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Best practices for sorghum cultivation and importance of value-addition

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Abstract

This reference book of the model training is a compilation of lectures delivered by the experts on latest aspects of sorghum development including millets on improved production technologies, crop management, preparation and value-added products, sweet sorghum, nutritional benefits, technology transfer and future implications. These apart, practical aspects of new process/methods, production and marketing were also covered. All the articles represented views of the respective contributors and they assume responsibility for any odd/advanced statements and opinions.

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FOREWORD

Although, sorghum and other minor millets have great potential to contribute to national food security and to achieve sustainable livelihood security in dryland ecosystems, their area under cultivation is going down. With changing needs of the people and time, it is facing strong competition from commercial and vegetable crops. However, the average productivity has increased from 522 kg/ha in 1969 to 907 kg/ha in 2014-15. It could achieve due to adoption of improved production technologies by the farmers. It is being utilized for various purposes such as food, feed, fodder and more recently as bio-fuel. The viable options and potential technology basket are available for enhancing grain and fodder production, intercropping, drought management, rainwater conservation, nutrient management, plant protection, sweet sorghum, market-oriented products and storage. These needs to be introduced at grassroot level through extension agencies to achieve the goal. For this, the Extension system has vital role to transfer valuable technologies and information to the end users. In this regards, it is our important duty to support in strengthening the extension system of sorghum growing states with latest development of sorghum.

With this objective, this Directorate is organizing training on "**Best practices for sorghum cultivation and importance of value-addition**" from 20th to 27th September, 2016 for field extension functionaries of sorghum growing states to empower them with latest technical knowledge and skills. It will includes theory and practical sessions on various aspects of sorghum development emphasizing preparation of value-added products, its marketing and importance of sweet sorghum for bio-fuel. Relevant literature on latest production technologies and a reference book comprising notes from the resource persons have been provided to the participants. I am sure this training will help to enhance the competency of the participants in their job performance.

I am thankful to all the resource persons and support from ICAR-IIMR, ICRISAT, NIN, NAARM, NIPHM, State Agriculture Department, Maharashtra and TSCOB-CTI for their contributions and support for this training. The financial support from the Directorate of Extension, Ministry of Agriculture, New Delhi is also duly acknowledged. I appreciate the support of scientists and officials of ICAR-IIMR involved in this programme. I compliment Dr. RR Chapke, Course Director and team for organization this training and for their efforts in bringing out the reference book.

(Vilas A Tonapi)

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Best practices for sorghum cultivation and importance of value-addition

Contents

1. Genetic improvement in kharif sorghum and latest kharif cultivars

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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 un-utilised 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 un-surmountable 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.

Varieties/ Hybrids	Grain Yield (q/ha)	Dry-Fodder Yield (q/ha)	Plant height (cm)	Maturity (Duration) (days)	Salient features
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 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

Varieties/ Hybrids	Grain Yield (q/ha)	Dry-Fodder Yield (q/ha)	Plant height (cm)	Maturity (Duration) (days)	Salient features
					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.

2. Major sorghum pests and their management

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Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important cereal crops grown in the semi-arid tropics of the world providing food, feed, fodder, fiber and fuel. It ranks fifth in world cereal production with an annual production of 55.7 million tonnes (FAOSTAT, 2012). The productivity levels of sorghum under subsistence farming are quite low mainly because of biotic constraints. Insect damage is one of the challenges that impacts sorghum yields. There are at least 150 insect species that can infest sorghum worldwide. These insects target various parts of sorghum plants at developmental stages, and they cause significant losses. About 32% of sorghum crop is lost due to insect pests during the rainy season (Borad and Mittal, 1983), and 26% during the postrainy season (Daware et al., 2012) in India. Sorghum shoot fly, *Atherigona soccata* (Rond.), spotted stemborer, *Chilo partellus* (Swin.), Oriental armyworm, *Mythimna separata* (Walk.), shoot bug, *Peregrinus maidis* (Ashm.), sugarcane aphid, *Melanaphis sacchari* (Zehnt.), sorghum midge, *Stenodiplosis sorghicola* (Coq.), head bugs, *Calocoris angustatus* (Leth.) and head caterpillars, *Helicoverpa armigera* and *Eublemma* are the major pests worldwide.

Shoot bug and midge are attaining the status of major pests in certain pockets of peninsular India. Sugarcane leafhopper, *Pyrilla perpusilla*, a pest of sugarcane has been found to damage sorghum in Northern part of India grown for fodder purpose.

Seedling pests
Shoot flies
Geographical distribution: Southern Europe, North and East Africa, India and the Middle East.
Host plants: Sorghum, corn, bajra, rice, wheat, ragi, various Gramineae (Poaceae).
Biology: Shoot fly, *Atherigona soccata* (Rond.) is one of the major pests that destabilizes the sorghum production. Adult female measures about 3-3.5mm in length. Body is grey-brown and abdