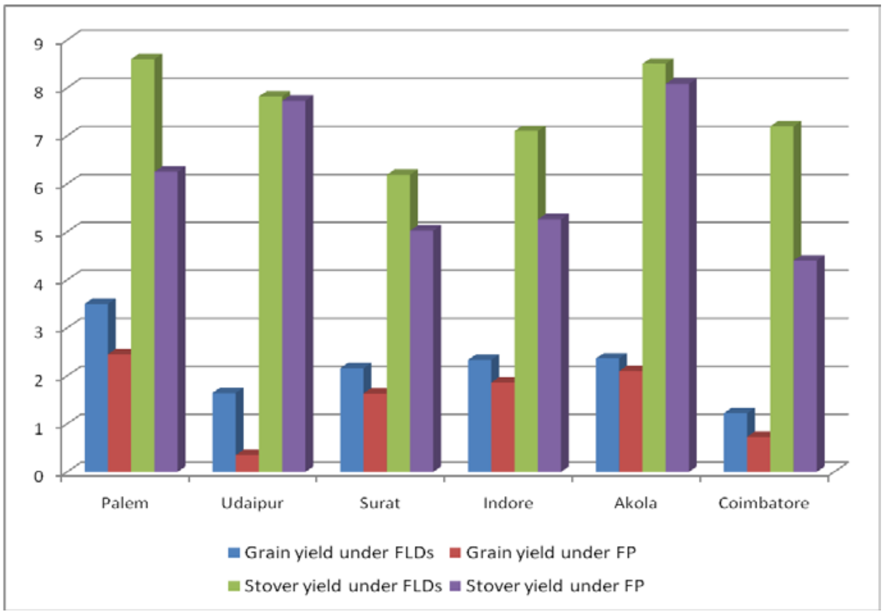

Fig. 1 Performance of *kharif* FLD cultivars over local check (t /ha)

2. Frontline demonstrations on *rabi* sorghum

Rabi sorghum is valued mainly for direct human food consumption and fodder for livestock. In last two decades, the *rabi* sorghum area has increased (3.23 m ha during 1991-96 and 3.59 m ha during 2013-14) with increase in yield (from 539 kg/ha to 840 kg/ha during the same period). Maharashtra is major sorghum growing state followed by Karnataka and Andhra Pradesh in the country. *Rabi* sorghum is mostly grown in dryland conditions on residual soil moisture of rainy season. The productivity of *rabi* sorghum is dependent on quantity of rains during pre-season monsoon and water holding capacity of soil, use of moisture conservation practices, use of high yielding cultivars on basis of soil types and available production technologies. Whereas, in few pockets of Western Maharashtra and Karnataka, the crop is grown on irrigated conditions with two to four irrigations with higher productivity up to 3.5 to 4.0 t /ha. The productivity of *rabi* sorghum is less (840 kg/ha during 2013-14) than that of rainy season (*kharif*) sorghum (1033 kg/ha). The important reasons for that are; (i) non-adoption of improved sorghum cultivars on soils type basis and (ii) the crop is grown on residual soil moisture. Keeping these in view, FLDs on sorghum were organized with latest high yielding *rabi* sorghum varieties at different locations.

Highlight of results

During 2013-14, in Telangana, CSV 22R gave 39% more grains yield (1.82 t/ha). Sorghum variety *viz*., CSV 18R yielded higher (2.33 t /ha) grains in *Marathawada* region of Maharashtra. Performance of CSV 29R was found better in terms of grains yield (1.45 t /ha) at Bijapur centre. Demonstrated variety; Phule Revati gave higher grain yield (1.87 t /ha) than the local varieties viz., *maldandi* and *dagadi* (0.52 t /ha) in Solapur area. Phule Vasudha was also performed better (1.86 t /ha) in Western Maharashtra region. The improved sorghum cultivars increased the grain and fodder yields over local check in all the locations. The yield advantages were ranged from 29% to 194% in grain and 28% to 150% in fodder. Among the locations, the highest yield in both grain (1.97 t /ha) and fodder (5.57 t /ha) was observed in *Marathwada* region of Maharashtra (Table 5 & Fig. 2).

State-wise yield gaps

It is cleared from Table 5 and Fig. 2 that the grain yields of sorghum was lower under farmer's practice (1.06 t. ha^{-1}) as compared to FLD's (1.64 t. ha^{-1}) indicating wider gap (63%), across the states. However, lower yield gap (50%) was found in case of stover yields under farmer's practice (2.69 t. ha^{-1}) as compared to FLD's (3.93 t. ha^{-1}).

Table 4 Economics of FLDs on sorghum

S. No.	FLD Centre	Grain yield ($t.ha^{-1}$)		Stover yield ($t.ha^{-1}$)		Cost of cultivation ($Rs.ha^{-1}$)	Net return ($Rs.ha^{-1}$)		B:C ratio	
		FLD	LC	FLD	LC		FLD	LC	FLD	LC
1	Parbhani	1.97	0.67	5.57	2.85	14831	44576	14768	3.00	2.00
2	Solapur	1.26	0.52	2.72	1.09	14208	20903	7508	2.39	2.10
3	Rahuri	1.73	1.04	4.40	2.51	29491	17032	6591	1.58	1.31
4	Bijapur	1.45	1.12	2.78	2.19	7867	22136	16013	2.81	2.13
5	Tandur	1.83	1.32	4.78	3.73	14102	40250	31176	2.86	2.38
	Mean	1.65	1.27	3.72	2.47	16100	28979	15211	2.53	1.98

Table 5 State-wise yield gap between FLDs and farmer's practice (FP)

S. No.	Location	Grain yield ($t.ha^{-1}$)			Stover yield ($t.ha^{-1}$)		
		FLD	LC	Yield gap (%)	FLD	LC	Yield gap (%)
1	Maharashtra	1.65	0.74	122	4.23	2.15	96
2	Karnataka	1.45	1.12	29	2.78	2.19	27
3	Telangana	1.83	1.32	39	4.78	3.73	28
	Mean	1.64	1.06	63	3.93	2.69	50

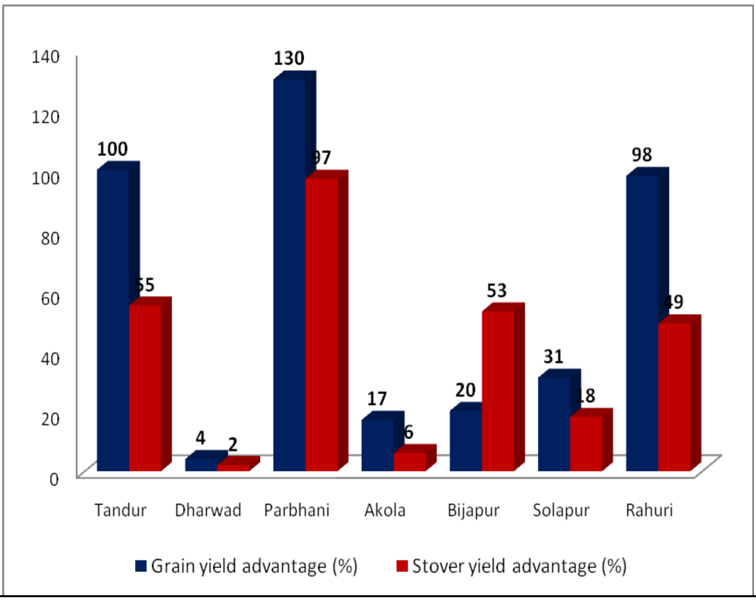

Fig. 2 Yield advantage of *rabi* FLD varieties over local check (%)

Transfer of technology through Extension programmes

The sorghum production technologies developed by the research institutes are disseminated through various Extension agencies of Central and State Agricultural Universities and also through Frontline demonstrations, on-farm trials and by conduct of Farmer's Days.

During last five years, more than 35,000 farmers and different stakeholders were exposed to the latest sorghum technologies through various extension programmes organized by this institute such as short duration trainings, hands-on trainings, krishi melas, field day, field visits, video shows, frontline demonstrations, method demonstrations, etc. The following extension programmes were also conducted to transfer of the production technologies effectively.

Training

In order to popularize the sorghum production technologies, regular training of the field extension functionaries of the state department of agriculture and line departments, non-governmental organizations and others involved in the transfer of technologies of sorghum is organized at DSR, Hyderabad. Several national level workshops-cum-seminars and training programme are being organized.

Linkages

The linkages not only with State department of agriculture of different states but also with the line departments involved in sorghum popularization of sorghum *viz*., Department of Animal husbandry, Department of dairy etc., the State Agricultural Universities, other central institutions like NDDB, MANAGE, NIRD, sister ICAR institutions and various non-governmental organizations involved in the transfer of sorghum production technologies have been established to popularize sorghum production technology.

Live demonstrations

Regular demonstrations are being laid at the institute farm with the popular, released and pre released cultivars of sorghum for the exposing the improved cultivars to the farmers, extension officials, and visitors to the institute. Apart from these demonstrations, demonstrations are also laid down in the select farmer's fields to demonstrate the production potential of the released improved cultivars.

11. Sweet sorghum syrup and jaggery

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Introduction

Sweet sorghum syrup, also referred to as sorghum molasses, *sorgho*, or *sorgo*, is made by boiling the sweet juice of the sorghum cane (*Sorghum bicolor*, formerly known as Holcus sorghum). Sorghum syrup is not derived from the sorghum grain or from sugar cane. And while it is often referred to as molasses, molasses is a by-product of the sugar industry--it is what is left when the granulated white sugar is removed. Sorghum syrup is a natural sweetener produced from the juice extracted from the stalks of sweet sorghum plants.

They are mostly grown commercially for making sorghum syrup, the stout, corn-like sorghum plants are handsome and interesting horticultural grasses with plume-like tassels. Members of the Poaceae family, sorghums have been grown for centuries for grain, syrup, brooms, and forage crops. Sorghums like sandy soil or garden loam, and need to be cultivated and kept free of weeds like corn. Sweet sorghum is mostly grown for forage to produce 'sorghum syrup' unlike most other sorghum varieties that are grown for grains. Some of the varieties of sorghum can get as tall as eight to 15 feet, so these larger canes need to be grown in rows at least six feet apart. The plants take 120 days to mature

It is sweet sticky syrup, dark amber in color with thick consistency. It does not have any unpleasant after taste. It can be used as a table sweetener or exchanged for other sweeteners in baking one cup to one cup. It tastes delicious spread on hot toasts or crisp biscuits. Sorghum syrup may crystallize like honey, but liquefies when gently reheated.

Jaggery Production:

Jaggery is a lump sugar made from sugarcane juice usually. With high sugar juices like toddy juice etc also jiggery can be prepared. Preparation of jiggery is also attempted from sweet sorghum juice. Different cultivars of sweet sorghum (*Sorghum bicolor(L)* Moench) were evaluated for quality of jaggery . Data are presented in Table- I. Among all the cultivars it was observed that BJ-248 yielded good quality jaggery with best crystallization followed by Wray. The jaggery prepared from BJ-248 possessed good crystallization and appearance, similar to sugarcane jaggery. The crystalline structure was due to low content of reducing sugar (0.34 g) and high amounts of sucrose (16.96 g) when compared to other cultivars. Quality of jaggery prepared from SSV-84 and NSS-104 had poor crystallization due to its high reducing sugar content. Jaggery prepared from NSS 104 and SSV-84 have confectionery taste. However, maximum jaggery production was observed with SSV-84 yielding 7.67 % followed by BJ-248 yielding 5.88%.

The analysis of jaggery shows a range of 3 to 16 % w/w of reducing sugars when compared to sugar cane jaggery (9–12%w/w). Significant quantities of Iron (17.9 mg/100g) and Calcium (1457 mg/100g) were also observed in sorghum jaggery as compared to sugarcane jaggery (Table –VII). The percent yield of jaggery varies from 2.15 in Cowley to 7.67 in SSV-84 (Table –VIII). The yield of jaggery per 10-L juice was found to be 1.66 (SSV-84) followed by 1.35 (Wary) and 1.32 (BJ-248).

Table-I Selected genotypes for Jaggery preparation

S.No	Genotypes	%Reducing Sugar	Cane Yield (t/ha)
1	Keller	1.030	41.63
2	RSSV- 38	1.103	47.67
3	Wray	1.160	37.86
4	NSS-211	1.180	34.71
5	RSSV- 7	1.227	50.30
6	RSSV-15	1.227	45.93
7	NSS- 20	1.383	33.72
8	NSS- 221	1.430	54.00
9	RSSV -44	1.510	48.39
10	RSSV- 49	1.550	62.31
11	BJ-248	1.597	34.49

Table –II Evaluation of Sweet Sorghum genotypes for the production of Jaggery

S. No.	Variety	pH of Juice	Brix (%)	Reducing Sugars (%)	Sucrose (%)	Total Sugars (g)	Yield (%)	Yield (Kg/10 L) Juice
1	SSV-84	4.31	19	1.34	16.61	17.95	7.67	1.66
2	NSS-104	4.64	16	1.50	11.20	12.70	5.79	1.28
3	Wray	4.68	21	0.66	16.80	18.30	5.77	1.35
4	BJ-248	4.65	20.5	0.89	16.96	17.85	5.82	1.32
5	Keller	4.88	20	1.26	16.74	18.0	4.32	1.02
6	Cowley	4.75	16	1.61	11.24	12.8	2.15	0.47
7	BJ-238	4.71	18	2.40	14.30	16.7	5.93	1.35
8	SSV-74	4.60	18	2.00	13.80	15.8	3.72	0.80

Note: Observations are an average of two replications

Table – III Chemical Analysis of Jaggery from NSS-104

Sen.	Test Parameters	Results
1	Calcium mg/100g	1457.0
2	Iron, mg/ 100g	17.9
3	Chlorides, mg/kg	7375
4	Sulphates, ppm	2343
5	Total Carotenoids, mg/100g	543.0
6	pH	7.25
7	Color (540 NM)	540
8	Moisture	12.85
9	Reducing Sugars	1.45 %
10	Total Sugars	82 %

Table – IV Chemical Analysis * of Jaggery in selected genotypes

Variety	pH	Brix (%)	Reducing Sugar (%, w/w)	Sucrose (%, w/w)	Total Sugar (%, w/w)
BJ-248	7.08	44.7	3.6	74.8	78.4
Wray	6.43	44.7	14.1	74.3	88.4
SSV-74	5.88	45.0	16.1	65.1	81.2
NSS-104	6.89	44.5	12.8	58.4	71.2
Keller	6.09	44.7	10.7	56.5	67.2
Cowley	5.90	44.7	16.2	62.6	78.8
BJ-238	5.91	44.8	20.1	55.1	75.2

** All observations are mean of five replications.*

Syrup Production

Sorghum syrup is produced by extracting the juice from the sorghum stalks, and then boiling it down to the desired consistency. Sweet sorghum syrup production offers farmers an excellent opportunity to improve farm income and productivity. Ideally suited for the small landowner with limited capital, this crop requires only 1 to 3 acres. Sweet sorghum yields 800 to 1200 L of syrup per acre, and sorghum syrup sells for Rs.1000/L. The marketing outlook for sorghum syrup is also very favorable. Almost all the sorghum syrup produced is sold within 2 months after it is processed. Sorghum syrup is generally unavailable from May to October. So, even if syrup production is increased several-fold, a ready market will be available. Sweet sorghum, or "sorgo," is closely related to other sorghum crops. It differs from grain sorghum mainly in that its grain yields are low and its stalks are taller and juicier and have a high sugar content. It reproduces by seed and produces tillers, but it has no rhizomes. It is a perennial grass under tropical conditions, but it is winter-killed in areas where frost occurs. Some sweet sorghum varieties are grown for syrup production, while others are grown for forage (silage).

Processing of Syrup

Juice Extraction

The percentage of juice extracted is an important factor in mill operation. The juice extraction rate depends upon the mill speed, the moisture content of the cane, the mill adjustment, and the feeding rate. The rollers must be adjusted to spacings close enough to produce maximum extraction. To set the mill rollers initially, evenly space the feed roller 3/8 inch from the top roller. As a general rule, juice is lost if the bagasse ("pomace" or "chews") contains visible juice and is not broken at the joints as it comes from the mill. Cane ordinarily contains more than 70 percent water and 10 to 15 percent fiber, but it is impossible to extract all the juice. With a three-roller power mill, the weight of the juice extracted should be 50 to 60 percent of the weight of the stalks, unless they are very hard and dry. Often 50 percent more juice can be obtained by "double passing" than by putting the stalks through only once. Be sure to check the mill to see how much juice it is extracting. Under normal conditions, an efficient mill will deliver 22 to 25L of juice from 250 Kg of clean stalks. Weigh 250 Kg of stalks, run them through the mill, and catch and weigh the juice. If necessary, tighten the rollers to increase the extraction of juice.

Production of natural syrup from sweet sorghum stalk juice (Small scale)

Generally, good quality syrup can be produced from sorghum genotypes with high percentage of reducing sugars and low percentage of sucrose in their juice, while high quality jaggery production requires just the opposite composition. For ethanol production the total sugar content of juice is important and not its composition. Sweet sorghum syrup production offers farmers an excellent opportunity to improve their income from sorghum crop. The marketing outlook for sorghum syrup is also very favourable, but the processing of sweet sorghum juice is the most critical aspect of making high quality syrup. The yield and quality of sorghum syrup are influenced by the equipment and process used in manufacturing and by the syrup maker's knowledge and skill.

A protocol was developed for the production of natural, chemical-free, quality syrup from the juice of sweet sorghum hybrid "Madhura". Nearly 500 kg syrup prepared from juice of hybrid "Madhura" has been test marketed mainly in Phaltan and Pune during last three years. A bottling machine has been used successfully to package the syrup so that its shelf-life is increased. The response of consumers to the coloured syrup has been very encouraging. Also the syrup is entirely chemical-free as only natural ingredients such as the aqueous extracts of okra fruits or plants are used for facilitating scum removal. The nutritional quality of syrup was also found to be excellent. When extensive screening of a large number of sweet sorghum genotypes was done, it was found that the entries RSSV-9, RSSV-24, RSSV-45, NSS-221, NSS-104 and SSV-84 gave good quality syrup. Also the hybrids developed at NARI such as Madhura, NARI-SSH-3, NARI-SSH-15, NARI-SSH-40 and NARI-SSH-21 produced good quality syrup.

Economic analysis of table syrup production from sweet sorghum hybrid "Madhura" was carried out for one hectare during one season for a processor as well as a farmer by considering all the costs of a syrup processing unit as well as raw material and transport. The study revealed that the total cost of production of table syrup from 22.5 t/ha of stripped stalks of Madhura for a farmer is about Rs. 55,000 and about Rs. 64,000 for a processor producing 2000 kg of syrup (9% recovery) in one season. If calculated on per kg basis, the cost of table syrup for a farmer and a processor would be about Rs. 27 and Rs. 31 respectively. The sensitivity analysis of costs based on variable stalk production shows that the costs of syrup production for a farmer as well as a processor could be reduced linearly with a linear increase in stalk yields of sweet sorghum. For example, for 35 t/ha of stripped stalks of sweet sorghum with 9% syrup recovery, the costs would be Rs. 18 and Rs. 6 per kg for a farmer preparing table and crude syrup respectively.

Table. 5 Chemical composition of sweet sorghum syrup compared with honey

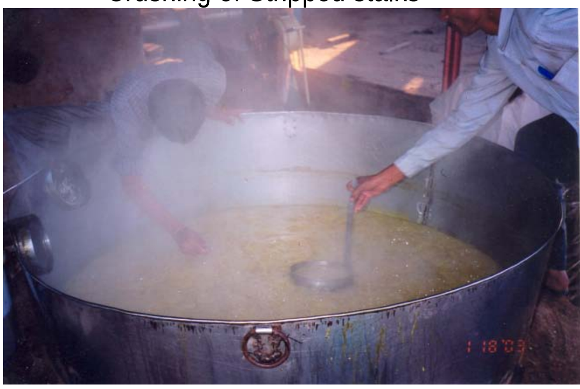
	Sweet sorghum syrup	Honey
Calorific value, Cal/g	2.60	3.26
Total soluble solids, % wt	77.00	81.00
Proteins (N X 6.25), % wt	1.65	-
Ash, % wt	3.69	0.59
	mg/100 g	
Calcium	160.00	5.00
Phosphorous	11.00	4.10

	Sweet sorghum syrup	Honey
Riboflavin (Vitamin B_2)	10.00	0.06
Vitamin C	11.50	5.00
Nicotinic acid	153.00	32.00
Iron	0.86	0.59
Sodium	86.00	4.70
Potassium	1810.00	90.00
Sulphur	Not detected	8.00
Benzoic acid	Not detected	
Added colouring matter	None	
Pesticide residues	Not detected	

Data for Honey is from literature; Analysis of sample of Madhura by CFTRI, Mysore and ITALAB Pvt. Ltd., Mumbai

Crushing of Stripped stalks

Syrup preparation



Temperature recording and scum removal

Syrup prepared

Table-1 Nutritional Information per Serving:		
Serving Size	100 g of Sorghum syrup	
% Daily Requirements		
Total Calories	290	14%
Calories from carbohydrates	290	
Total fat	0 g	0%
Trans fat	0 g	0%
Cholesterol	0 g	0%
Total carbohydrate	75 g	25%
Dietary fiber	0 g	0%
Sugars	75 g	

Sucrose		
Glucose		
Fructose		
Protein	0 g	0%
Minerals		
Calcium	150 mg	15%
Iron	3.8 mg	21%
Magnesium	100 mg	25%
Phosphorus	56 mg	6%
Potassium	1000 mg	29%
Sodium	8 mg	0%
Zinc	0.4 mg	3%
Copper	0.1 mg	6%
Manganese	1.5 mg	77%
Selenium	1.7 mg	2%
Vitamins		
Thiamine	0.1 mg	4%
Riboflavin	0.2 mg	10%
Niacin	0.1 mg	1%
Vitamin B6	0.7 mg	34%

References

Ratnavathi, C.V. 2005 Developing sorghum as an efficient biomass and bio-energy crop and providing value addition to the rain damaged kharif grain for creating industrial demand Final Report of the project NATP RNPS 24, National Agricultural Technology project, pp 40 Indian Council of Agricultural Research, New Delhi.

Ratnavathi, C.V., P.K. Biswas, M. Pallavi, M. Maheswari, B. S. Vijay Kumar and N. Seetharama, Alternative-uses of-sorghum-and-pearl-millet-in-Asia-Proceedings-of-an-expert-meeting,-ICRISAT,-Patancheru,-Andhra-Pradesh,-India,-1-4-July,-2003.2004; 188-200.

12. Sweet sorghum – Juice quality and ethanol production

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Introduction

In recent years, there is an intensive search for suitable alternative feed stock to the existing sugarcane molasses for ethanol production, which has triggered search for alternate crops due to the acute water shortages all over the country's sugarcane growing areas. Further, recent policy of the Government of India to blend 5% ethanol in petrol has prompted all sugar industries to look for alternate feed stocks for making alcohol more economically and meet the need in case of shortage of molasses. Sorghum crop is known for its efficient dry matter production among cereals. Sweet sorghum is a special type of sorghum that accumulates sugars (sucrose, glucose and fructose) in stalks, which form 70-80% of total biomass, apart from yielding considerable amount of grain. Sweet sorghum as a crop has wide adaptability, drought tolerance, and tolerant to water logging, saline alkali conditions, exhibits quick growth rate and rapid sugar accumulation. Being a C4 plant, sweet sorghum has a high photosynthetic potential producing 30-50 tons green cane along with 1.5-2.5 tons grain/ha accumulating dry matter at a rate of 50g/m2/ day.

Sweet sorghum, which is a crop close to sugarcane in respect of its sucrose accumulation and juicy nature of the stem, offers an excellent alternative feed stock apart from others such as sugarbeet. The advantage of sweet sorghum over sugarcane is that it is a four-month duration crop and can be raised through seed. The other advantage is that it can be grown with less inputs and water (maximum 2-3 irrigations) and even can be grown under rainfed conditions. The expected yield/recovery of ethanol (fuel grade) from sweet sorghum cane is 2000 –2500 litres /ha (50 litres /ton). The by-product from sweet sorghum i.e its grain can also be utilized for ethanol production as currently sorghum grain is used for potable alcohol whose recovery is upto 400 litres per ton of grain. There is a good market for potable alcohol whose price is primarily decided by the molasses price. However, grain alcohol extraction technology is different from the stalk ethanol.

Sweet sorghum varieties

In addition to fuel alcohol production, Sweet sorghum can also be used for the production of jaggery, syrup and paper depending on the sucrose content and ratio between sucrose and reducing sugars content. Sweet sorghum research was started at Directorate of sorghum research in 1988 and many varieties and hybrids are being evaluated under the All India Coordinated Sorghum Improvement Programme (AICSIP). Two varieties were released so far, SSV 84 and HES 4, the former being the national release. Recently, a variety RSSV 9 from MPKV, Rahuri and a hybrid NSSH 104 from Directorate of sorghum research, Hyderabad were recommended for release. The sugar content varies from 16-23% brix and the fermentable sugars range from 15-21%. Most of the sweet sorghum varieties mature between 115-125 days during the rainy season. Stalks can be harvested either along with grain or 4-5 weeks after the grain harvest. However, sweet sorghum varieties and hybrids bred under the national programme of AICSIP at Directorate of sorghum research have the capability to produce high biomass up to 45-50 tones/ha with juice brix between 18 and 22% and a grain yield of 1.5-2.5 tones/ha. NSS 209, NSS 216, NSS 218, NSS 219, RSSV 24, RSSV 46 and RSSV 59 are some of the promising genotypes identified from NATP breeding trial.

Findings from pilot study for ethanol production

A pilot study in collaboration with M/s Renuka Sugars in Munoli, Belgaum was conducted during 2002-03 for the production of ethanol (95%) from sweet sorghum juice. This study was first of its kind in India. Two varieties sweet sorghum (SSV 74 & SSV 84) and one hybrid (Madhura) were grown in more than 600 acres of dryland in farmer's fields. Nearly 125 hectares located in 66 villages (157 farmers) were covered with variety SSV 84. The juice brix was 18% and about 112 tones of cane were used for one fermentor of capacity 60 KL. Fermentation was carried out for 48 hrs. The recovery of ethanol was approximately 9% of the juice and bagasse obtained was 46.44% with 2.58% sugars, which was successfully used for the cogeneration (2086 calories/tons). The fermentation of sugars was slow as the left over fermentation still contained sugars that contribute to 6.4% brix.

Special fermentation strains for sweet sorghum

The Yeast strain that is commonly used in distilleries does not efficiently ferment sweet sorghum juice sugars and the complete fermentation of sugars takes 72 hours. Strains that are more effective in terms of thermal tolerance and ethanol tolerance as compared to distillers strain were isolated and identified at Directorate of sorghum research. These are the non-pathogenic strains of and *Candida tropicalis* and S*treptococcus* Sps.

Further, the quality of rectified spirit obtained from sweet sorghum is of superior quality with good flavor/odour as it is low in aldehydes and free from sulphates. The bagasse from sweet sorghum has a higher biological value than that of sugarcane when used as feed for animals with the available newer technologies and energy efficient industries.

Competitiveness of sweet sorghum versus sugarcane

The net income (at paid out costs) to the farmers from sweet sorghum cultivation accrue higher net returns (Rs.16625/ha) than sugarcane cultivation by Rs.1125/ha in the area of trials conducted by Praj industries, Pune while it is lower in sweet sorghum (Rs.16180/ha) than in sugarcane (Rs.22000/ha) in catchment area of Sagar sugars, Chittoor, which of course has to be ascertained by repeated field trials. However, interestingly the output-input ratio of sweet sorghum cultivation is higher than that of sugarcane in both the locations. In other words, the sweet sorghum cultivation yields higher returns per rupee invested and that too in a shorter period of just 4 months. The key analytical factors that contribute to sweet sorghum juice quality are mainly juice extractability, sucrose, reducing sugars content and purity of juice. In this context, juice from sweet sorghum and sugarcane are compared (Table. 2).

Sweet sorghum genotypes show wide variability in juice quality and juice extractability. Evaluation of 160 sweet sorghum genotypes for juice extractability at physiological maturity using a two-discharge roller mill indicated variability from 14% to 68%. Recovery of juice during crushing determines the relative juiciness of sweet sorghum genotypes. Total concentration of sugars was lowest until the boot stage and it reached highest at the soft dough stage. Sweet sorghum juice mainly contains sucrose, glucose and fructose. While sucrose is the predominant sugar during the whole developmental stages, it constituted only about 50% of soluble sugar at the boot stage, glucose and fructose making the remainder. Concentration of glucose was always higher than that of fructose. A study on changes of the chemical quality of juice was done in terms of its inversion at different periods of time after harvesting the cane. The parameters such as Juice brix, pH, total sugars, reducing sugars and sucrose were evaluated. Cane from NSS-104 was harvested and upto 48 hours with an interval of 6 hours samples was drawn and juice quality was determined. After 48 hours, there is 17% reduction in sucrose content. Inversion of sucrose results in higher production of aldehydes during fermentation. This is higher compared to sugar cane. The presence of high reducing sugars and invertase activity make the juice unable to produce good quality jaggery and sugar. Therefore, sweet sorghum juice is only suitable for ethanol and syrup production.

Table. 2 Comparison of the juice of sweet sorghum and sugarcane

S No.	Character	Sweet Sorghum	Sugar Cane
1.	Appearance	Juice is thick and turbid.	Juice is clear and transparent.
2.	Contents	High starch & chlorophyll	Has no starch.
3.	Density	High	Low almost equal to water.
4.	Sugars	Sucrose and high amount of reducing sugar (2-4%).	Contains more sucrose and less reducing sugar (0.5 to 1.0 %).
5.	Invertase activity	High invertase.	No Invertase.
6.	Time of sugar accumulation	Starts after flowering.	Sucrose accumulates at early stage.
7.	Purity of juice	70-90%.	90-98%.

Apart from net returns, other issues do not straight away qualify sweet sorghum to compete with sugarcane molasses rather to complement with the latter from industry point of view The sugarcane industry is active for six months in a year and it is proposed that the existing machinery and operating system can optimally be used for sweet sorghum in the lean period of sugarcane crushing season, thereby generating employment and increased capacity utilization of sugar industries. Sweet sorghum can be grown successfully in June and February planting for maximum green cane yield and sugar content to ideally suit the lean periods of sugarcane. Sugarcane is a long duration crop and highly demanding in terms of water and it can be grown only some areas with assured irrigation. In contrast sweet sorghum is highly adapted to a variety of growing environments.

Options available for entrepreneurs

While majority of the distilleries approached us are in favor of undertaking whole process from contact farming to ethanol marketing by them selves, few entrepreneurs expressed their interest in manufacturing intermediate product such as crude syrup concentrate from sweet sorghum juice using the available boilers which is equivalent to sugarcane molasses and selling to distilleries for ethanol preparation. The other possibility is hiring the closed down distilleries and other infra structure, machinery to manufacture rectified spirit (95% ethanol) and market to the user industries that make fuel ethanol (100%).

Seed production and distribution

In the wake of high enthusiasm shown by sugar industries Directorate of Sorghum Research Rajendranagar, Hyderabad made attempts to produce breeders seed of sweet sorghum variety SSV 84. The crop was raised in four hectares at Hyderabad during *rabi* 2003-04 producing about 13.5 tons seed. The seed was distributed to different sugar industries in Andhra Pradesh, Tamil Nadu, Maharashtra, Karnataka and Orissa. Apart from this, Directorate of sorghum research is continuously producing seed of CSV19SS, SSV 84 and CSH 22SS.

13. Prospects for sorghum biofortification

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Malnutrition - the silent epidemic

Malnutrition is not defined as a lack of food, but rather the right kind of food. Globally malnutrition is responsible for more deaths than any other cause, accounting for >20 million mortalities annually (Kennedy *et al*., 2003). Micronutrient malnutrition, often known as hidden hunger, primarily the result of diets poor in bio-available vitamins and minerals, causes blindness and anaemia (even death); afflicts more than one-half of the developing world's population or more than 2 billion people, especially the women and preschool children (Bouis, 2002; Welch and Graham, 2004). The poor people living in the arid and semi-arid tropics suffer from deficiencies of calories and micronutrients as they cannot afford a variety of food items in their diet. The main objective of breeding in staple food crops remained productivity enhancement and increased profitability to farmers and agricultural industries till recently, and nutritional improvement of the agricultural produce was never given due consideration, especially in developing countries, though the primary source of all nutrients for people comes from agricultural products. Of late micronutrient malnutrition is increasingly being recognized as a serious food-related health problem world-wide.

Three of the most widespread micronutrient deficiencies are that of iron, zinc and vitamin A. Iron is a redox-active constituent of the catalytic site of heme and non-heme iron proteins. Iron deficiency affects nearly 3.7 billion people (Welch, 2002). Iron deficiency adversely affects cognitive development, resistance to infection, work capacity, productivity and pregnancy, and about half of the anaemia cases can be attributed to it. Zinc is involved in RNA and DNA synthesis, and is a constituent of many zinc-containing enzymes critical to cellular growth and differentiation. An estimated 49% of the human population is at risk for inadequate zinc in their diet (Brown *et al.*, 2001). Zinc deficiency leads to impaired growth, immune dysfunction, increased morbidity and mortality, adverse pregnancy outcomes, and abnormal neuro-behavioural development. Vitamin A is a group of fat soluble nutritionally unsaturated hydrocarbons, which include retinol, retinal, retinoic acid, and several pro-vitamin A carotenoids. Preformed vitamin A is found in animal products such as meat, fish, poultry and dairy foods, while pro-vitamin A is found in plant-based foods such as fruits and vegetables, the most common is beta-carotene. It is important for growth and development, for the maintenance of the immune system and good vision – both low-light and colour. Vitamin A also helps in skin and cellular health, and maintenance of teeth, skeletal and soft tissues and mucus membranes. Vitamin A deficiency is the leading cause of preventable blindness in children leading to blindness in 2.5-5 lakh children each year and increases the risk of disease and death from severe infections (http://www.who.int/nutrition/topics/vad/en/).

Biofortification - a powerful intervention tool

Many agricultural tools (e.g., diversification, cropping systems, fertilizers and soil amendments, small livestock production, aquaculture, etc.) could be used to increase the nutrient output of farming systems (Graham *et al.*, 2007). Food fortification and diet supplementation with micronutrients can directly facilitate easing of micronutrient malnutrition to some extent. But, these interventions require infrastructure, sophisticated processing techniques and product control, purchasing power, or access to markets and health care systems for their success. Hence, new approaches are needed to address the persistent problem of micronutrient malnutrition in a sustained manner, especially to reach the poor population in the remote rural areas. The development of micronutrient-dense staple crop cultivars using the best traditional breeding practices and modern biotechnology or in other words 'Biofortification' is a powerful intervention tool in this regard.

Biofortification provides a comparatively cost-effective, sustainable, and long-term means of delivering more micronutrients to people with poor access to markets or health care systems. Consumption of micronutrient-enriched staple plant foods, can significantly improve the nutrient status in the target populations. Biofortification is a scientific method for improving the nutritional value of foods already consumed by those suffering from hidden hunger (Bouis *et al.*, 2011). Biofortified cultivars can be obtained through conventional breeding when sufficient genetic variability for micronutrients is present in the target crop or by exploiting transgressive segregation or heterosis. In the absence of such variability genetic engineering tools have to be explored.

Advantages: (i) Biofortification capitalizes on the regular daily intake of a consistent and large amount of food staples and hence, implicitly targets low-income households where staple foods form major part of the diet. (ii) After the one-time investment to develop seeds that fortify themselves, recurrent costs are low, and the varieties can be shared internationally and thus making it cost-effective. (iii) Nutritionally improved varieties will continue to be grown and consumed year after year, making the system highly sustainable, even if government policies change or funding weakens. (iv) It provides a feasible means of reaching undernourished populations in relatively remote rural areas, where access to commercially marketed fortified foods is limited. (v) Biofortification may have important spinoff effects for increasing farm productivity in developing countries in an environmentally beneficial way. Seeds rich in minerals would produce more viable and vigorous seedlings, and higher plant stand in less fertile soils resulting in enhanced crop yields (Nestel *et al*., 2006). Moreover, these trace minerals may also help plants to resist diseases and other environmental stresses.

Criteria: Before developing and distributing micronutrient-dense staple food crops certain criteria have to be met, which will ensure that the benefits of biofortification reach the target people. The criteria include: (i) The crop productivity must be maintained or enhanced to guarantee widespread farmer acceptance. (ii) The micronutrient enrichment levels must have significant impact on human health. (iii) The micronutrient enrichment levels must be relatively stable across various growing environments and climatic zones. (iv) Bioavailability of micronutrients in enriched lines must be tested in humans to ensure that they improve the micronutrient status of people preparing and eating them in traditional ways within normal household environments. (v) Consumer acceptance (taste and cooking quality) has to be tested to ensure maximum impact.
Three primary issues have been identified that are required to make biofortification successful (Bouis and Welch, 2010): (i) A biofortified crop must be high yielding and profitable to the farmer. (ii) The biofortified crop must be shown to be efficacious and effective at reducing micronutrient malnutrition in humans. (iii) The biofortified crop must be acceptable to both farmers and consumers in target regions where people are afflicted with micronutrient malnutrition.

Breeding for micronutrient enrichment: The basic steps include: (i) Identification of genetic variability within the range that can influence human nutrition. (ii) Introgressing this variation into high yielding, stress tolerant genotypes possessing acceptable end-use quality attributes. (iii) Testing the stability of micronutrient accumulation across the target environment. (iv) Large-scale deployment of seed of improved cultivars to farmers. The biofortification programme requires that agricultural researchers make direct linkages with various specialists like nutritionists, public health officials, sociologists, political scientists, food technologists and economists, thus requiring a multidisciplinary research approach.

HarvestPlus

HarvestPlus, a global alliance of research institutions and implementing agencies, is the Biofortification Challenge programme of the Consultative Group on International Agricultural Research (CGIAR), which seeks to reduce micronutrient malnutrition among the poor by breeding staple food crops that are rich in micronutrients (http://www.harvestplus.org). It is coordinated by the International Centre for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI). It is directed at using plant breeding as an intervention strategy to address micronutrient malnutrition by producing staple food crops with enhanced levels of bioavailable essential minerals and vitamins that will have measurable impact on improving the micronutrient status of target populations. This programme has been able to assemble a multi-CGIAR Centres team along with collaborators from Universities, NGOs and International Institutions comprising scientists from plant breeding, food science, nutrition, economics and sociology to tackle the problem of micronutrient malnutrition (Bouis and Welch, 2010). HarvestPlus's strategy for biofortification involves three phases – discovery, development and dissemination (Fig. 1).

In the first phase of HarvestPlus (2004-2007) the target crops were rice, wheat, maize, common bean, cassava and sweet potato that are consumed by the majority of the world's poor in Africa, Asia and Latin America. Good genetic variability for iron and zinc contents in the target crops has been reported (discovery phase). Where sufficient variability for desired trait is not available, genetic engineering and genomics tools are being explored. In 2008, HarvestPlus received one-year funding from the Bill and Melinda Gates Foundation to bridge from Phase I to Phase II. The Phase II (2009-2013) is aimed at specific biofortified crop variety development for target countries and populations, and breeding feasibility and germplasm discovery studies for 10 additional staples, namely banana/plantain, barley, cowpea, groundnut, lentil, pearl millet, pigeon pea, potato, sorghum and yams. Impressive progress has been made at meeting the goals of the HarvestPlus programme since its inception in 2003. The high micronutrient content discovered in the germplasm (donors) is being introgressed to adapted high yielding background in many of the target crops in several institutions world-wide. The Bill and Melinda Gates Foundation funded Grand Challenges 9 is developing several transgenic crops. More than 25 countries primarily in Asia and Africa are expected to benefit from spillover effects following initial release of biofortified crop cultivars in target countries. A summary of biofortified target crops and country-wise release schedule is given in Table 1. HarvestPlus III (2014-2018) will demonstrate the viability of biofortification as a global solution and lay foundation to scale up delivery in target countries and expand delivery to new countries, strengthen the pipeline of biofortified varieties, and research, communicate and advocate strategically.

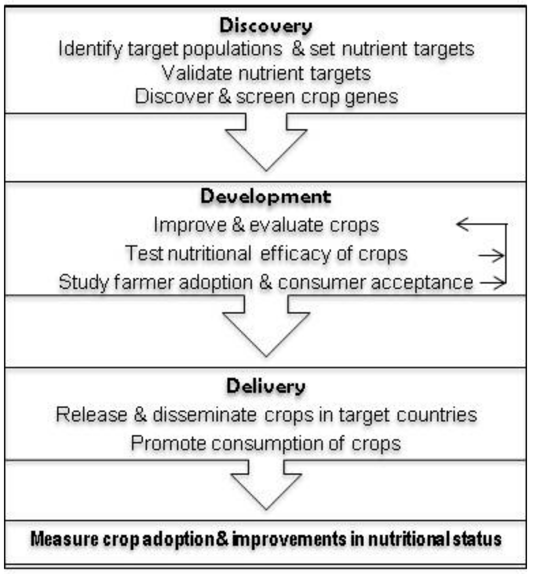

Figure 1. The Biofortification process

Success stories

As a first product of HarvestPlus efforts, vitamin A-rich orange fleshed sweet potato (OSP) was released in 2007 in Mozambique and Uganda. Under Reaching End Users project (REU) OSP was released to 24,000 households in these two countries. As of now 68% of households in

Mozambique have adopted the orange varieties, and 61% have adopted OSP in Uganda. The intake of OSP among children and women increased by two-thirds or more in both countries when OSP was available, leading to a significant rise in vitamin A intake. Notably, for children aged 6-35 months, OSP contributed 78% of their total vitamin A intake in Mozambique and 53% in Uganda. Since the first release seven years back, more than 1.5 million farming families have adopted OSP and other nutrition-smart crops. Policy makers from around the world met in Kigali during April 2014 and made a commitment to scale up these types of nutritious food. By forging new partnerships across sectors, HarvestPlus and its partners aim to reach more than 100 million people with such nutrition-smart crops by 2018 (Bouis, 2014).

Table 1. Biofortified target crops and country-wise release schedule (Saltzman *et al*., 2013)

Crop	Nutrient	Target country	Lead institutions	Release year
Banana/ Plantain	Provit. A	Nigeria, Ivory Coast, Cameroon, Burundi, DR Congo	IITA, Bioversity	Unknown
	Provit. A, Iron*	Uganda	Queensland University of Technology, NARO	2019
Bean	Iron (Zinc)	Rwanda, DR Congo	CIAT, RAB, INERA	2012
		Brazil	Embrapa	2008
Cassava	Provit. A	DR Congo	IITA, CIAT, INERA	2008
		Nigeria	IITA, CIAT, NRCRI	2011
		Brazil	Embrapa	2009
	Provit. A, Iron*	Nigeria, Kenya	Donald Danforth Plant Science Center	2017
Cowpea	Iron, Zinc	India	G.B. Pant University	2008
		Brazil	Embrapa	2008
Irish potato	Iron	Rwanda, Ethiopia	CIP	Unknown
Lentil	Iron, Zinc	Nepal, Bangladesh, Ethiopia, India, Syria	ICARDA	2012
Maize	Provit. A	Zambia	CIMMYT, IITA, ZARI	2012
		Nigeria	CIMMYT, IITA, IAR&T	2012
		Brazil	Embrapa	2013
		China	Institute of Crop Science, YAAS	2015
		India	DBT	Unknown
Pearl millet	Iron (Zinc)	India	ICRISAT	2012
Pumpkin	Provit. A	Brazil	Embrapa	2015
Rice	Zinc (Iron)	Bangladesh, India	IRRI, BRRI	2013
		Brazil	Embrapa	2014
	Provit. A*	Philippines, Bangladesh, Indonesia, India	Golden Rice Network, IRRI	2013
	Iron*	Bangladesh, India	University of Melbourne, IRRI	2022
	Iron	China	Institute of Crop Science, CAAS	2010
Sorghum	Zinc, Iron	India	ICRISAT	2015
	Provit. A*	Kenya, Burkina Faso, Nigeria	Africa Harvest, Pioneer Hi-Bred	2018
Sweet potato	Provit. A	Uganda	CIP, NaCCRI	2007
		Mozambique	CIP	2002
		Brazil	Embrapa	2009
		China	Institute of Sweet Potato, CAAS	2010
Wheat	Zinc (Iron)	India, Pakistan	CIMMYT	2013
		China	Institute of Crop Science, CAAS	2011
		Brazil	Embrapa	2016

* Denotes transgenic variety; ( ) Denotes secondary nutrient

n 2011, three varieties of conventionally bred vitamin A-rich cassava were released in Nigeria with the goal of reaching 50,000 farming households by 2013. These cassava cultivars that are naturally rich in pro-vitamin A were identified by the International Centre for Tropical Agriculture in Columbia (CIAT). New cultivars with a total carotenoid content range of 100–10,000 mg/100 g in fresh cassava have been developed by selective breeding of cassava with high-carotene germplasm by CIAT and the International Institute of Tropical Agriculture (IITA) in Nigeria (Chavez *et al*., 2005). These cultivars were introduced in Kenya for an efficacy trial conducted in 2012 among school aged children (Talsma *et al*., 2009). Caretakers and children perceived a significant difference in taste between white and pro-vitamin A-rich cassava. Both preferred pro-vitamin A-rich cassava over white cassava because of its soft texture, sweet taste and attractive colour (Talsma *et al*., 2013). It was found that the yellow color of pro-vitamin A-rich cassava is no barrier for consumption in the target population. In 2014, a new set of vitamin A cassava varieties were released that can provide up to 40% of the vitamin A recommended daily allowance for children under five. They are 25% richer in beta-carotene than the first set of vitamin A cassava varieties released in 2011 and which are now being grown by over 250,000 Nigerian farmers. The newer improved varieties are expected to gradually replace the earlier ones. HarvestPlus and partners expect to reach more than 350,000 Nigerian households with vitamin A cassava in 2014 alone through an innovative e-market system. The system involves commercial multiplication and sale of the varieties by medium-scale farmers and a farmer-to-farmer dissemination arrangement that ensures poor farmers receive stems freely.

In 2012, five conventionally bred iron-rich bean varieties, bred by the Rwanda Agriculture Board and the International Center for Tropical Agriculture (CIAT), were released in Rwanda to reach more than 200,000 farming households by the end of 2013. In the same year two conventionally bred vitamin A maize varieties were released in Nigeria and three in Zambia (to reach up to 25,000 Zambian farming households by the end of 2013. Field tests found that these new varieties yield three to four times more than local varieties. HarvestPlus research shows that consumers like orange maize as much as white maize, and they are able to distinguish the orange maize from the more stigmatised yellow maize, commonly associated with food aid. Three nutrition feeding trials are either underway or in preparation, to test the efficacy of orange maize on public health.

Since 2012, conventionally bred iron pearl millet was commercialized and sold to farmers in India. The high-iron pearl millet variety ICTP 8203Fe developed by ICRISAT was released as 'Dhanshakti' in Maharashtra during April 2013. Dhanshakti is the first mineral biofortified crop cultivar to be officially released and reaching farmers' fields in India. In the field trials conducted during 2010 and 2011, ICTP 8203Fe had 71 ppm of iron density. Based on its superior performance, Nirmal Seeds company produced and marketed truthfully labeled seed of ICTP 8203Fe to reach 25,000 households in Maharashtra in 2012. Test marketing of five zinc wheat 'Zinc Shakti Sai' through 1000 mini-kits in 2013-14 was also tried in India. The agencies involved are DWR, Karnal; IARI, New Delhi; PAU, Ludhiana and BHU, Varanasi.

Since 2013, the first high yielding rice varieties in Bangladesh that are rich in zinc have been made available to farmers. Over time more productive, more climate-smart and more nutrition-smart varieties will be released regularly. In the case of zinc rice there will soon be varieties which can provide up to 80% of an adult women's or child's daily zinc needs, 35% more than ordinary rice varieties.

The world's first human trial of pro-vitamin A-enriched banana with orange coloured flesh, expected to lift the health and well-being of millions of Ugandans and other East Africans will start very soon. The bananas have been harvested from the Queensland University of Technology field trial in Innisfail, north Queensland and transported to the United States for the world-first human trial. The human trial will last for six weeks with conclusive results known by the end of the year.

Indian scenario

The malnourishment, especially deficiency of micronutrients has been a persistent problem with alarmingly high deficit among children, adolescents, and pregnant and lactating women (Singh, 2007). Most recent surveys show that 40-50% preschool children and over 30% adults show anthropometric evidence of undernutrition. The intake of micronutrients in daily diet is less than 50% RDA in over 70% of Indian population (NIN, 2002). Deficiency of micronutrients is rampant. The loss due to micronutrient deficiency costs India 1% of its GDP, which amounts to a loss of about Rs. 27,720 crores per annum in terms of productivity, illness, increased health care costs and death (Kotecha, 2008). About 57% of preschoolers and their mothers have subclinical vitamin A deficiency. Iron deficiency anaemia (IDA) is the most serious public health problem (NFHS, 2011). Estimates of IDA in women and children have varied from 50-70%; pregnant women being particularly susceptible. The Micronutrient Initiative (http://www.micronutrient.org) reports that 62% of pre-school children are deficient in vitamin A, leading to an annual 330,000 child deaths; and 58.7% of pregnant women, 63.2% lactating mothers and 69.5% of pre-school children are anaemic. The prevalence of zinc deficiency has not been adequately investigated, partly due to lack of suitable biomarkers.

The two most cost-effective approaches to alleviate micronutrient malnutrition would be dietary diversification and crop biofortification. In the year 2004, Department of Biotechnology (DBT) has initiated the India Biofortification Programme to develop and disseminate varieties of rice, wheat and maize biofortified with iron, zinc and pro-vitamin A. In March 2007, HarvestPlus signed an MoU with DBT; and in August 2010, Indian Council of Agricultural Research (ICAR), DBT and HarvestPlus signed agreement of cooperation to achieve high-quality research on developing and disseminating biofortified varieties in India. The India Biofortification Programme focuses on three projects: biofortification of wheat for micronutrients through conventional and molecular breeding; rice biofortification with enhanced iron and zinc in high yielding non-basmati cultivars through marker assisted breeding and transgenic approaches; and development of micronutrient enriched maize through molecular breeding. During 2005-06, a programme on nutrition biofortification - incorporation of quality traits like essential amino acids, mono unsaturated fatty acids, iron and zinc in staple food crops was initiated. Work on the structural and functional genomics of tomato, and functional genomics of rice, sugarcane and shrimp was also initiated.

The DBT has funded projects on biofortification of groundnut and pigeon pea for alleviating vitamin A, and sorghum biofortification for high grain iron and zinc content during 11th Plan period. HarvestPlus is a collaborator in the development of some of these crops and also focuses on biofortified pearl millet in collaboration with ICRISAT.

Prospects for sorghum biofortification

Sorghum is the dietary staple of more than 500 million people over 30 countries in Africa and Asia. In India, sorghum is the fourth most important cereal consumed. Unlike other cereals sorghum is mostly consumed in the regions in which it is cultivated. Sorghum is the staple of central and western regions of Maharashtra and the northern regions of Karnataka and Andhra Pradesh. Though over India as a whole the consumption of sorghum has declined both in rural and urban areas, in inland regions of Central, Eastern and Western Maharashtra and Northern Karnataka sorghum is still an important crop with annual per capita consumption in rural areas ranging from 31.8 to 54.2 kg and in urban areas from 9.9 to 34.0 kg (Basavaraj and Parthasarathy Rao, 2012). Maharashtra (47%) and Karnataka (20%) grow a large proportion of sorghum compared to Andhra Pradesh (9%) and other states. In terms of nutrient intake, sorghum accounts for about 35% of the total intake of calories, protein, iron and zinc in the dominant production/consumption areas

(Parthasarathy Rao *et al*., 2006). Sorghum is a cheap source of energy, protein, iron and zinc next only to pearl millet among all cereals and pulses. The intake of iron and zinc appears to be below the recommended dietary allowance (RDA), particularly in low-income rural households in sorghum consuming regions. Targeting micronutrient-dense sorghum cultivars to these regions would help in alleviating micronutrient malnutrition. Biofortification of sorghum by increasing iron and zinc contents in grain is of widespread interest (Pfeiffer and McClafferty, 2007; Zhao, 2008; Ashok Kumar *et al*., 2009, 2013; Hariprasanna *et al*., 2012, 2014).

Sorghum grain has a nutritional profile better than that of rice, the chief staple food of majority, but the bioavailability of iron and zinc in sorghum is poor compared to other cereals and pulses. Levels of tannin, phytate, fibre, etc. determines the bioaccessibility of grain iron (4.13 ± 0.33%) and zinc (5.51 ± 0.32%), which is very low in sorghum compared to rice (8.05 and 21.4%, respectively), maize (7.83 and 7.82%, respectively) or wheat (5.06 and 8.93%, respectively) (Hemalatha *et al*., 2007). Reports from NIN, Hyderabad indicate that sorghum is superior to rice for contents of protein, minerals and iron, while the values are on a par or marginally better than that of wheat. Sorghum has only limited information base and research related to biofortification.

Preliminary studies at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) have indicated limited variability for grain iron and zinc contents (Reddy *et al*., 2005) in sorghum hybrid parents, advanced breeding lines and germplasm accessions. Later on, large genetic variability for grain iron and zinc concentrations has been reported in sorghum (Ashok Kumar *et al*., 2009 & 2012a, Sanjana Reddy *et al*., 2010). Over the years ICRISAT has evaluated a large number of landraces (2246), hybrid parents (>500 B-lines and 100 R-lines), breeding lines and commercial sorghum cultivars (67) for assessing grain iron and zinc concentrations and important agronomic traits, and the vast variability observed has been put on public domain in the form of a database (Ashok Kumar *et al*., 2012a). Characterization of popular Indian cultivars, hybrid parents, elite breeding lines and some selected germplasm accessions collected from the major sorghum growing states indicated sufficient variability for grain iron (12-83 mg/kg) and zinc (6-51 mg/kg) contents as well as high heritability (Hariprasanna *et al*., 2014). Based on the grain iron and zinc concentrations observed in the commercial cultivars and ICRISAT bred parental lines, the base level estimated is 30 mg/kg for iron and 20 mg/kg for zinc. Considering the level of sorghum consumption, nutrient retention in grain storage, milling and food preparation and nutrient bioavailability, HarvestPlus suggested a target of 70 mg/kg for iron and 40 mg/kg for zinc in sorghum (Ashok Kumar, personal communication). However, based on the extent of genetic variability observed among landraces, the target level for genetic enhancement has been put at 60 mg/kg for grain iron and 32 mg/kg for zinc at ICRISAT. The landraces identified can be used in the crossing programmes as donors for grain iron and zinc to develop improved varieties and hybrid parents.

Significant and positive association between the grain iron and zinc concentrations have been reported in most of the material studied at ICRISAT (Reddy *et al*., 2006; Ashok Kumar *et al.*, 2009, 2010 & 2012b; Sanjana Reddy *et al.*, 2010). At DSR also the grain iron and zinc contents were found to be significantly and positively correlated (0.2 – 0.5, $p < 0.05$) among the cultivars and parental lines, breeding lines and germplasm accessions, but not in some of the elite low-amylose lines. Close association between iron and zinc indicate that genetic control of iron and zinc content are linked, or physiological mechanisms for uptake or accumulation of iron and zinc in the grains are interconnected. Significant positive association between grain iron and zinc can result in simultaneous genetic improvement for both the micronutrients.

Limited studies have also been conducted to determine whether grain micronutrient status can be improved by external application of iron and zinc fertilizers (agronomic management), either as soil or foliar application or in other words possibility of ferti-fortification as reported in other crops like wheat and rice. The results suggest that soil type or micronutrient application have only a limited influence on sorghum grain iron and zinc concentrations when the soils are not deficient in these minerals (Reddy *et al*., 2007; Ashok Kumar *et al*., 2011). Experiments at DSR also revealed the same trend with no statistically significant difference in grain iron and zinc status due to external application of iron ($FeSO_4$) and zinc ($ZnSO_4$) fertilizers compared to control in any of the cultivars. However, mean iron content in the grains was higher in combined application of $FeSO_4$+$ZnSO_4$ compared to individual treatments. Significant cultivar × year (Ashok Kumar *et al*., 2010) or genotype × environment (G × E) (Hariprasanna *et al*., 2012) interactions have been reported for both grain iron and zinc content. As sorghum is grown in varied soil types with varying levels of fertility and nutrient management, it would be worthwhile to assess the stability of grain micronutrients through multi-location as well as multi-season evaluation for biofortification.

A unique biofortified sorghum hybrid, 3204, has been launched by Hytech Seed Company in the early July 2014. It is a dual season (*kharif* and late *rabi*) and dual purpose (grain and dry fodder) tall hybrid with bold shiny white grain. The iron and zinc in 3204 are one-and-half-times higher than common sorghum grain. The iron content in 3204 is 46 mg/kg grain compared to 30 mg/kg of common sorghum. Similarly 3204 contains 29 mg/kg zinc compared to 20 mg/kg in common type. With funding support from HarvestPlus, ICRISAT is working on increasing grain iron and zinc concentration in sorghum to reach the revised targets of 60 ppm iron and 32 ppm zinc. Among the different hybrids being evaluated, five hybrids ICSH 14001 (Fe 49 ppm and Zn 38 ppm), ICSH 14002 (Fe 46 ppm and Zn 32 ppm), ICSA 661 × ICSR 196 (Fe 45 ppm and Zn 36 ppm), ICSA 318 × ICSR 94 (Fe 45 ppm and Zn 34 ppm), ICSA 336 × IS 3760 (Fe 45 ppm and Zn 40 ppm), and a R line/variety ICSR 14001 (Fe 42 ppm and Zn 35 ppm) are promising and meeting the current breeding targets for grain zinc (ICRISAT, 2014).

To conclude, biofortification in sorghum appears to be a feasible strategy to alleviate the micronutrient malnutrition among the rural poor considering the high prevalence of micronutrient deficiency and significant intake of sorghum in the major consumption regions in India. The availability of high variability for grain micronutrient contents holds promise to develop superior varieties with enhanced nutritional quality. Once suitable donor parents for high iron and zinc content are identified, they can be utilized in breeding programmes to combine agronomic superiority and high micronutrient content in the grains. Proper understanding of micronutrient accumulation in the grains, genetic control and identification of genotypes that accumulate high iron and zinc contents irrespective of growing conditions will pave the way for development of micronutrient rich sorghum varieties. Wide adoption of such biofortified varieties and consumption by the target population will gradually ease the micronutrient malnourishment. Inclusion of sorghum in the Public Distribution System (PDS) in the target regions can also encourage the consumption by the poor people leading to better health status.

Suggested readings:

Ashok Kumar A, Anuradha K and Ramaiah B. 2013. Increasing grain Fe and Zn concentration in sorghum: progress and way forward. Journal of SAT Agricultural Research 11: 1-5.

Ashok Kumar A, Reddy BVS and Ramaiah B. 2012a. Fe and Zn concentrations in sorghum - datasets, http://hdl.handle.net/11038/10081, International Crops Research Institute for the Semi-Arid Tropics [Distributor] V6 [Version].

Ashok Kumar A, Reddy BVS, Ramaiah B, Reddy PS, Sahrawat KL and Upadhyaya HD. 2009. Genetic variability and plant character association of grain Fe and Zn in selected core collection accessions of sorghum germplasm and breeding lines. Journal of SAT Agricultural Research, 7: 1-4.

Ashok Kumar A, Reddy BVS, Ramaiah B, Sahrawat KL and Pfeiffer WH. 2012b. Genetic variability and character association for grain iron and zinc contents in sorghum germplasm accessions and commercial cultivars. The European Journal of Plant Science and Biotechnology 6 (Special Issue 1): 66-70.

Ashok Kumar A, Reddy BVS, Ramaiah B, Sahrawat KL and Pfeiffer WH. 2011. Options for Enhancing Grain Iron and Zinc Concentrations in Sorghum. Proc. Oral Presentations, 3rd International Zinc Symposium, Hyderabad, 10-14 Oct. 2011.

Ashok Kumar A, Reddy BVS, Sahrawat KL and Ramaiah B. 2010. Combating micronutrient malnutrition: Identification of commercial sorghum cultivars with high grain iron and zinc. Journal of SAT Agricultural Research, 8: 1-5.

Basavaraj G and Parthasarathy Rao P. 2012. Regional analysis of household consumption of sorghum in major sorghum-producing and sorghum-consuming states in India. Food Security 4: 209-217

Bouis H. 2014. Why nutrition-smart agriculture matters (https://www.devex.com/news/why-nutrition-smart-agriculture-matters-84050)

Bouis HE and Welch RM. 2010. Biofortification-A sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. Crop Science 50:S-20–S-32.

Bouis HE, Hotz C, McClafferty B, Meenakshi JV and Pfeiffer WH. 2011. "Biofortification: A New Tool to Reduce Micronutrient Malnutrition." Supplement, Food and Nutrition Bulletin 32: 31S-40S.

Bouis HE. 2002. Plant Breeding: a New Tool for Fighting Micronutrient Malnutrition. Journal of Nutrition 132: 491S-494S.

Brown KH, Wuehler SE and Peerson JM. 2001. The importance of zinc in human nutrition and estimation of the global prevalence of zinc deficiency. Food and Nutrition Bulletin 22:113-125.

Chavez AL, Sanchez T, Jaramillo G, Bedoya JM, Echeverry J, et al. 2005. Variation of quality traits in cassava roots evaluated in landraces and improved clones. Euphytica 143: 125–133. doi: 10.1007/s10681-005-3057-2.

Graham RD, Welch RM, Saunders DA, Monasterio I, Bouis HE, Bonierbale M, de Hann S, Burgos G, Thiele G, Liria R, Meisner CA, Beebe SE, Potts MJ, Kadiajn M, Hobbs PR, Gupta RK and Twomlow S. 2007. Nutritious subsistence food systems. Advances in Agronomy 92:1-74.

Hariprasanna K, Agte V, Elangovan M and Patil JV. 2014. Genetic variability for grain iron and zinc content in cultivars, breeding lines and selected germplasm accessions of sorghum [*Sorghum bicolor* (L.) Moench]. Indian J. Genet., 74: 42-49.

Hariprasanna K, Agte V, Prabhakar and Patil JV. 2012. Genotype × environment interactions for grain micronutrient contents in sorghum [*Sorghum bicolor* (L.) Moench]. Indian Journal of Genetics and Plant Breeding 72: 429-434.

Hemalatha S, Platel K and Srinivasan K. 2007. Zinc and iron contents and their bioaccessibility in cereals and pulses consumed in India. Food Chemistry 102: 1328-1336.

ICRISAT. 2014. Progress of sorghum biofortification research at ICRISAT reviewed. In: ICRISAT Happenings, In-house Newsletter, No. 1614. www.icrisat.org/newsroom/latest-news/happenings/happenings1614.htm

Kennedy G, Nantel G and Shetty P. 2003. The scourge of "hidden hunger": Global dimensions of micronnutrient deficiencies. Food, Nutrition and Agriculture, FAO. 32:8-16. (ftp://ftp.fao.org/docrep/fao/005/y8346m/y8346m01.pdf)

Kotecha PV. 2008. Micronutrient malnutrition in India: Let us say "no" to it now. Indian Journal of Community Medicine 33:9-10

Nestel P, Bouis HE, Meenakshi JV and Pfeiffer W. 2006. Biofortification of Staple Food Crops. Journal of Nutrition 136: 1064-1067.

NFHS. 2011. National Family Health Survey (NFHS-3). International Institute of population Sciences, Mumbai, India, 2005-2006; Jan.2011, 96 (1).

NIN. 2002. National Nutrition Monitoring Bureau, NIN, Hyderabad.

Parthasarathy Rao P, Birthal PS, Reddy BVS, Rai KN and Ramesh S. 2006. Diagnostics of Sorghum and Pearl Millet Grains-based Nutrition in India. International Sorghum and Millets Newsletter 47: 93-96

Pfeiffer WH and McClafferty B. 2007. HarvestPlus: Breeding crops for better nutrition. Crop Science 47: S88–S105.

Reddy BV S, Ramesh S, Longvah T, Elangovan M and Upadhyaya HD. 2006. Prospects of breeding Fe, Zn and b-carotene-dense sorghums. *In*: Book of Poster Abstracts, International Plant Breeding Symposium, Mexico City, 20-25 Aug., 2006. p. 75.

Reddy BVS, Ramesh S and Longvah T. 2005. Prospects of breeding for micronutrients and b-carotene-dense sorghums. International Sorghum and Millets Newsletter 46: 10-14.

Reddy BVS, Ramesh S, Sanjana Reddy P and Sahrawat K. 2007. Effect of Soil Micronutrient Fertilization on Sorghum Grain Fe and Zn Contents. Proc. Zinc Crops 2007- Conference on Improving Crop Production and Human Health, Istanbul, Turkey, 24-26 May 2007

Saltzman A, Birol E, Bouis HE, Boy E, De Moura FF, Islam Y, Pfeiffer WH. 2013. Biofortification: Progress toward a more nourishing future. Global Food Security 2: 9-17

Sanjana Reddy P, Reddy BVS, Ashok Kumar A, Ramesh S, Sahrawat KL and Rao PV. 2010. Association of grain Fe and Zn contents with agronomic traits in sorghum. Indian Journal of Plant Genetic Resources 23: 280-284.

Singh P. 2007. Micronutrient deficiency in India. Journal of Indian Society of Agricultural Statistics 61: 128-131.

Talsma EF, Melse-Boonstra A, de Kok BPH, Mbera GNK, Mwangi AM, et al. 2013. Biofortified Cassava with Pro-Vitamin A Is Sensory and Culturally Acceptable for Consumption by Primary School Children in Kenya. PLoS ONE 8(8): e73433. doi:10.1371/journal.pone.0073433.

Talsma EF, Mwangi AM, Mburu-de Wagt A, Brouwer I, Melse A, et al. 2009. Yellow cassava and vitamin A status in Kenyan school children: proposed investigation design. Annals of Nutrition and Metabolism 55: 378–378.

Welch RM and Graham RD. 2004. Breeding for micronutrients in staple food crops from a human nutrition perspective. Journal of Experimental Botany, 55: 353-364.

Welch RM. 2002. The impact of mineral nutrients in food crops on global human health. Plant and Soil 247: 83-90.

Zhao Z. 2008. The Africa biofortified sorghum project–Applying biotechnology to develop nutritionally improved sorghum for Africa. Pages 273–277 *in* Biotechnology and sustainable agriculture 2006 and beyond. Proceedings of the 11th IAPTC&B Congress, Aug 31–18, 2006, Beijing, China (Xu Z, Li J, Xue J and Yang W, eds.). The Netherlands: Springer.

14. Current status of sweet sorghum biofuel industrial experiences for pilot–production of bioethnol

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Rationale for producing biofuel from sweet sorghum: India's growing dependence on petroleum imports and concomitant vulnerability to external price shocks lead to economic setbacks, and trade imbalance. The Government of India mandate blending of ethanol (10%) with gasoline has necessitated the searching alternative feedstocks other than sugarcane molasses. The prices of molasses are highly variable with its inadequate supply and inconsistency over the years led to the search for alternate feedstock such as sweet sorghum. Sweet sorghum is a multi-purpose crop grown for food, feed, fodder, and fuel. The stem accumulates sugars up to 10-15% in its stalk as similar with sugarcane. The ethanol is produced from stem sap, while, the grains are produced on the top of the plant are used as food. Thus, ethanol production from sweet sorghum does not compromise food security. Ethanol is produced from sweet sorghum stem juice through fermentation technology as similar with molasses based process. The crop matures in about 3.5-4.0 months contrary to sugarcane of 12-18 months.. Thus, ethanol production from sweet sorghum does not compromise food security unlike corn. Ethanol is produced from stalk juice through fermentation technology as similar with molasses based process.

Agricultural yields: The yields realizable in optimum conditions include fresh stalk yields (35 to 40 t $ha^{-1)}$, juice brix (16-18%), sucrose (8-11%), and juice yield (12-14 KL ha^{-1}).

Industrial yields: The yields realized in various pilot studies include ethanol recovery (6-9% of juice), unit ethanol yield (35-40 L per one tonne of stalks crushed), and total ethanol yields (1200-1500 L/ha /one crop cycle, bagasse yield (5-7 t ha^{-1}). Power from bagasse cogeneration process can be produced to the extent of 3.5 MW ha^{-1} of crop.

Cultivar option: Currently available crop cultivars are CSH 22SS, SSV84, SSV74, and CSV 19SS, CVS 24SS (public sector), and Madhura, & SPSSV 11 and SPSSV 30 (private sector).

Economics: The cost of cultivation of sweet sorghum is about Rs15, 000 ha^{-1} comprising of paid-out costs with a net income of Rs.16, 250 –25, 000 ha^{-1} based on yield levels and price (Rs.500-700/ t) offered by the biofuel industries.

Industries tested sweet sorghum feedstock in pilot-studies in collaboration with DSR: DSR had organized pilot-studies in collaboration with biofuel distilleries such as M/S Renuka Sugars, Belgaum; Sagar Sugars, Chittoor AP; Praj Industries, Pune; National Sugar Institute, Kanpur; Somaiya Organo-chemicals, Sakarwadi; India Glycols Ltd, Khashipur; KCP Sugars, Laxmipuram, AP; Nav Bharat Ventures, Samalkot, AP; M/S Tata chemicals Ltd, at Nanded, Praj Industries Ltd, Pune, etc.

Bioethanol (biofuel) from sweet sorghum stalks produced in pilot studies
Juice from stalks of sweet sorghum can be fermented to produce ethanol using the existing crushing machinery and distillery available at sugar factories complexes. The details of pilot studies organized are presented below.

1. Renuka sugar factory, Belgaum, Karnataka

DSR organized first pilot-study in collaboration with Renuka sugar factory, Belgaum, Karnataka (during 2001-2003) and the recovery of ethanol obtained was about 40-50 L/ tonne of stalk crushes(Huligol et al 2003),

2. DSR successfully organized pilot test on sweet sorghum for ethanol production in collaboration with National Sugar Institute (NSI), Kanpur, 2005 (Image 1).

Subsequently in 2005, second pilot-study was successfully organized in collaboration with National Sugar Institute (NSI), Kanpur (Min of Food, Government of India). At NSI, 100 TCD experimental mill was used to produce bioethanol from sweet sorghum juice (syrup). The alcohol yield realized was about 40L per tonne of stalks crushed (Image 1).

Image 1. Sweet sorghum pilot study: Sweet Sorghum cane being put in the cane carrier and Prof GK Shukla, Director, NSI , Kanpur and other faculty are overseeing the crushing process (Shukla et al 2006)

3. NRCS collaborated in organizing the big mill test(BMT) of sweet sorghum at Sagar Sugars & Allied Products, Nelavoy, Chittoor, AP, 8 -10 Sept 05.(Image 2)

In the BMT of sweet sorghum the 100 tonnes sweet sorghum cane was used comprising both Cvs.PAC 52093 and SSV 84. The crops were planted during the last week of May 2005 and grew to a height of over 3.0-3.5m. The detrashed (excluding sheath) cane was fed to the feeder channel either directly from trucks or from conveyors and the cane was crushed in the fibrizer and passed through diffuser. Water was added to the juice at the last mill for facilitating higher juice extraction. Subsequently, the extracted juice was dewatered and sent to clarification tank from where it was directed to fermentation and subsequent distillation of ethanol.

During this process, juice and bagasse sample were analyzed for quality parameters such as POL% juice, purity, TRS (%), Juice Brix etc. Initial results given by the process lab shows that sweet sorghum clarified juice recorded following quality parameters. Juice Brix: 7.64%, POL%: 3.08, Purity: 40.31%, pH: 8.5, TRS: 5.30% etc. It is estimated about 35-40 Lit of ethanol per one tonne of sweet sorghum cane. The Management of M/S Sagar Sugars had expressed happiness over successful conduct of first big mill test and fermentation and distillation process.

Other personnel who has involved in BMT include R Venugopal, Sr GM (Agri.), Mr Surendran, Asst. VP, Mr. Pandian, DGM (Cane), Surendra Naidu (DCM), Balasubramanian, AGM (Distl), SN Murthy, Sr Mngr (Process) etc.(Sagar Sugars, Chittor); Anil Mandke,(Praj Indust., Pune) and, Mr Rama Krishnaiah, Asst Cane Commi, (Chittor), etc


Image 2. Sweet Sorghum bigmill test organized at Sagar Sugars, Chittoor, AP, October 2006

4. Tata chemicals sweet sorghum based bioethanol plant at Nanded and experience of sweet sorghum plantation in farmers' fields at Nanded (Image 3):

Under contract farming, farmers were supplied with 5kg of Phorate granules, 3kg seed, and 1 bag of Urea (50kg) on credit basis. Majority of the farmers applied phorate in soil along with seed as prophylactic measure followed by endosulfon spray at about 3-4-leaf sage. The sowing was done with locally available bullock drawn seed drills wherein the row to row distance was just 30cm only. Although TCL advised them to followed wider row 45 or 60 cm, this could not be adopted as farmers followed their traditional practice. Thinning is done in some farmer fields. Because of closer row planting, the crop lodged in some places especially when crop reached the hard-dough stage. The crop produced good ear heads.

In general, the pest infestation was less because of plant protection measures taken as required. However, there were few pests that occurred on sorghum and recorded infestation due to stem borer (< 10%), aphids (< 5%) and shoot bug (< 3%). The brix content observed from ten farmer fields varied from 10.5 to 16.5%. Brix at hard-dough (15.5%) was higher than at soft-dough or flowering (10.5-12.0%). In demonstration fields laid out by TCL R&D, where different grades of TCL customized fertilizers are under test with sweet sorghum. More aphid population (10-30%) was noticed where Tata's customized fertilizers (TCF) were applied. Relatively dark green leaves were noticed due to application of TCF treatments. In another trial on dates of planting, 4 sweet sorghum cultivars (CSH 22 SS, SPSSV 11, NTJ2, JK Recova) were planted in combination of three management practices (recommended, farmers method, need based). The experiments were planted at 10-day interval and so far 5-dates of sowing were completed (22/07/08 to 26/09/08). As sowing delayed the more incidence of shoot fly was noticed besides reduction in plant height. CSH 22SS is showing better performance in different sowing dates.

The constraints expressed by the TCL officials include whether sweet sorghum can be staggered beyond middle of July, whether there are any suitable varieties for rabi with high sugar and stalk yields? Under the buy-back arrangement farmers are paid @ 500/ tone (excluding harvesting and transporting charges) where TCL bear all harvesting & transportation costs. Alternatively, the TCL is exploring to use the PKV developed harvester in the coming season which needs modification of machinery. The farmers which are growing the sweet sorghum are the active members of the Tata Kisan Sansar (T KS). The plant has capacity to crush the 900 tonnes/day (TCD) and produce 30 KLPD that means it requires the stalks to be harvested from at least 60 acers @ 15t/acre and supplied daily. The Engineers suggested that the stalk girth of sweet sorghum should be more to avoid jamming in the rollers. Based on the earlier experiences from previous pilot studies, the sweet sorghum fermentation process generates almost zero-effluents in the spent wash. The spent wash is conveniently mixed with press mud to make organic fertilizers.

Even rectified spirit or ENA produced for sweet sorghum is of excellent quality to that of grain alcohol based with no aldehydes, sulphur, etc. The TCL officials acknowledged the services rendered by the DSR in arranging the planting materials, production technology, training and other services.


Image.3. 30 KLPD, 900 TCD; 4 tandem mills -sweet sorghum based plant set by M/s Tata chemicals Ltd, Nanded, processing of sweet sorghum for bioethanol. Sweet sorghum is grown over 7000 acres in 2008 and 2009.

5. KCP.SICL, Lakshmipuram(AP)sweet sorghum big-mill test (BMT) experience, 17 April 2007

As per the invitation received from AGM (Cane), DSR scientists visited the KCP Ltd., participated the BMT test and evaluated the sweet sorghum stalk yield and quality for ethanol production. The company planned to introduce sweet sorghum as relay or sequence crop after paddy/ turmeric to suit the availability feedstock after the sugarcane crushing in mid April. The company has grown and developed the sweet sorghum crop as per the technical advice and seed materials supplied by NRCS. Three cultivars namely SSV 84, CSV19 SS and Urja (from Praj Ind. Pune) were planted in one acre (0.407 ha) field (deep Vertisols ($\geq$ 1.0 m deep) belonging to the sugarcane contract farmer of Kokkiligadda vill. during first week of January 2007.

The crop was raised with supplemental irrigation (one in every 15 days) with adequate fertility. The days taken to 50 % flowering were 60d in SSV 84, 67 d in CSV 19SS and 72 d in Urja. Quality data collected at weekly interval from flowering to hard dough stage indicated that Urja has the highest brix (15.6%) followed by SSV 84(10.30%) and CSV 19SS (7.70%). Similarly, *CV* Urja recorded highest POL, Purity, and TRS than others.

The crop was harvested manually and brought to the factory on the next day. The detrashing was partly done (30% only) as the stalks grew very tall and the laborers have difficulty in removing the leaves with sickle. Leaves were removed manually only as leaf removal with sickle, which is a common practice in sugarcane, may cause breakage of stem in the middle part for sweet sorghum. The entire stalk from one acre was fed to the cane carrier after the sugarcane crushing is over. The crushing and extraction process was similar to sugarcane as there was no problem of jamming of 3 tandem rollers etc. The total stalk yield obtained from one-acre crop (avrg. 3 cultivars) as weighed at the electronic weighbridge was 14t/ acre (35 t ha^{-1}).

Samples from primary, mixed and last mill juice were collected for quality analysis on TRS, RS, Brix, CCS ethanol recovery (%) etc. The data from the primary juice revealed that sweet sorghum mixed sample has the 17-19% of brix, 11-12 % of POL with a purity of 62-64%. The results obtained in the big mill test on quality parameters are encouraging to upscale this crop for ethanol in the factory command area late rabi/ early summer situation but under contract farming of sugarcane model. The company expressed the need for cultivars to realize more stalk yield with superior quality traits.

6. Sweet sorghum pilot plantation at India Glycols, Kashipur, Uttrakhand, 16 Oct 2006

Met Sr. Vice President, adviser Cane & AGM (ETP) and discussed on the potential of utilizing sweet sorghum feedstock as supplementary to sugarcane in Uttaranchal.The SSV 84 & RSSV 9 sweet sorghum cultivars were planted on 8th May, 8th June and 8th July in the fields close to the distillery. The Crop grew to height of 2.8-3.3 m height. The crop development was good excepting some incidence of Anthracnose& Zonate leaf spot especially after flowering. The crops planted on 8th June were better than May and July fist week planted ones. Although the spacing adopted within the rows was ≤15 cm. It is estimated about 45 t/ha of stalk yield is realized. The brix values recorded at mid grain filll stage varied from 10-11.5%, while it has increased to 13.5-16.3% at harvest maturity. In general, the June first week planted crop recorded higher brix than May and July first week planted crop.

R&D Lab fermentation results for both May and June planted crops indicated that alcohol recovery was from 3.0-4.3% and 5.13-7.26% in May and June planted crop respectively. The results on alcohol recovery from sweet sorghum with SSV84 and RSSV 9 were encouraging at India Glycols Ltd. The company has decided to extend to large pilot study in the next summary, Kharif seasons in collaboration with NRCS. M/S India Glycols Ltd. proposes to compare competitiveness of sugarcane Juice with sweet sorghum Juice rather than molasses since it has already a facility (RAB plant) to utilize sugarcane juice directly to ethanol production. The company already planned to produce ethanol from cereal grains especially broken rice etc. We suggested to utilize sorghum grains as feedstock in comparison with Maize or broken rice etc. It has been decided that company will invite Director, NRCS in New Delhi in the next month for undertaking MOU/possible collaboration for joint projects under NAIP. Mr RS Sharma of M/S Compro Ltd. Delhi took a brief 15 min. live video coverage of the talks given by Dr N Seetharama Director NRCS, and Cane Adviser, Dr Jaising Saroj. The matter covered includes both current efforts and potential of sweet sorghum as a biofuel and biobased products crop in Uttaranchal and future plans.

7. Somaiya Organo chemicals (SOC), Sakarwadi, MS, 10, Oct. 2007 (Image 4)

The SOC has planted 200 acres of sweet sorghum crop during kharif 2007. The seed materials of SSV 84 supplied by NRCS were used for large scale planting. The crop condition and growth were good and it was grown to a height of > 3.0m.The technical guidance of NRCS was followed for implementing the crop development and management.The company had commissioned a three mill tandem crushing unit with 240 TCD capacity exclusively for sweet sorghum and this facility helped the SOC in production of bioethanol in the existing stand alone 90 KLPD disillery.

Image 4. Sweet sorghum mill established at SOC, Sakarwadi, MS

Conclusions: Producing bioethanol from sweet sorghum with appropriate economic, environmental and social policies will enhance the India's food & energy security, and environmental sustainability; besides creating remunerative markets to the farmers. The large-scale crop cultivation is recommended under contract farming with buy-back arrangement between growers and agro-industry or entrepreneurs' as similar to existing sugarcane industry.

Way-forward:

- Pre-feasibility, commercialization and scaling-up of cultivation in collaboration with biofuel industries, entrepreneurs, farmers, NGOs, etc.
- Develop cultivars producing high stalk yield & biomass per unit time, input, energy and land area in different agro-ecologies.

References

Huligol RV, Ramakrishna and Govind Misale. 2004. A trial with sweet sorghum. CFC and ICRISAT. 2004. Pages 333–337: In Alternative uses of sorghum and pearl millet in Asia: proceedings of the Expert Meeting, ICRISAT, Andhra Pradesh, India, 1–4 July 2003. CFC Technical Paper No. 34. P.O. Box 74656, 1070 BR Amsterdam, The Netherlands: Common Fund for Commodities; and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 364 pp.

Rao, S.S., Patil J.V., Prasad P.V.V., Reddy D.C.S., Mishra J.S., Umakanth A.V., Reddy B.V.S., and. Kumar A.A. 2013. Sweet sorghum planting effects on stalk yield and sugar quality in semi-arid tropical environment. Agronomy Journal. 105:1458–1465: Doi:10.2134/agronj2013.0156. (A072-NAAS Rating 7.6).

Hunter EL and Anderson IC .1997. Sweet sorghum. Horticultural Revi. 21:73–104. John Wiley and Sons, NY.

Planning Commission, GOI. 2006. Report on Integrated Energy Policy. Planning Commission, Government of India, New Delhi dated 09.08.2006. Pp 148.

Rao SS. 2005. Collaboration on sweet sorghum big mill test –NRCS and Sagar Sugars. Jowar Samachar. 1(2): pp 2.

Rao, S.S., Patil J.V., Prasad P.V.V., Reddy D.C.S., Mishra J.S., Umakanth A.V., Reddy B.V.S., and. Kumar A.A. 2013. Sweet sorghum planting effects on stalk yield and sugar quality in semi-arid tropical environment. Agronomy Journal. 105:1458–1465: Doi:10.2134/agronj2013.0156. (A072-NAAS Rating 7.6).

Shukla GK, Gupta SK, Singh Lakhendra, Rao SS, Ratnavathi CV and Dayakar Rao B. 2006. Successful pilot production of bio-ethanol from sweet sorghum in sub-tropical north India. Jowar Samachar. 2(1):1.

15. Nutritional benefits of sorghum with special emphasis on value addition

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Introduction

Sorghum is one of the most drought tolerant cereal crops currently under cultivation. It offers farmers the ability to reduce costs on irrigation and other on-farm expenses. Sorghum when regularly consumed offers us adequate fibre which is lacking in refined and polished cereals and many other millets. On an average around 28 g of fibre has to be taken per day from all sources by an adult. Most of the below mentioned benefits of sorghum are due to the fibre. Another striking feature is the absence of gluten (an amino acid) in sorghum as it can safely be consumed in celiac disease.

Sorghum on primary and secondary processing, the value addition can be brought about. By adding other foods in required quantities we can prepare other finished foods such as noodles, vermicelli, pasta etc.

Sorghum or Jowar can be used to prepare delicious recipes from the flour or rava in combination of other ingredients. In this way most traditional recipes can be prepared economically
These prepared foods were subjected to sensory evaluation on a 5 point scale for different properties like the appearance, color, shape, size, texture and taste by a panel of judges. Total score of points for different properties were averaged to assess the overall acceptability of the food product.

Health Benefits Associated with Consumption of Sorghum

Sorghum matches in composition as well as the nutritive value of many other cereals and grain products. There are some additional substances naturally found in sorghum which have proven to be associated with many health related benefits. Health benefits associated with consumption of Sorghum in various disease conditions is discussed as below.

Sorghum and Diabetes

Diabetes is a disease condition that presents with abnormally high levels of glucose and inability of the body to breakdown it for energy purposes. As a result of these high levels of glucose tend to accumulate leading to damage in organs. There are many causes related with the disease occurrence. Diets and consumption of certain food substances also play an important role in disease process. Foods like refined or processed rice, removal of bran from wheat flour, intake of highly refined wheat flour like ‘maida’ typically consumed in western diets making more prone for non-communicable diseases like diabetes. Sorghum is a coarse grain containing abundant amount of complex substances. These complex substances include a type of long chain sugars known as starch. Resistant nature of this type of starch delays the absorption leading to slow rise of glucose in the blood. This is in contrast to the highly refined foods consisting of less starch which are readily absorbable causing rise in blood glucose levels. Sudden increase of glucose increases the release of insulin in to the blood. Insulin is a naturally secreted hormone in response to high levels of glucose which leads to increased uptake and breakdown of glucose in the cells. These rapid changes in insulin levels can lead to insulin resistance and diabetes.



Studies conducted on supplementation of sorghum foods in human subjects are few and limited to show any related benefits in diabetic subjects. A study is being conducted at National Institute of Nutrition, Hyderabad with supplementation of sorghum rotis over two months in diabetic subjects. Of the 150 Diabetics who participated, 121 completed the trial. Results have been encouraging showing a better control of blood glucose and glycosylated hemoglobin. Glycosylated hemoglobin is the most specific form to assess control of blood glucose over a longer period.

Glycemic Index of Sorghum: GI of a food denotes the amount of glucose rise in the blood when 50 g of available carbohydrate from a particular food is consumed *vis.a.vis* a reference food such as white bread or glucose, given at the same level. It is measured for the first 2 hours after partaking a food on empty stomach. GI essentially takes into account only carbohydrates. The purpose is to approximately understand how much a food delivers glucose and is useful in planning diet for diabetes and obesity. A few sorghum foods with corresponding reference food is shown below.

When GI is multiplied with the usual portion size it give the Glycemic Load which is more appropriate in arriving at an individual's blood glucose rise when that particular food is consumed in the usual quantity.GL varies from country to country and within the country from region to region.

Glycemic Index of Test Foods and corresponding reference food.

Test Foods	Sorghum	Wheat	't' Value
Multigrain roti	68±12.02	64 ±9.24	0.83*NS*
Coarse rawa upma	53 ±2.84	58 ±6.85	2.16*
Fine rawa upma	56 ±9.83	67 ±10.8	2.31*
Flakes Poha+	45±6.30	74 ±11.4	6.96**
Pasta	46 ±5.27	72± 4.89	10.74**
Biscuits	54± 6.47	57 ±6.51	1.024 *NS*

+ compared with rice flakes

Sorghum and Obesity

Obesity is termed as a condition in which excess amount of fat deposits are present in the reserve stores of the body leading to complications such as diabetes, coronary heart disease etc. Increased amount of fat deposits in arteries supplying various organs and "a condition called as atherosclerosis" occurs. Involvement of arteries of vital organs like heart and brain can lead to clot formation decreasing the blood supply to them. These types of patients do often have increased appetite and less satiety feeling at the end of a meal. This in turn leads to overeating. Supplementation of foods with sorghum varieties could be helpful in these patients. Sorghum contains increased amount of fiber as compared to other grains. Fiber helps to curb food intake by a sense of stomach fullness thus leading to an increased satiety feeling which in turn leads to decreased food intakes.

Presence of resistant starch in sorghum impairs its digestibility, notably for infants . This resistance is desired in other applications to fight human obesity and to feed diabetic people. Edible products incorporating slowly digestible starch are known to exhibit a low glycemic index. Moreover sorghum increases satiety. This is desirable in diabetes and in obesity conditions.

Sorghum in Cancer Prevention

Studies on sorghum consumption have shown to reduce risk of certain type of cancers in humans as compared to other cereals in certain organs like rectum, breast and ovary. The role of sorghum in prevention of these cancers may be related by neutralizing the toxic substances which initiate changes in cells and hence called as antioxidant effect. Tiny parts of sorghum do have high antioxidant activity as observed in laboratory findings as compared to other cereals and fruits, thus offering similar health benefits commonly associated with fruits.

Sorghum and Gastro-intestinal Tract Disorders

Diverticular disease is a condition in which small or large round shaped swelling arise leading to obstruction of the gut. This manifests in the form of constipation. One of the reasons associated with this condition is with decreased consumption of less fibre foods. Sorghum has higher levels of fibre which helps for smooth passage of feces thus preventing diverticular disease and erosions in the tract. These conditions are found to be rare in habitual consumers of sorghum and more frequent in refined cereal consumers. Gluten enteropathy or celiac disease is another condition in which patients are sensitive to consumption of a protein called gluten present in outer layer of wheat. Thus they are allergic to wheat and loose vital nutrients in feces. Sorghum is free of gluten thus its consumption is beneficial in these patients.

Sorghum and hypercholesterolemia:

The grain sorghum has waxes containing policosanols. These have been shown in animal studies to inhibit endogenous cholesterol synthesis. The grain sorghum lipids significantly reduce plasma non-HDL cholesterol concentrations in a dose dependant manner in laboratory animals. This effect may be due to plant sterols. It is now thought that these components of GSL extract may work collectively in lowering plasma and liver cholesterol concentrations. It is further indicated that grain sorghum contains beneficial components that could be used as food ingredients or dietary supplements to manage cholesterol levels in humans.

Precaution: Sorghum causes aberrations in protein metabolism. This may lead to a condition called pellagra if sorghum is consumed for long periods without proper correction for aminoacid imbalances. A combination of aminoacids from different pulse/ cereal food intermittently is advisable to avoid pellagra.

16. High yielding sorghum cultivars for kharif

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Sorghum with its ability to survive in water limiting conditions provides an option for marginal farmers and fits very well in a sustainable agricultural model. It is a major dry land cereal grown as a dual purpose crop for food, feed and fodder over million hectares, primarily in Maharashtra, Karnataka, M.P., A.P., Rajasthan, Tamil Nadu, U.P. and Gujarat. Sorghum research in the country can be illustrated as a glaring example which has significantly contributed towards the green revolution in drier areas. Sorghum has originated in East Africa with its secondary centre of origin in India. Due to its wide range of adaptation in tropical and temperate climates and free gene exchange among various races, sorghum is endowed with wide range of variability.

Efforts have been made to improve the sorghum cultivars in India since 1930s. Most of the varieties till 1960s were the result of pure line selection practiced in local land races. The locals were tall, photosensitive, late maturing, flowering after the rainfall seized, and characterized by localized adoption and low harvest index. However, hybridization among the local cultivars reflected about 5% yield improvement at experimental level which could not make any impact on production till the 1960s. The hybridization and selection up to a limited extent among improved land races could not bring genetic improvement to a perceptible level but basic traits for local adaptation were preserved. Notable among the varieties developed during this period and cultivated till recently are the Co series in Tamil Nadu, The Nandyal (NT), Guntur (G) and Anakapalle series of A.P., the PJ kharif and rabi selections, Saonar, Ramkel, Aispuri, the Maldandi and Dagadi selections of Maharashtra, Bilichigan, Fulgar white, Fulgar yellow, Kanvi, Nandhyal, Hagari, Yanigar varieties of Karnataka, Budh Perio (BP 53), Sundhia and Chasatio of Gujarath, selections of Gwalior and Indore from M.P., RS selections of Rajasthan. Since most of these locals are tall, photosensitive and late maturing with low yields, production of relatively short duration photoperiod insensitive sorghums had become the primary objective of almost all the sorghum improvement programmes. In rainy season genetic improvement of varieties was achieved during 60's by production of relatively short duration photoperiod-insensitive sorghums with short height by manipulating the gene for height and maturity by introducing American germplasm and adopting temperate x temperate and temperate x tropical crosses. The major genotypic changes brought about during the 1960s triggered cultivar-input-management interaction and resulted in quantum jumps in productivity imparting stability to production. This resulted in quantum jump in the productivity from 560 kg/ha in 1970 to 1000kg/ha in 2000.

In 1962, ICAR launched the "Accelerated Hybrid Sorghum Project" with an objective to initiate the hybrid breeding in sorghum. Through the efforts of Rockefellar Foundation, a wide range of germplasm was made available in India which involved male steriles, several converted lines and tropical varieties collected from Indian sub continent and several African countries. During the next four decades, remarkable progress has been achieved by diversifying the parental lines for yield, maturity, height, disease and insect tolerance and quality by utilizing indigenous and exotic germplasm. The early efforts made to identify heterotic combinations among male sterile and converted dwarf lines, resulted in the development of the hybrids, CSH 1, CSH 2 and CSH 3. CSH 1, an early duration and dwarf hybrid was released in 1964 for all India cultivation. This hybrid became most popular with the farmers as it had high yield potential, suited to light soils and low rainfall areas. Subsequently, CSH 2 in 1965 and CSH 3 in 1970 were released. Inspite of their better yield potential and suitability of growing in both kharif and rabi seasons, these hybrids could not become popular because of the seed production problem in both these hybrids due to their common male parent IS 3691 being shorter than respective male sterile lines.

The use of dwarfing, earliness and photo insensitivity traits was helpful to realize higher grain yield in these hybrids which ultimately proved to be a disadvantage for fodder production. Further genetic improvement was thus oriented to rectify the problems through genetic enhancement and use of improved derivatives. As new male steriles and dwarf derivatives became available, further hybrid breeding was based on these genetically enhanced indigenously bred parental lines. Efforts were augmented to develop new dual purpose hybrids. During the decade, 1970-79, three hybrids CSH 4, CSH 5 and CSH 6 were released. Though CSH 4 had better fodder yields than CSH 1, due to shorter duration grain deterioration remained to be the major impediment for the spread of this hybrid. The real breakthrough in grain yield and apparent quality was made by developing hybrids like CSH 5 in 1975 and CSH 6 in 1976 based on new male sterile lines 2077B and 2219B respectively and new restorer CS 3541. These hybrids showed less grain deterioration and good quality of seed along with remarkable improvement in yield (Table 1). CSH 6 due to its short duration of 100 days became popular for intercropping with other pulse crops. Further increase in yield levels were achieved by the development of superior male sterile line 296 B. 296 B being a very good combiner when combined with CS 3541, (restorer of CSH 5 and CSH 6) resulted in development of a superior hybrid CSH 9. During 1980-89, the hybrids CSH 9, CSH 10 and CSH 11 were released. CSH 9, a medium duration hybrid yields about 39 q/ha. This hybrid is widely adopted and is extensively grown. Later two hybrids, CSH 10 and CSH 11 based on the same male sterile line, 296 B were released. CSH 10, a tall hybrid though produces 30-40% more fodder than CSH 9 could not be promoted due to seed production limitation. CSH 11, another hybrid of CSH 9 range, has marginal advantage in grain yield productivity. Due to smaller seed size, this hybrid is not popular among farmers. Among medium maturity hybrids of 110-115 days, CSH 5 and CSH 9 are most popular, with an average of 35 and 38 q/ha grain yield respectively and a matching fodder yield of 95-100q/ha.

In the subsequent decade (1990-99) most of the hybrids tested in AICSIP trials were based on 296 B with different restorers but could not make any remarkable dent for grain yield except for the hybrid CSH 13. Though the grain yield levels of this hybrid are marginally improved, the fodder yields are 40% higher than that of CSH 9. It is an ideal dual purpose hybrid and is recommended for both grain sorghum and fodder sorghum growing areas of the country. Another hybrid CSH 14 based on male sterile line AKMS 14A is an early duration hybrid with a maturity comparable to CSH 1 and has yield on par with CSH 9. It provides a better choice for the areas of CSH 1 adaptation, light soil and deficient rainfall areas. The hybrid is popular with farmers of Karnataka and Maharashtra.

The introduction of the rainy season sorghum hybrids like CSH 1, CSH 5 and CSH 9 brought a remarkable increase in the sorghum production in India. After the release of the hybrid CSH 9 in 1981, the yield level of experimental hybrids has not advanced over this hybrid to any significant level and thus yield plateau is reached. However, useful diversification for early maturity and higher fodder yield has been achieved with the release of CSH 14 and CSH 13 respectively. Seed growers are facing problem in seed production of the hybrids particularly based on 296 A due to low temperature at flowering time in major seed production areas in Andhra Pradesh during October-November sowings. The need for diversification of female parent of hybrids was felt in view of above seed production problems and stagnating yield levels. As a result of intensive breeding programme to develop improved male sterile line and restorer a productive medium maturing hybrid CSH 16 was developed. It is based on a new male sterile line 27 A and a new restorer C 43. CSH 16 yields about 42 q/ha of grain yield and 97 q/ha of fodder yield. The hybrid has bold seed and is preferred by the farmers. It has better level of tolerance to grain moulds and downy mildew and its fodder quality is good. This was found to be good for ethanol production.

Another early maturing hybrid CSH 17 based on the male sterile line AKMS 14 A has been released for the states of TamilNadu, Gujarat, Madhya Pradesh and Rajasthan. It yields about 40q/ha of grain and 90q/ha of fodder. Another medium maturing hybrid CSH 18 developed at Indore centre yields about 41 q/ha of grain and 130 q/ha of fodder. The grain and fodder quality of this hybrid are superior. The parent of this hybrid IMS 9A is based on a local variety Vidisha. This local not only contributes to high stover yield but also for improved grain quality.

CSH 23 is another early maturing hybrid released in 2005 for the states of Maharashtra, Karnataka, AP, MP, Gujarath, Rajasthan and UP. It takes 101-103 days to mature and yields about 43 q/ha of grain. One more medium maturing hybrid, CSH 25 was released for zone II in 2008. It is developed from the parents PMS 28A and C 43. It yields 43 q/ha of grain and 120 q/ha of fodder and was found to have good tolerance to shoot fly and grain moulds.

Another medium maturing hybrid, CSH 27 was released recently in 2012 for zone I involving the states of Rajasthan, N.Gujarat, UP, AP and Tamilnadu. It is a dual purpose hybrid with 39 q/ha of grain and 136 q/ha of fodder yield. It is developed based on the parents 279A x CB 11. It has better level of tolerance to grain moulds. The latest hybrid which has been recommended for release in zone II comprising of the states of Maharashtra, Karnataka and MP, South Gujarat, North AP. CSH 30 is an early maturing hybrid with good level of tolerance to grain moulds.

The varietal improvement programme has also been taken up simultaneously and till date CSV 1 to CSV 27 were released through AICSIP. However, popular recent kharif varieties are SPV 462, CSV 15, CSV 20, CSV 23 and CSV 27.

In the first phase of varietal improvement, besides release of swarna (CSV 1), a pure line selection from IS 3924 in 1968, six more varieties derived from temperate x tropical crosses were released. CSV 1, CSV 2 and CSV 3 are early maturing (100-105 days) tend to yield 138-207% higher than local. CSV 4 and CSV 5 are relatively dwarf varieties maturing in 110-115 days and combine good grain quality and resistance to grain deterioration even when caught in rains. CSV 6 is a relatively tall variety. The sources of resistance to grain mould and leaf diseases were located in zera-zera germplasm from Ethiopia, mechanism of resistance studied and resistance was consciously transferred in high yielding back ground. The resistance to these diseases was located in CS 3541 which is a dwarf derivative of IS 3541, a zera-zera from Ethiopia. Tan plant pigment conferring resistance to most of leaf diseases was discovered and it was augment in various breeding programmes of temperate x tropical crosses. Improved temperate and tropical germplasm from Ehiopia in various breeding programmes enabled to evolve many improved varieties eg. CSV 10, CSV 11, SPV 462, CSV 13, CSV15 etc. By now all the breeding programmes incorporated tan plant pigment in their kharif nurseries.

The high yielding kharif variety, CSV 15 was developed from SPV 462 and CSV 13. It is a dual purpose variety with grain yield as high as the hybrid CSH 5 and fodder yield equal to that of CSH 10. It yields about 36q/ha of grain yield and 121 q/ha of dry fodder yield. An early maturing variety, CSV 17 was released which was most suitable for low rainfall areas. Another variety, CSV 20 was released with grain and fodder yields of 31q/ha and 133 q/ha respectively. The latest dual purpose varieties, CSV 23 and CSV 27 have high yield potentials of 22 and 28q/ha of grain and 155 and 193q/ha of fodder yields respectively.

In kharif yield stagnation and the grain quality are the major problems that needs research attention. To break the yield plateau it is important to utilize the unutilised germplasm from the world collection and bring about the useful genetic diversity in the material. Breeding for grain mould resistance is a high priority area so that the market profitability and food value can be enhanced. Evolving grain mould resistant male steriles is the immediate requirement to strengthen the resistance in present day hybrids. Another problem during kharif is shootfly. It is not infrequent to experience aberrant rainfall where onset of monsoon gets delayed. This builds up unsurmountable pressure of shoot fly causing economic losses in late plantings. Therefore, in order to stabilize the sorghum production, incorporation of grain mould and shoot fly resistance in times to come would provide an insurance against the crop losses.

Table 1: List of popular sorghum varieties and hybrids

Varieties/ Hybrids	Grain Yield (q/ha)	Dry-Fodder Yield (q/ha)	Plant height (cm)	Maturity (Duration) (days)	Salient features
Varieties					
SPV 462 (CO 26/ DSV 2)	33	97	208	110-115	Tall, dual purpose, bold round attractive seed, sweet stalk, tolerant to insect pests, grain deterioration and several leaf diseases.
CSV 13 (SPV 475)	35	97	181	110-114	Medium tall, medium bold seed semi-compact head, thin stem, tolerant to insect pests, grain deterioration and several diseases.
CSV 15 (SPV 946)	36	121	232	107-112	Tall, Dual purpose, medium bold round seed, glume small & straw colour, large ear head, oblong shape, semi compact. Resistant to all leaf spot diseases.
CSV 17	25	68	150	97	Early maturing, tan plant type with dark green leaves, white dull midrib colour, well exerted, cylindrical, semi compact panicle, creamy seed colour, free threshing, moderately resistant to shoot fly and stem borer.
CSV 20 (SPV 1616)	31	133	240	109	Tall, semi-compact panicle with dense clustering of grain in panicle branches, panicle shape oblong and pearly white bold seed, for All India cultivation.
CSV 23 (SPV 1714)	22	155	215	115	dual-purpose variety, Normal rainfall sorghum growing regions of the nation The variety was found to be tolerant for shoot fly and stem borer
CSV 27 (SPV 1870)	28	193	235	115	Tall, Dual purpose variety, yellow green colour midrib, Well exerted semi-compact panicle, Greyed yellow seed, resistance to grain moulds, Non-lodging, non-shattering,
Hybrids					
CSH 5	34	93	174	110-115	Medium tall, thick juicy stem, medium bold seed, large long head, resistant to grain deterioration and leaf spot diseases.
CSH 6	34	81	161	95-100	Early maturing, thin stem, medium bold and hard seed resistant to grain deterioration, tolerant to leaf spots and other diseases.
CSH 9	39	98	182	110-115	Medium tall, thick juicy stem, vigorous growth, bold round seed, large semi compact head, tolerant to insect pests and diseases.
CSH 10	36	120	233	105-110	Tall, dual purpose, vigorous plant, bold seed, tolerant to insect pests and diseases.
CSH 11	41	92	194	105-110	Medium tall, loose and large panicle, small seed, thick stem tolerant to insect and leaf spot diseases, some lodging under

Varieties/ Hybrids	Grain Yield (q/ha)	Dry-Fodder Yield (q/ha)	Plant height (cm)	Maturity (Duration) (days)	Salient features
					severe drought.
CSH 13	39	144	261	110-115	Tan, Tall, dual purpose, panicle broad, semi loose, spindle shape, seed round medium bold, light creamy in colour and free threshing. Tolerant to grain moulds and leaf diseases
CSH 14	38	88	181	102	Medium tall, semi loose panicle, bold seed, tolerant to grain mould and leaf spots.
CSH 16	42	95	210	110	Medium tall, long loose panicle with open apex, bold seed, highly tolerant to grain moulds and resistant to leaf diseases.
CSH 17	41	90	185	103	Tall, early maturing, panicle semi loose, white round seed, tolerant to shoot fly and stem borer.
CSH 18	41	131	212	112	Tall, midrib dull green, thick and juicy stem, white medium bold seed, medium maturity, resistant to grain moulds.
CSH 23	41	87	178	96-101	Tall (180cm), dull green midrib, medium bold, white seed. Early maturity (103 days) avoid terminal drought.For Zones – I & II:Maharashtra, Karnataka, AP, MP, Gujarat, Rajasthan, UP
CSH 25	43	128	205	110	Kharif hybrid- Rainfed kharif sorghum areas under normal time of sowing especially for Maharashtra and Karnataka and central zone II areas. Tan, tall, white midrib, semi-compact ear- head, pearly white seed, medium almond shape, tolerant to grain-mold and shoot fly.
CSH 27	39	136	200	106	Tan, cylindrical semi compact earhead, white bold elliptical seed, medium maturity, tolerant to grainmold and resistant to lodging. Recommended for rain fed kharif cultivation in Rajasthan, N.Gujarat, UP, AP and TN.
CSH 30	44	141	216	105	Tan plant color with symmetric semi compact panicle and white bold elliptical seed. It is early maturing with tolerance to grain moulds. Recommended for rainfed kharif cultivation in Maharashtra, Karnataka, MP, South Gujarat, North AP

SPV 462 is released as CO 26 in Tamil Nadu and as DSV 2 in Karnataka.

17. Seed production in sorghum & IPRs

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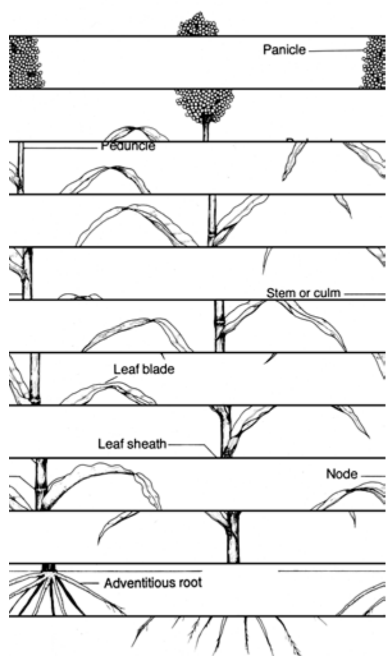
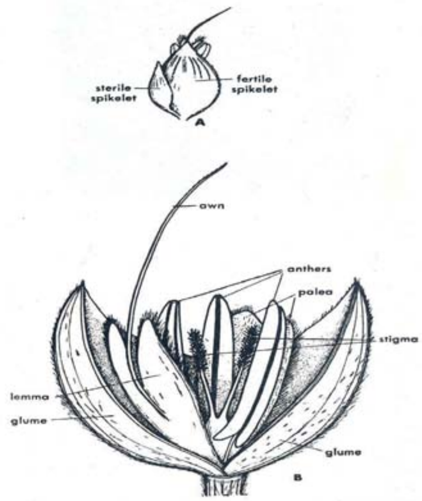
Sorghum (Sorghum bicolor (L.) Moench.) is grown world wide for food, feed , fodder, fuel, and industrial products. In India sorghum is the most important cereal for poor people in semi arid zones where sorghum hybrids were developed from temperate x tropical crosses by manipulating height and maturity genes; and the critical stages of growth, viz, seedling, flowering and grain filling coinciding with periods of assured rainfall. This resulted in quantum jump in productivity from 570kg / ha in 1970 to 1000kg / ha in recent times. Seed is the key input in modern agriculture as the quality of seed determines the quantum out put of a crop. The high quality seed in terms of high genetic and physical purity, healthiness, high germination, vigor and viability assures the potential of crop production under suitable and favorable agro climatic conditions. The seed quality with all its ramifications must be cardinal virtue of a strong seed production program. The quality of the certified seed class of a hybrid or variety depends on the maintenance of genetic purity, physical purity, seed health, vigor, and viability potential during total seed production chain. The seed technological principles those govern the quality seed production in sorghum are detailed in the following sections.

Plant morphology

Sorghum plant has a single solid erect stem supported by a strong adventitious root system (Figure 1). Sorghum can tiller, but tillering capacity is dependent on the cultivar and environmental conditions, especially tillering is profuse at low temperature. The cylinder of stem with the clasping sheath is called as culm. The culm thickness at the base may vary from 0.5 to 5.0 cm in diameter with 0.5 to 4.0 m long in height, exhibiting series of nodes and internodes. Leaves are arranged alternately on the stem, usually in two ranks. Each leaf originates from a node and has a sheath and blade or lamina.



Sorghum plant morphology



Spikelets of sorghum. A: Pair of spikelets; B: Fertile spikelet

Anthesis: The flowering in sorghum inflorescence resumes from the top and continues successively downwards for several days. Lodicules swell and create the pressure on the glumes to open the flower. Usually, the stigmas and anthers emerge at the same time. However, it varies from variety to variety. There are varieties where anthers emerge first followed by stigmas. The flowering starts sometimes starts on the vary day of complete panicle exscertion or may start after three to four days after emergence of panicle emerges from the boot leaf (Schertz and Dalton, 1980). Flowering continues downwards and the the flowers open in a horizontal plane across the panicle at the same time. Generally, flowering in a panicle is completed in seven to eight days depending on the size of panicle, ambient temperature and humidity at flowering and the genotype. Cooler and humid climate usually extend the flowering period. Thje pedicellate spikelets flower two to four days after the sessile spikelet on the same branches and it helps in completing the pollination in all remaining flowers. The blooming occurs at early in the morning. In India, particularly in Southern part, blooming begins at about midnight 2 am and continues until 8am (Doggett, 1988).

Anthesis and pollination

The floral initiation (Primordial formation) starts at 30 to 40 days after germination (but may range from 19 to 70 days or more) Floral initiation marks the end of the vegetative growth and the meristematic activity. Sorghum usually flowers in 55 to 70 days in warm climates, but it could be as early as 30 days or as late as 100 days or more. The flowering (anthesis) in a panicle starts from the top and it travels successively to lower whorls. Flowering is completed over a period of 4 to 5 days (6-8 days under cooler conditions).

Floral (Primordial) initiation

Sorghum Seed Multiplication Chain

In India, the seed multiplication is in four stage generation system viz., Nucleus seed, b) Breeder seed, c) Foundation seed, d) Certified seed. The seed certification under law is voluntary. Apart from certified Seed, the seed is also sold as truthfully labeled seed (TLC). However the certified seed has the advantages like high genetic and physical purity, freedom from disease and pest, high germination and seedling vigor. The seed of different classes can be produced based on the forecasting the demand of annual certified seed requirement based on multiplication ratio, replacement rate and additional seed requirement. The area to be planted and target seed of each class is calculated by multiplying area and quantity with a factor X 200 (Table 1).

Table 1: Estimation of seed targets (t) and area requirement (ha) for different classes of seed multiplication.

	Breeder seed	Foundation seed	Certified seed	Grain
Area (ha)	0.5 ha =	100 ha =	20,000 ha =	4 m ha
Quantity (t)	1 t	200 t	40,000 t	

Seed class

The commercial end-products in sorghum are varieties and hybrids. Once the decision is taken to release a cultivar with specific characteristics and the variety or hybrid is identified with a name, sorghum breeders make a limited increase of seed of new varieties and hybrid parents. Seed multiplication of any class depends upon the actual requirements and the buffer stock. In sorghum, seed is therefore multiplied in four stages (nucleus, breeder, foundation and certified), called seed classes. The linkage between seed class is given in Fig. 2.

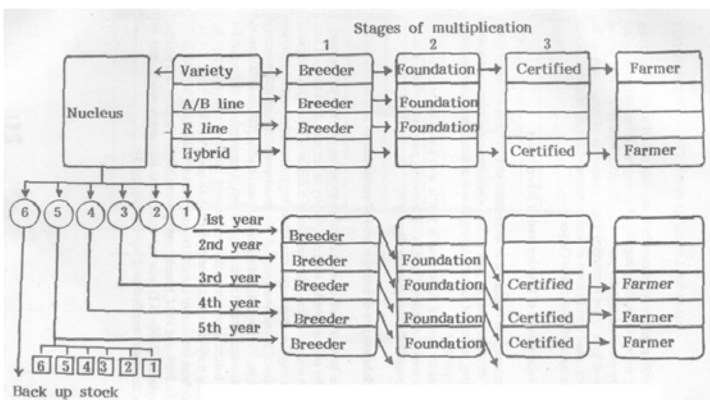


Fig 2. Linkages between seed classes

A. Nucleus seed

It is the first stage in the chain of seed multiplication of a released variety or hybrid parents. This fundamental stock of seed obtained from the selected individual plants of parental lines of a hybrid (A, B, R line) or an open - pollinated variety is the only seed that can be used to produce its own seed class. Nucleus seed should be of the highest genetic purity and the responsibility of it lies with the originating breeder.

B. Breeder seed

Breeder seed of a released OPV or hybrid parents is produced by or under the direct control of the sponsoring plant breeder. This class of seed is the base of the first and recurring increase of foundation seed and required to be inspected by a monitoring team consisting of a breeder , seed certification officer, representatives of National Seed Corporation (NSC) and State Seed Corporation (SSC).

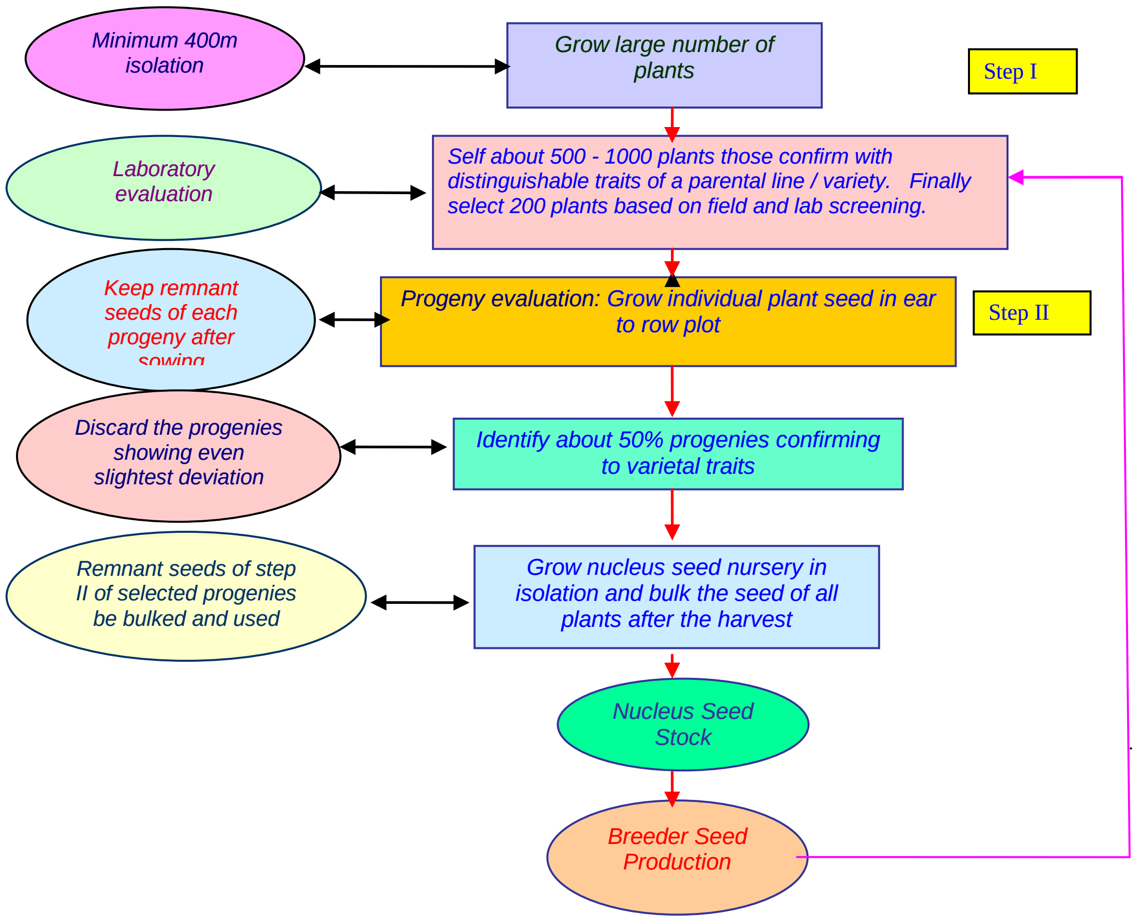


Figure 1: ***Scheme of nucleus seed production in sorghum***

C. Foundation seed

Foundation seeds of a released open-pollinated variety or hybrid parents are produced from breeder's seed, the production of which is carefully supervised or approved by the breeder and seed certification agency at the experimental station or recognized seed farms. It is a source for certified seed class and should satisfy the minimum seed certification standards.

D. Certified seed

Certified seed of a released open-pollinated variety or hybrid is produced by registered seed producers, duly certified by seed certification agency and produced on a large scale for general farm scale.

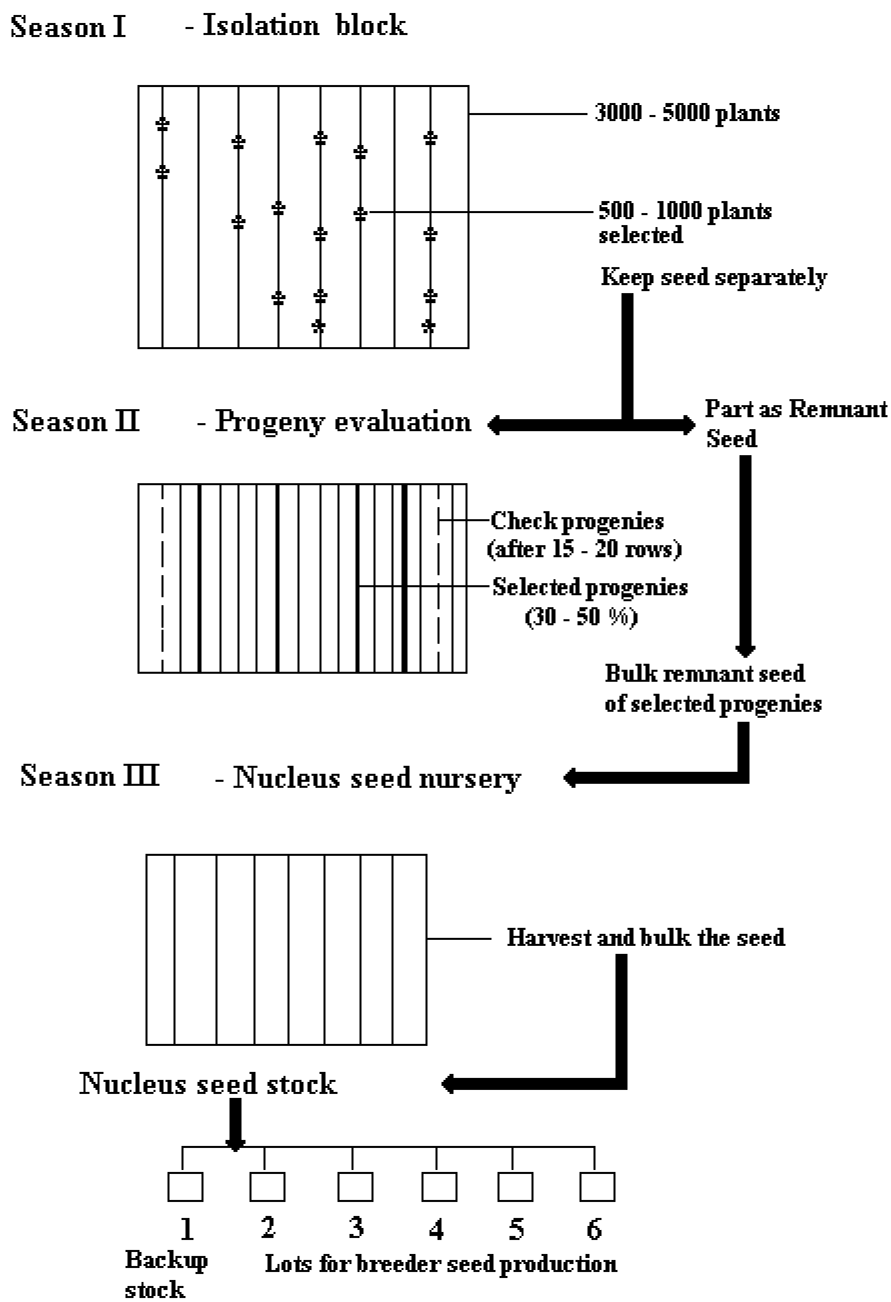


Fig. 3 NUCLEUS SEED PRODUCTION OF OPEN-POLLINATED VARIETY

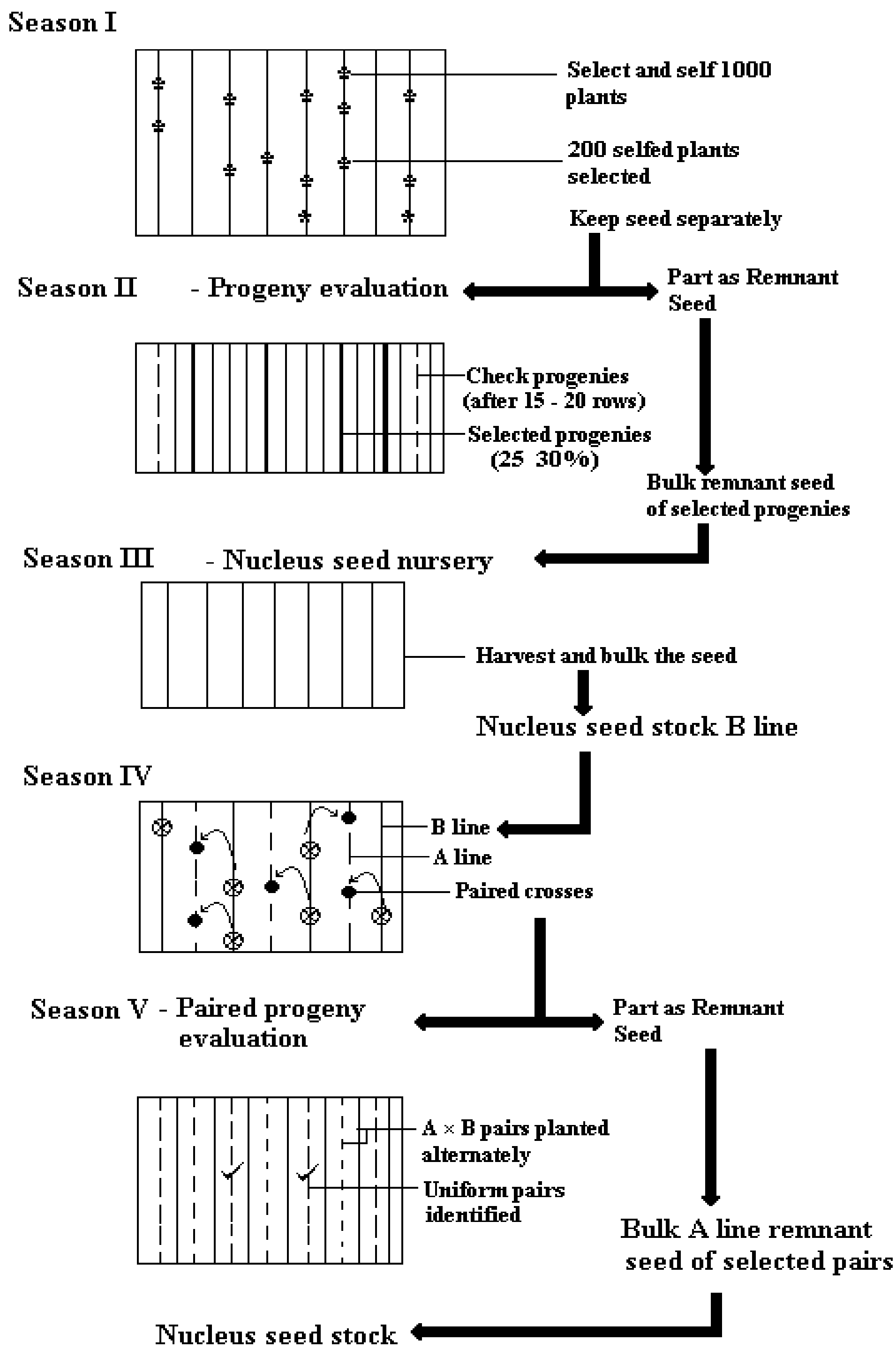


Fig. 4 NUCLEUS SEED PRODUCTION OF MAINTAINER (B) LINE & MS (A) LINE

2. Hybrids:

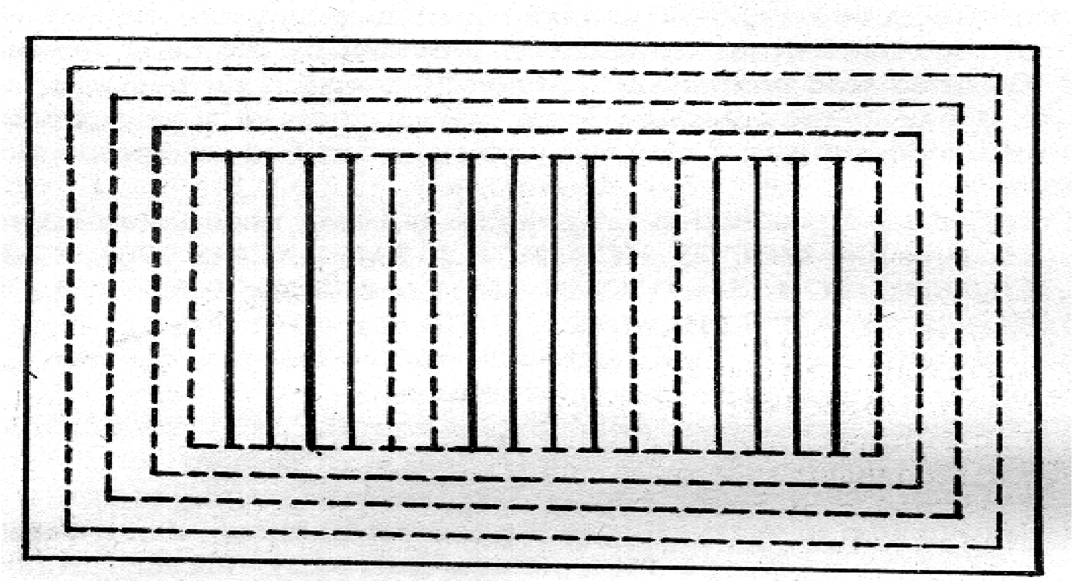
Certified seed of OPV and hybrid is produced in sorghum. The stipulated isolation distance for certified seed production, both for hybrids and OPVs is 200 -400m. The pattern of planting and production of OPVs is the same as for the breeder and foundation seed production (Fig. 2). Production must be acceptable to seed certifying agency and fulfill all requirements of certification.

Certified seed is generally arranged through contract growers. Some private seed companies also undertake certified seed production programmes.

The certified seed of a hybrid is produced by growing male sterile line with a specified restorers line in an isolated field (Fig.5 & 6).

Synchronisation of A and R line is crucial for certified hybrid seed production. This can be mainpulated by (1) differential dates of sowing (2) manipulating of water and fertilizer to one of the hybrid parents and (3) removal of extra early tillers in A or R line to synchronise the ability of pollen shedding and stigma receptivity.

Off-type plants in R line and pollen shedders in A line should be roughed out carefully to maintain genetic purity. A satisfactory certified seed production can be achieved if seed village concept is followed.



--------- Restorer line (R line)   ______ Male sterile line (A line)

Fig. 5 Showing pattern for certified hybrid seed production in pearl millet

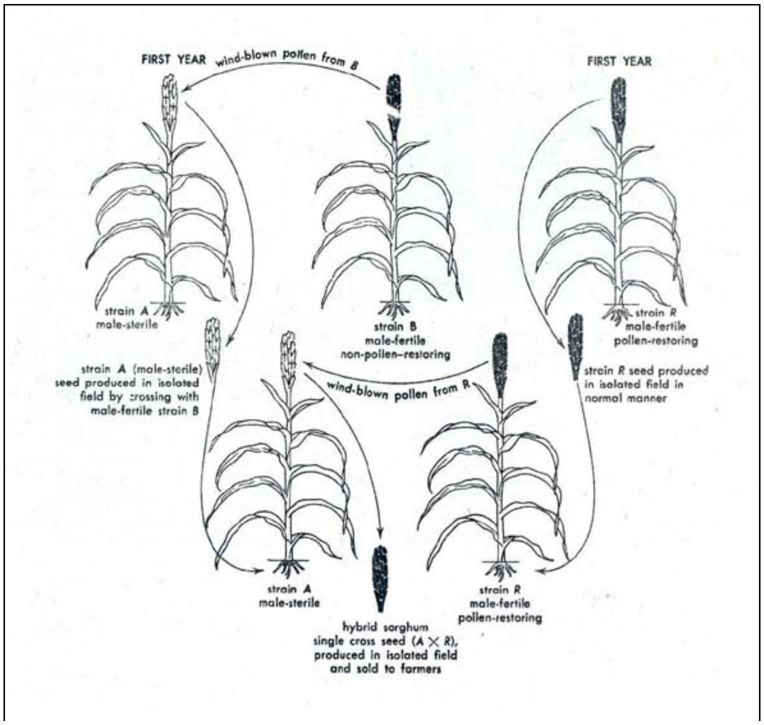


Fig. 6 Scheme for sorghum hybrid seed production in an isolated field

Table 2. Isolation standards for the production of different classes of sorghum seed.

Contaminants	Minimum distance (m)	
	Foundation seed	*Certified seed*
Fields of other varieties	400	200
Fields of same variety but not confirming to purity	400	200
Johnson grass (Sorghum halepense)	400	400
Forage sorghum with high tillering and grassy panicle	400	400

Note: Different flowering dates for modifying isolation distances are not permitted.

Table 3: Specific certification standards for different classes of sorghum seed production

Factor	Maximum Permitted (%)	
	Foundation seed	*Certified seed*
Off-types (earheads) at any one inspection at and after flowering.	0.05	0.10
*Earheads infected by kernal smut and grain smut and head smut at final inspection.	0.05	0.10

- ***Seed fields can however be certified if diseased earheads are removed and burnt and the fields show on re-inspection, infection not more than maximum permissible level. Only one such re-inspection is permitted.***

Note: Seed fields should be thoroughly rouged to remove plants infected by sugary disease (**Sphacelia sorghi*****) / Ergot (*****Claviceps spp*****), so that the prescribed standards are must at seed stage. However the seed fields shall not be rejected on account of presence of sugary / ergot infected earheads.***

Table 4: Specific seed standards for different classes of sorghum seed.

Factor	Standards for each class	
	Foundation seed	*Certified seed*
Pure seed (minimum)	98.0%	98.0%
Inert matter(maximum)	2.0%	2.0%

Factor	Standards for each class	
	Foundation seed	*Certified seed*
Other crop seeds (maximum)	5 /Kg	10/ Kg
Weed seeds (maximum)	5/ Kg	10 /Kg
Other distinguishable varieties (maximum)	10/ Kg	20/ Kg
Ergot , Sclerotia, seed entirely or partially modified as Scelerotia, broken Sclerotia, or ergotted seed (Sphecelia sorghi-Mc Rae, & Claviceps spp) (maximum)	0.020% (by no.)	0.040% (by no.)
Germination (minimum)	75%	75%
Moisture (maximum)	12.0%	12.0%
For vapour proof containers (maximum)	8.0%	8.0%

b) Seed Drying: Seeds contain varying amounts of moisture at harvest, and if they are to be stored for subsequent planting it is essential that their moisture content is reduced to a safe level. High moisture in seeds reduces seed viability and causes mechanical damage during processing. In addition to this, high moisture in seeds provides favorable atmosphere for pest and disease attack in storage. Sorghum seeds should be dried to the moisture content of 9% to avoid the breeding and multiplication of insect population in storage.

c) Seed Cleaning and grading: The sieve aperture sizes of top and bottom screens of air screen cleaner differ with genotypes. Generally the top screen may be around 12/64" or 4.75mm with round holes and the bottom screen at 9/64"or 3.5mm with round holes. The specific gravity separator helps in upgrading the quality of seeds by rejecting the seed that is inferior in specific gravity.

d.) Seed Treatment: Seed treatment also provides protection against storage pests (rice weevil) and shoot fly. The fungicides like Thiram or captan @ 3g/kg and insecticides like Malathion dust (5%) (premium grade) @ 0.6g per kg seed are recommended for sorghum seed treatment. Thiram (75 WDP)g in 0.5 lt water can be used to slurry treat the sorghum seeds in the processing chain.

e) Seed Packing: Processed seed can be packed in cloth bags or poly lined bags @ 3 – 4kg / bag , sewed with proper label of particular seed class and can be sealed with lead seal.

Seed storage management

a) Storage under controlled environment: The genetic damage will not show up in the crop grown from that seed in the first generation, but will begin to segregate in the subsequent generations. Therefore, it is very important to store breeder seed and germplasm material carefully so that the loss of viability and genetic damage is minimized. As soon as seed germination falls by 20-30% from the initial seed germination of 90-95%, the seed should be regenerated. Such seeds should be stored under controlled conditions at a particular temperature and relative humidity regime (Table 5).

Table 5: Suggested conditions for storing breeder seed and germplasm.

S.No.	Duration of storage (years)	Temperature (° C)	Relative humidity (%)
1	5-7	15 - 20	45 - 50
2	20-25	2 – 4	40 – 45
3	50 or more	-10	40 - 45

Design: A design includes features of shape, configuration, pattern, ornament or composition of lines and colours applied to article in two or three-dimensional form by any industrial process. The process can be manual, chemical, mechanical or combination of all. The grant is for 10 years initially and non-renewal leads to it becoming public property. The Indian Design Act, 2000 with its subsidiary legislation is in force in compliance with TRIPs provisions. (IDA, 2000). For agriculture sector, forms of designs of textiles patterns, ornaments, embossments that are new, original, and industrially applicable. Traditional heritage in textiles, folklore, toys, village artifacts are all areas to which protection can be extended under this Act. Researchers can build portfolios based on indigenous knowledge of communities for grant of IP protection under this asset.

Trademark: is a sign that individualizes the goods of given enterprise and distinguishes them from the goods of its competitors. It is limited to word marks, abbreviations, names, elements, and hologram. When applied to articles of commerce it is with a view to indicate to the purchaser that they are the goods manufactured or dealt in by particular person as distinguished from similar goods manufactured or dealt in by other persons. It helps to identify the product and its origin, guarantees its unchanged quality, and advertises the product. It also confers on the proprietor a kind of monopoly right over the use of the mark, essential to protect it and the goodwill attached to it, prevents the use of fraudulent marks on merchandise. Items likely to cause confusion, marks, obscene, religious sentiments, and of society, Official seals, identical marks are not considered for registration under this protection. Such distinguishing marks constitute protectable subject matter under the provisions of the TRIPS Agreement. The Agreement provides that initial registration and each renewal of registration shall be for a term of not less than 7 years and the registration shall be renewable indefinitely. Compulsory licensing of trademarks is not permitted. Keeping in view the changes in trade and commercial practices, globalization of trade, need for simplification and harmonization of trade marks registration systems etc., a comprehensive review of the Trade and Merchandise Marks Act, 1958 was made and a Bill to repeal and replace the 1958 Act has since been passed by Parliament and notified in the Gazette on 30.12.1999. This Act not only makes Trade Marks Law, compliant with TRIPS but also harmonizes it with international systems and practices.

Geographical Indications: One category of commercial marks more often used in agriculture than industry is geographical indications, including appellations of origin. Geographical Indications of Goods (GI) are defined as that aspect of industrial property, which refers to the geographical indication referring to a country or to a place, situated therein as being the country or place of origin of that product. Typically, such a name conveys an assurance of quality and distinctiveness, which is essentially attributable to the fact of its origin in that, defined geographical locality, region or country. Under Articles 1 (2) and 10 of the Paris Convention for the Protection of Industrial Property, geographical indications are covered as an element of IPRs. They are also covered under Articles 22 to 24 of the Trade Related Aspects of Intellectual Property Rights (TRIPS) Agreement.

These are marks associated with products originating from a country, region or locality where the quality, reputation or other characteristics of the product are essential attributable to its geographical origin. Most geographical indications relate to agricultural products or those derived from them, more specifically as in the case of wines and spirits. Protection of such marks prevents third parties from passing off their products as those originating in the given region. Famous examples are champagne and Scotch whisky. Art.22 of the TRIPs indicates GI indications to recognize that goods that have originated in an area where the given quality of goods is attributed to that area. It prevents others to misuse/unfair trade practice. GI depends on acceptance by members of the group and countries are not obligated to grant GI if country of origin is not protecting. India has submitted two proposals to WTO along with Egypt, Cuba, Pakistan, Indonesia where it requested for additional protection as given to wines and spirits be extended to other products as well. India has put forth that under Article 24 of TRIPS, work needs to be expedited so that benefits may extend to wider range of products. This was addressed in the Doha Declaration too but due to subsequent confusion among member countries on other issues, this could not be sorted out as proposed during the Cancun summit.

Trade Secret: provides protection to persons/institutions on information, which is lawfully under their control from being disclosed to, acquired to or used by others without their consent. Thus under TRIPs members shall protect undisclosed information which is secret in the sense that it is not generally known among or readily accessible to persons, has commercial value because it is secret; and has been subject to reasonable steps under the circumstances, by the person lawfully in control of the information, to keep it secret. (Part II, Section.7: Art.39.1 & 2. of TRIPS). Members, when submitting undisclosed test or other data, for the marketing of new pharmaceutical or of agricultural chemical products, shall protect such data against unfair commercial use. In addition, Members shall protect such data against disclosure, except where necessary to protect the public or unless steps are taken to ensure that the data are protected against unfair commercial use (Art.39.3).

Patent: The purpose of a patent is to provide a form of protection for technological advances. Patent protection provides a reward not only for the creation of an invention, but also for the technologically feasible and marketable. This incentive promotes creativity and encourages healthy competition to develop new technology, which is marketable, useful to the public and desirable for public good.Characteristics that invention must have in order to be patent protected are:

1. New invention – i.e. the invention must never have been made before, carried out or used before or made public before the date it is filed. It should be novel.
2. Non-obvious and inventive- A sufficient advance in relation to the state of art before it was made to be considered worth patenting. It should involve an inventive step if when compared with what is already known, it would not be obvious to someone with a good knowledge and exposure of subject.
3. Industrially applicable – It needs to be of use in some way. An invention should be applicable or used in some of kind of industry. This means that the invention must take a practical form of an apparatus or device a product such as new substance or method of operation.

Plant varieties: Protection of plant varieties is perhaps yet another important issue for researchers in agriculture. This has been also one of the most discussed issues after TRIPS. Developing countries were obliged to adopt protection of plant varieties by patents or other means. However, crucial issues on how IP protection affects the access of farmers to vital inputs like seeds have been long debated. While formulating its strategy for protection of plant varieties India resorted to consider principles embodied in other allied international agreements. Intellectual property protection for plant materials is of several modes. The US model of plant patents which differs from normal or utility patents. Several countries allow patents on cells too. The sui generis form of plant variety protection (PVP) is yet another type of plant breeders' rights. With biotechnology emerging as a major tool in research and developmental activities, plants on gene constructs, transformed plants can also be patented.

References

Hanna, W.W., Bashaw, E.C. and Schertz, K.F. (1972). Apospory in Sorghum bicolor L. Moench. Science, 170:338-339.

Kannababu N, Tonapi, VA and Seetharama N. (2004). Sorghum seed production manual. NRCS TECH / 1 / 2004. ISBN: 81-89335-02-2. Rajendranagar, Hyderabad – 500 030, Andhra Pradesh, India: National Research Centre for Sorghum: 105pp.

Kannababu, N. and Rana, B.S. (2003). The economics of sorghum hybrid seed production. Seed Research., 31 (1): 1-7.

Kannababu, N. and Seetharama, N. (2002). Sorghum nucleus and breeder seed production. Information Bulletin No.4/2002. NRC Sorghum, Hyderabad – 500 030.

Kannababu, N., Tonapi, V.A., Rana, B.S., and Rao, S.S. (2002). Influence of different synchronization treatments on floral behavior of parerntal lines and hybrid seed set in sorghum. Indian Journal of Plant Physiology., 7 (4): 362-366.

Murty, D.S. Tabo, R. and Ajayi, O. Sorghum hybrid seed production and management. Information Bulletin No. 41. ICRISAT, Patancheru, AP. – 502 324.

Murty, U.R. (1986). Milo and non-milo cytoplasm in Sorghum bicolor (L.) Moench., II. Fertility restorers and sterility maintainers on milo cytoplasm. Cereal Research Communication. 14: 191-196.

Murty, U.R. (1992). A noval male sterility system in sorghum, Sorghum bicolor (L.) Moench. Current Science., 63: 142-143.

Murty, D.S., Tabo, R. and Ajayi, O. (1994). Sorghum hybrid seed production and management. Information Bulletin No.41, ICRISAT Patahcneru, India. P.67.

Quinby, J.R. (1974). Sorghum improvement and the genetics of growth. College Station, texas, USA: Texas A & M University Press.

Sorghum and Millets Diseases. I edition 2002. Edited by John F. Leslie. Publisher: Iowa State Press; 2121, A Black well Publishing Company, State Avenue, Aures, Iowa 500014. Pages 504.

Sorghum. 2000. Origin, History, Technology and Production. Edited by C Wayne Smith (and) Richard A Frederikhen. Publisher John Wiley & Sous, Inc 605, Third Avenue, New York. NY 10158-0012 (212), 850-6011. Fax. (212) 850-6008. Pages 811.

Swarnlata and Rana, B.S. (1986). Inheritance of biological yield and harvest index in Sorghum. India J. Genet. 46: 149-153.

Swarnlata and Rana, B.S. (1987). Significance of performance per se and combining ability of parental lines in sorghum hybrid production. In: Proc. 2nd Inter. Conf. on Quantitative Genetics. May 31-June 5, 1987. Releigh North Corolina, U.S.A.

Tonapi, V.A. and Karivaratharaju (2002). Effect of lime induced iron stress on plant growth, seed yield, and quality in sorghum. International Sorghum and Millets News letter. 43: 51

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18. Extension reform scheme under NMAET during XII Plan

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Introduction

1.1 Agricultural Technology, including the adoption/ promotion of critical inputs, and improved agronomic practices were being disseminated under 17 different schemes of the Department of Agriculture & Cooperation during the 11th Plan. The Modified Extension Reforms Scheme was introduced in 2010 with the objective of strengthening the extension machinery of these schemes under the umbrella of Agriculture Technology Management Agency (ATMA). NMAET has been envisaged as the next step towards this objective through the amalgamation of these schemes. National Mission on Agricultural Extension and Technology (NMAET) consists of 4 Sub Missions:

(i) Sub Mission on Agricultural Extension (SMAE)
(ii) Sub-Mission on Seed and Planting Material (SMSP)
(iii) Sub Mission on Agricultural Mechanization (SMAM)
(iv) Sub Mission on Plant Protection and Plant Quarantine(SMPP)

1.2 The common threads running across all 4 Sub-Missions are Extension & Technology: The aim of the Mission is to restructure & strengthen agricultural extension to enable delivery of appropriate technology and improved agronomic practices to the farmers. This is envisaged to be achieved by a judicious mix of extensive physical outreach & interactive methods of information dissemination, use of ICT, popularisation of modern and appropriate technologies, capacity building and institution strengthening to promote availability of quality seeds, mechanization, plant protection etc. and encourage the aggregation of farmers into Interest Groups (FIGs) to form Farmer Producer Organizations (FPOs).

1.3 SMAE: Sub-Mission on Agricultural Extension will focus on awareness for Personnel trained under Agri-Clinics and Agri-Business Centres Scheme (ACABC) and Diploma in Agriculture Extension Services for Input Dealers (DAESI) to provide extension services to the farmers. Use of interactive and innovative methods of information dissemination like pico projectors, low cost films, handheld devices, mobile based services, Kisan Call Centres (KCCs) etc.

1.4 SMSP: The interventions included in the Sub-Mission will cover the entire gamut of seed chain from nucleus seed to supply to farmers. SMSP also envisages strengthening of Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA).

1.5 SMAM: This will focus on farm mechanization and mainly cater to the needs of the small and marginal farmers through institutional arrangements such as custom hiring, mechanization of selected villages, subsidy for procurement of machines & equipments, etc.

1.6 SMPP: This envisages increase in agricultural production by keeping the crop disease free using scientific and environment friendly management practices in diverse and changing agro-climatic conditions, pesticide management, and Bio-security through capacity building programmes.

Farmers' skill trainings and field extension as contained in all 4 Sub Missions of NMAET (Viz. SMSP, SMAE, SMAM and SMPP) will be converged with similar farmer-related activities going on through ATMA. Five-tiered modes of extension carried out in broadcast or interactive electronic modes will also cut across extension activities in all the four Sub Missions. The gaps in all farmer centric trainings and field extension in respect of other Sub-Missions of NMAET would also be included in the SREP at district level.

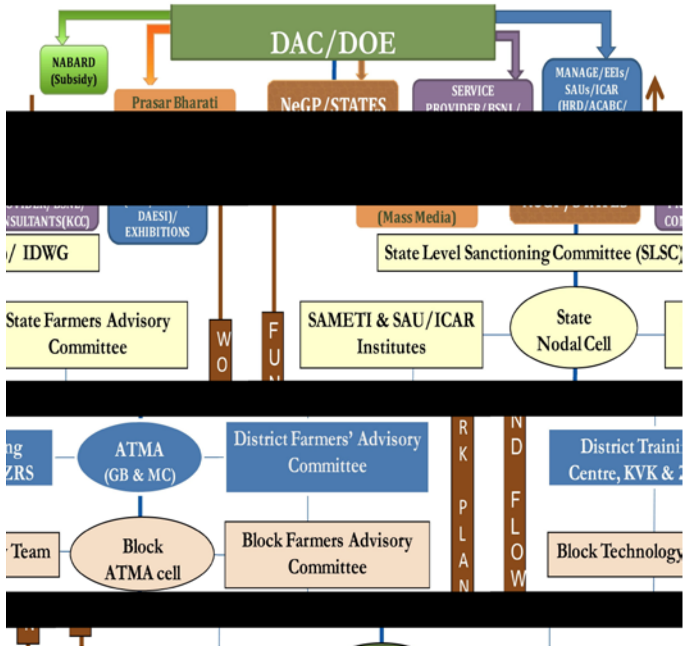
SMSP	SMAE	SMAM	SMPP
Seed Village Programme	Farm Schools, Demo Plots, Trainings, Exposure Visits	Capacity Building by Institutions identified by the State Government	Pest Monitoring (including Pest Scouts), FFSs, IPM Training to Farmers

Five Tiered Modes of Awareness Campaign (TV, Newspapers, Booklets, KCC, Internet, SMS) will also be used for disseminating information or providing services under all schemes and programmes perta Funds earmarked for such activities under different Sub-Missions of NMAET, Missions & Schemes / Programmes will be utilized through ATMA. Such convergence arrived at through SREP / SEWP will avoid duplication and ensure wider coverage in terms outreach to farmers and gamut of activitiesining to agriculture and allied sectors (including various Sub-Missions of NMAET. Technical, legal, administrative & regulatory functions and other components (not related to farmer centric extension) will continue to be discharged independently under the respective Sub-Missions.

Support to State Extension Programmes for Extension Reforms (ATMA Scheme): This Scheme shall focus on the following key extension reforms:

- Encouraging multi-agency extension strategies involving Public/ Private Extension Service Providers.
- Ensuring an integrated, broad-based extension delivery mechanism consistent with farming system approach with a focus on bottom up planning process.
- Adopting group approach to extension in line with the identified needs and requirements of the farmers in the form of CIGs & FIGs and consolidate them as Farmers Producer Organisations;
- Facilitating convergence of farmer centric programmes in planning, execution and implementation.
- Addressing gender concerns by mobilizing farm women into groups

The above objectives shall be met through strengthened institutional arrangements, dedicated manpower, Innovative Technology Dissemination component and revamped strategy. The organizational structure at various levels has been depicted in the following diagram:



2.7 COMPONENTS OF THE SCHEME:

2.7.1 Specialist and Functionary Support at various levels:

It is proposed to re-designate the Subject Matter Specialists (SMSs) as Assistant Technology Managers (ATMs). In order to rationalize number of cultivators per functionary at block level, an average figure of 3 Assistant Technology Managers (ATMs) per block have been envisaged in place of 2 SMSs per block provided so far.

2.7.2 Cafeteria of Activities:

Optional items form the ATMA Cafeteria from where the States can choose activities as per its priorities. The Cafeteria also contains mandatory components which include manpower, training of extension personnel, organization of Farmers' Advisory Committees, Farmer Friends, joint visits with scientists, low cost publications etc.

2.7.3 Innovative Technology Dissemination Activities:

Use of interactive & innovative methods of information dissemination like Pico Projectors, low cost films, hand held devices, mobile based services etc. and other innovative extension approaches (e.g. Kala Jatha) are included as mandatory activities.

2.7.4 Increasing Coverage of Activities, Inclusion of New Activities and Infrastructure Support:

Funds available under RKVY can be used to supplement extension activities undertaken under this Scheme which has provisions for the same under the 12thPlan.

2.8 SPECIALIST & FUNCTIONARY SUPPORT:

Extension related manpower is proposed at three levels.

2.8.1 State Level:

(i) **State Nodal Cell**: the State Nodal Cell (SNC) will consist of State Nodal Officer, State Coordinator, Gender Coordinator and supporting staff.

(ii) SAMETI: The overall staff position at State level is given below.

Posts	State HQ.	SAMETI				Total Staff
No. of Blocks	State Coordinator + Gender Coordinator	Director	Dy. Director	Accountant / Clerk	Computer Programmer	
< 100	1 + 1	1	4	1	1	9
100 – 400	1 + 1	1	8	1	1	13
> 400	1 + 1	1	12	1	1	17

2.8.2 District Level: Each ATMA Unit consisting of
i) Project Director-1; (ii) Deputy PD – 2; (iii) Accountant-cum-Clerk – 1; and (iv) Computer Programmer/Operator–1

2.8.3 Block Level:
(i) One BTM is provided in each Block to co-ordinate the ATMA related activities of the BTT and BFAC.
(ii) On an average three Assistant Technology Managers (ATMs) are to be placed in each Block (2 to 4 depending on size of the Block) exclusively for delivery of extension services in agriculture and allied sectors as per priority areas for various Blocks.

2.10 SUPPORT FOR INNOVATIVE ACTIVITY AT VILLAGE LEVEL (FARMER FRIEND):
(i) It is necessary to identify and groom progressive farmers (including women farmers) with requisite qualification (Senior Secondary/ High School) & experience as Farmer Friend (FF), one per two census villages.

3.0 CAFETERIA OF ACTIVITIES

3.1. ATMA CAFETERIA:
(i) Some additional / new activities and revised unit costs for a few existing items in the 11th Plan, as indicated in bold and italics, have been included in the Cafeteria of Activities.

MAIN ACTIVITIES INCLUDED IN THE CAFETERIA:
3.2. FARM SCHOOLS: In order to have a visible impact and to ensure proper monitoring, cluster approach needs to be adopted by covering various Blocks in rotation every year.

3.3. DEMONSTRATIONS: It is necessary to follow a cluster approach in organization of demonstration plots within a block to have a discernible impact on the production of crops/ allied area.

3.3.2. FORMATION OF COMMODITY INTEREST GROUPS:
I. To ensure household food and nutritional security, Farm Women's Food Security Groups (FSGs) @ at least 3 per block are to be formed each year. These FSGs are to be provided support for training, publication and access to inputs @ ` 10000 per group.

3.3.5 Joint Visits by Scientists and Extension Functionaries: Three visits per month to one visit per week in the last two years.

3.3.6 Incentive for Exemplary Extension Work: It is proposed to have six awards (3 sets of first and second position) at Districy level each year. The awards will be worth ` 25000 and ` 15000 peraward for 1st and 2nd position in each of the three season viz. Kharif, Rabi And Zaid.Besides the above awards, best PPP (Public Private Partnership) initiatives in the field of agriculture and allied area may be supported.

3.4 MAIN ACTIVITIES INCLUDED IN INNOVATIVE TECHNOLOGY DISSEMINATION (ITD) COMPONENT:

3.4.1. Display Boards: These Board will also contain broad details of main schemes (including their major components, eligibility, subsidy pattern etc.) applicable in that area.

3.4.2.Pico/ Ultra-Light Portable Projector + Low Cost Films: Pico projectors (or alternatively ultra-light portable projectors) have been found to be very appropriate in rural areas and these are easier to operate without any laptop. 2 Pico Projectors per block are to be provided to field functionaries for disseminating best agricultural practices. The low cost films would focus on specific themes and preferably directed by farmers themselves so as to have greater acceptability among the audience.

3.4.3 Use Of Hand Held Devices:

Use of hand-held devices for on the spot data entry and subsequent updation through voice recognition has been pilot tested with the collaboration of IIT, Chennai. At least 20000 extension workers (average of about 45 units per district) in 400 districts are to be covered during the XII Five Year Plan.

3.4.4 *Kala Jathas*, Certified Crop Advisors and Other Innovative Methods: Path-breaking and interesting methods such as '*Kala Jathas' (road shows)*, Wall Posters, Extension Buses, Certified Crop Advisors etc. have been tried successfully in some States to deliver the message effectively and informally in an interactive manner.

3.5 INVOLVEMENT OF AGRI-CLINICS & AGRI-BUSINESS CENTRES AND DAESI TRAINEES

3.5.1 Supplementary Manpower through ACABC: The trained candidates should be involved in delivering extension services to the farmers.

3.5.2 Supplementary Manpower through DAESI: Another avenue for involvement of private entrepreneurs in extension related activities is Diploma in Agricultural Extension Services for Input Dealers (DAESI).

3.5.3. The PD, ATMA may prepare an inventory of agricultural graduates trained under the scheme of Agri-Clinics & Agri Business Centres and the list of agri-entrepreneurs established in the district by browsing MANAGE website (www.agriclinics.net) and DAESI trained input dealers.

3.6. SETTING UP OF COMMUNITY RADIO STATIONS (CRSs): During the XII Five Year Plan, 1/3rd of the districts, on an average should have a Community Radio Station per State. The amount earmarked for this purpose shall be `6 lakh per district subject to a minimum of `40 lakh per new CRS per year provided further that this would be the outer limit on aggregate amount for that year subject to break up of year wise of costs approved for that CRS.

IV. OTHER OPERATIONAL MATTERS

4.1. OTHER OPERATIONAL MATTERS:

4.1.2. In order to carry out the extension activities in difficult areas an additional 5% allocation for 227 districts(36% out of 618) in the difficult areas viz. Left wing affected districts, North Eastern and Hill States for field activities may be utilized. ATMAs should capture Unique Identification (UID) details of the farmer beneficiaries under the components of availing training, exposure visits, demonstration plots, farm schools, revolving fund for the CIGs etc. and upload the details in the Electronic Monitoring System developed by the Department.

V. CONVERGENCE OF EXTENSION WORK

5.1. CONVERGENCE:

5.1.1. This convergence should be institutionalized by ensuring that State Extension Work Plan [which emanates from Strategic Research and Extension Plan (SREP)] covers field level training & extension components for all modes of Mission. SREP is an ideal platform to provide convergence from the conceptual level and prioritization point of view. IDWG will further underline such a convergent approach at the State level.

5.1.2 A single ATMA Governing Board headed by the District Magistrate will provide commonality in approach & implementation and avoid duplication. ATMA Governing Board shall act as an over-arching umbrella at District level to oversee all extension related activities in other

5.1.3. Convergence with other Farmer Centric Schemes of DAC:
5.1.4. Convergence with Research System:
5.1.5 Convergence with Development Departments:
5.1.6 Convergence with & Involvement of Non-Governmental Sector:

5.2. NETWORKING: State level bodies/ officers viz. State Nodal Officer/ State Coordinator/ Gender Coordinator will ensure networking of all ATMAs so as to foster information sharing (success stories, best practices, research/ extension issues, application of innovative technologies & strategies, etc.). All District ATMAs shall establish their own portals to share information regarding their activities/ innovations/ successes to the outside world. This Portal shall also have links to related websites both at State and National level.

VI BUDGET ALLOCATION, RELEASE & UTILISATION

6.1. ALLOCATIONS AND SCHEME COST:

6.1.1. Centre–state share: The funding support for the Scheme shall be in the ratio of 90:10 (Centre : State) for all components except Farmer Friend and ITD components. For Farmer Friend, it will be 50:50 ratio between the Centre and the States. In case of Innovative Technology Dissemination (ITD) interventions 25% expenditure will need to be borne by the States. 100% GOI funding support to be provided to UTs (without legislature) for all components.

VII. MONITORING AND EVALUATION

7.1. MONITORING AND EVALUATION (M&E):

7.1.1. Activities of the scheme shall be monitored and evaluated at periodic intervals through a specific mechanism generated at different levels – Block, District, State & National Level.

7.1.2. Cumulative Monthly Progress Reports (MPRs) for each district are to be uploaded by the Project Director, ATMA in a web-based interface.

7.1.3. SPECIALIST AND FUNCTIONARY SUPPORT ELIGIBLE UNDER THE SCHEME

Specialist and Functionary Support	Ceiling on Unit Cost Norms	Proposed Ceiling for Activity	Remarks
STATE LEVEL			
State Nodal Cell 1. State Coordinator (one) 2. Gender Coordinator (0ne)	*Rs.40000/month each*	*Rs.4,80,000/ year for each*	*One State Coord. and one Gender Coordinator.*
SAMETI 1. Director (one) 2. Faculty in the thrust areas (4 or 8 or 12) (HRD, Agriculture Extension Management, IT & Post Harvest Management) *3.* Accountant-cum-Establishment Clerk (one)	*Pay Scales/ remuneration as per Annexure-II (c)*		Faculty positions linked to No. of Blocks in the State (<100 Blocks – 4, 100-400 Blocks – 8 and > 400 Blocks – 12)
4. Computer Programmer (one)/ Computer Operator	*Rs.16000/month**	*Rs.1,92,000/ year*	*As given in Annexure II (b)*
DISTRICT AND BLOCK LEVEL			
AT DISTRICT LEVEL 1. Project Director, ATMA (1) 2. Dy. Project Director ATMA(2) 3. Accountant-cum-Establishment Clerk (1)	*Pay Scales/ remuneration as per Annexure-II (c)*		*As given in Annexure II (c)*
4. Computer Programmer / Computer Operator (1)	*Rs.16000/month*	*Rs.1,92,000/ year*	
AT BLOCK LEVEL 1. Block Technology Manager (BTM) (1)	*Rs.20000 + Rs. 5000 as opex/ month*	*Rs.3,00,000/ year*	
2.Assistant Technology Manager (Average 3 per block)	*Rs.11000+ Rs. 4000 as opex/ month*	*Rs.1,80,000/ year*	

Annexure-III(a)

ATMA CAFETERIA

LIST OF ACTIVITIES ELIGIBLE UNDER THE SCHEME ' SUPPORT TO STATE EXTENSION PROGRAMMES FOR EXTENSION REFORMS' AND ASSOCIATED COST CEILINGS/ NORMS

(All components with 90:10 cost sharing ratio between Centre and States except in case of Farmer Friends where it would be 50:50)

Note: Newly included/ modified items in the Cafeteria are given in Bold and Italics.

(Amount Rs. in Lakh)

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
A.	**State Level Activities**				
A.1	**Monitoring & evaluation**				
	(a)Quarterly review workshops and R-E Interfaces (pre-seasonal)	Per workshop/ Interface	0.75	2.25	Up to a maximum of 3 Workshops
	(b) Concurrent Monitoring & Evaluation.	Annually	Up to 15.00 lakh	**8.00 Lakh for States below 100 Blocks**	Yearly activity shown as 3rd Party M&E has been changed to yearly concurrent evaluation.
				10.00 Lakh for States with 100 to 200 blocks	
				12.00 Lakh 201 to 400 blocks	
				15.00 Lakh for States with over 400 blocks.	
	(c) Expenses for Inter Departmental Working Group on extension reforms and other contingencies including Operational support TA/ DA, hiring of vehicle/POL, and contingencies for officers of State Nodal Cell and State Coordinator and Gender Coordinator	Per year	**Up to 10.00**	**5.00 Lakh for States below 100 blocks**	This includes operational expenses for SFAC also.
				7.00 Lakh for States with 100 to 200 blocks	
				8.50 Lakh for States with 201 to 400 blocks	
				10.00 Lakh for States with over 400 blocks	
A.2	(a) Training courses-National / Inter State / within the State (SAMETI)	Per day per Participant	0.015*	***Avg. 2.0 per block***	***Up to 10 functionaries per Block for trainings***

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
	level - Both Govt. & Non-Govt. extn. Functionaries (including NGOs, Para Extension Workers, Input Suppliers, Farmer Friends, ATM, BTM, Project Director, Dy. Project Director, Director & Faculty of SAMETI, officers of SNO				*preferably between 3 to 30 days.*
	(b) Induction Training of ATMA functionaries	*Per day per Participant*	*0.010**	*Actual*	*Actual no. of BTMs & ATMs in position in 2014-15 and the newly recruited BTMs & ATMs in subsequent years.*
	(c) Refresher Training of all ATMA functionaries	*Per day per Participant*	*0.010**	*Actual*	*Actual number of all technical functionaries minus the BTM & ATM who are being provided with induction training. Two trainings of 3 day duration (i.e. 4 day including travel) each.*
	d) Development of Quality Resource Material for Training & HRD Interventions	*Per day per Participant*	*0.015**	*15 Workshop Days per State for states with less than 100 blocks*	*10 Experts/ Participants are expected to participate in each Workshop to be held once in two*
				30 Workshop Days per State for states with 101-400 blocks	
				45 Workshop Days per State for states with more than 400 blocks	
A3	Exposure Visit of	Per participant	0.01	Avg.0.75 per block	Up to 5

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
	extension functionaries and PRI members to progressive states. (A group of minimum 5 participants).	per day			functionaries per Block per batch of an Exposure Visit. Maximum period of an exposure visit not to exceed 7 days (excluding journey time).
A4	Organization of State level exhibitions/ Kisan Melas/ Fruit/Vegetable shows etc.	Per Year	***6.00***	***6.00***	One Exhibition / year
A5	Participation in Krishi Expo & Regional Fair organized/ supported by DAC.	Per State	***2.00***	***2.00***	***Actuals limited to the activity ceiling***
A6	***Award for best performing ATMA***	Per Year	***1.50***	***1.50***	***Trophies and certificates can be given for overall performance and for selected activities.***
A7	**(a) Farmer Awards – Best farmers representing different areas of agriculture**				
	• State level	per year per farmer	0.50	5.00 per state	10 farmers per state @2 farmers per activity
	• District level	per year per farmer	0.25	2.50 per district	10 farmers per district @2 farmers per activity
	(b) Incentive for Exemplary Extension Work to District/Block level Extension functionaries	***No. of Awards***	***0.25 per season for kharif, Rabi and zaid***	***0.15 + 0.10 for first and second prizes respectively in each season***	***2 Awards per 3 cropping season @ Rs.15000 for 1st position and 10000 for 2nd position (thrice a yr.)***
	(c) Incentivising Scientists and ext. personnel	***Lump sum***			***1.00 crore lump sum for incentivising Scientists and ext. personnel. The states may nominate Scientists and extension functionaries as per the numbers indicated below: States with < 20***

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
					districts – 1 official Satates with 21-30 distts -2 officials States with > 31 distts. – 3 officials. The names may be sent to MANAGE for processing of applications at GoI level.
	(d) Lumpsum grant for PPP model	*Lump sum*			*Rs. 1 crore , 3 crore and 5 crore in the year 2014-15, 15-16 and 16-17 respectively are lump sum amount funds available for the purpose. States may forward suitable proposals for PPP model to GOI, who would then allocate the funds according to merit.*
A.8	For SAMETI				
	(a)Operational Expenses for SAMETI	*Per year*		*Avg. 0.14 per Block with a minimum of 9.00 per SAMETI*	
	(b)Documentation of success stories etc. (preparation and dissemination).	Per year	Actual	5.00	
	(c) Vehicle hiring and POL	Per year	-	4.00	
	(d) Non – Recurring Equipment	One time	-	• Rs. 3.00 for less than 100 blocks • Rs.4.5 with 100-200 blocks • Rs. 6.0 with 201-400 blocks Rs. 8.00 with more than 400 blocks	One time Grant shall only be used when the hard-ware/equipment becomes obsolete
B	**DISTRICT LEVEL ACTIVITIES**				
	I. Farmer oriented activities:				

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
B.1	Developing / Revisiting Strategic Research & Extension Plan (SREP)	Per district	1.5	1.5 per district	One time
B.2	Training of farmers for not more than 7, 5 and 2 days duration respectively.				
	(a) Inter-State	Per farmer per day	0.0125	0.625 per block	Cost norms are inclusive of: i) Travel cost by bus or second class sleeper ii) Refreshments / Meals and Stay during training iii) Expenditure on training venue, training material and agricultural inputs, if any iv) Cost of honorarium and/or travel of the trainer v) Any other justifiable expenditure. Considering fixed cost on travel of farmers, training cost should go down as number of days increases or nature of refreshment / meals should improve.
	(b) Within State	Per farmer per day	0.01	1.00 per block	
	(c) Within District level	Per farmer per day	0.004 / 0.0025	4.00 per block	Likely expenditure or State / location specific cost norms needs to be got approved in advance. Limit of Rs. 400 for District level training only if it is residential, otherwise Rs. 250
B.3	Organizing demonstrations				
	(a) Demonstration (Agri.)	Per demonstration	Upto 0.04 per demo* of 0.4 ha. As per Appendix- I	5.00 per block	Frontline demonstration at Farm School on a maximum area of 2.5 acre at same rates as approved under the Guidelines of National Food Security Mission for

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
					the crops mentioned therein. For other crops rates, rates may be decided by ATMA MC subject to a maximum of Rs. 4000 acres covering items mentioned in NFSM Guidelines. The approved norms under NFSM for Rice/ Wheat/ Pulses is Rs.Rs.3000/ acre and Rs.2000/ acre for coarse cereals
	(b) Demonstration (allied sector)	Per demonstration	0.04 per demo for allied sectors	2.00 per block	
B.4	Exposure visit of farmers				
	(a) Inter State	Per day/ participants	0.008	0.40per block	Up to 5 farmers per Block per batch of an Exposure Visit. Maximum period of an exposure visit not to exceed 7 days (excluding journey time).
	(b) Within the State	Per day/ participant	0.004	0.80 per block	Up to 5 farmers per Block per batch of an Exposure Visit. Maximum period of an exposure visit not to exceed 5 days (excluding journey time).
	(c) Within District	Per day/ participant	0.003	0.30 per block	Up to 5 farmers per Block per batch of an Exposure Visit. Maximum period of an exposure visit not to exceed 3 days (excluding journey time).
B.5	Mobilization of farmer groups of different types including Farmer Interest Groups, Women Groups, Farmer Organizations, Commodity Organizations, and Farmer Cooperatives etc.				
	(a) Their capacity building, skill development and support services	Per group/ per year	0.05	1.00 per block	Upto 20 groups per block

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
	(b) Seed money /revolving fund	Per group	0.10	1.00 per block	Only to viable groups on competitive basis
	(c) Food Security Groups	Per group	0.10	0.20 per block	2 FSGs/Block is mandatory. These will be all women farmers' groups and Seed Money will be given for Household food security garden
B.6	Rewards and incentives –Farmer Groups	Per year per group	0.20	1.00 per district	Best organized group representing different enterprises (5 groups)
B.7	Farmer Awards	Per year per farmer	0.10	0.50 per block	Best farmers representing different enterprises at Block Level
	II. Farm Information dissemination				
B.8	District level exhibitions, kisan melas, fruits/ vegetable shows	Per district		4.00 per district	
B.9	a)Information dissemination through printed leaflets etc and local advertisements.	Per district	-	4.00 per district	
	b) low cost publication	Per Publication		0.72 per block	Desirable component-10 copies of 6 publications @ 12 publication (max.) to be distributed in all the villages of the block
B.10	Development of technology packages in digital form to be shared through IT network.	Per package	0.20	2.00 per district	For production of max. 10 packages
	III. Agricultural Technology Refinement, Validation and Adoption:				
B.11	(a) Farmer Scientist Interactions at district level 25 farmers for 2 days.	Per interaction	0.2	0.40 per district	2 interactions per district
	(b)Designate expert support from KVK/SAU at District Level	Per Month/per District	0.02	0.24 per District	KVKs/SAUs have to designate expert in charge of one district. He would

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
					provide instant guidance to district functionaries/BTMs/ SMSs within his respective district. The support includes that of Mobile Phone
	(c) Joint visits by Scientists & Extension Workers	per visit per district	• 0.012 in 2014-15 • 0.014 in 2015 -16 & 2016-17	0.288/ district in 2014-15 0.364/ district in 2014-15 and 2015-16	Desirable Component 24, 26&26 visits during each yr starting from 3rd year in each Districts@ Rs.1200/ visit in the third year and Rs. 1400/ visit in 4th and 5th year
B.12	Organization of Kisan Gosthis to strengthen Research – Extension – Farmer linkages (1 per block in each of the 2 seasons).	Per programme	0.15	0.30 per block	
B.13	Assessment, Refinement, Validation & adoption of Frontline technologies and other short term researchable issues through KVK sand other local Research Centres.	Per District		5.00 / district	As per assessment of KVK/ local Research Centres/ and/ or issues emerging from SREP
	IV. Administrative / Capital expenses at District and Block level				
B.14	RECURRING				
	(a) TA/ DA and Operational expenses for district level *	Per district		7.8	Operational expenses may included service
	(b) Hiring of vehicles and POL	Per district	-	1.8	This includes TA/ DA
	(c)Operational Expenses exclusively for block level (Including Hiring of vehicles and POL)	Per Blocks	-	0.3	
	(d) Operational Expenses for DFAC Meetings	Per Meeting	0.05/Meeting	0.20	4 Meetings @ Rs. 200/farmer for 25 farmers

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
	(e) Operational Expenses for BFAC Meetings	Per Meeting 6	0.025/Meeting	0.15	BFAC meetings @Rs.100/farmer for 25 farmers
	Non – Recurring (i) Equipment (Computer etc.)	(i) Per District		4.00	One time Grant. Shall only be used when the hardware becomes obsolete.
B.15	Farm School		Rs.29,414/Farm School (AS given at Enclosure I).+ Rs.4000/ group of Farm Schools		Farm Schools will be preferably organised in a cluster approach so as to have a demonstrable impact. Normative allocation is based on the number of Blocks x 3 per year.
C.	**Innovative Activities – State Level**				
C.1	Implementation of Extn. Activities through Agri-preneurs trained under Agri-Clinic Scheme or any other Scheme	To be approved by IDWG/SLSC		No. of ATMA blocks x 0.25 lakh	The activity to be taken up should be as per approved norms e.g. if demonstration is to be taken up, the norms for demo. given in the cafeteria is to be adhered to.
C.2	P.G. Diploma in Agricultural Extension through MANAGE	Per beneficiary	0.15/beneficiary y	0.325/block	Funds would be released to MANGE on behalf of the States based on the number of participants nominated by the states.
D.	Innovative Activities – District Level				
D.1	Support for district level Training Institutions – It may include both “Operational Expenses” and Non- Recurring expenditure	One Institution per ATMA district per year.		5.00/ district	
D.2	(i)Setting up CRS		Rs. 14,55,000/-	Rs.65.00/state/year	

S. No.	Indicative Activities to be Undertaken	Cost norms			Remarks
		Unit	Unit Cost Ceiling	Tentative Ceiling on Activity	
	(ii) Content Creation (a) Ist year for two hrs. of daily programme i.e 730 hrs/year.		Rs. 17,15,500/-		
	(b) 2nd year for one and half hour of daily prog. I.e. 540hrs./year		Rs. 12,87,800		
D.3	Farmer Friend	One FF/ 2 Village	0.06/ FF per year	Actuals	50% is to be borne by State Govt.
E.	**OTHER INNOVATIVE ACTIVITIES**				
E.1	Innovative activities – State component			25.00/ state	To be approved by IDWG
E.2	Innovative activities – District component			0.5/ block	To be recommended by ATMA and approved by IDWG

NOTES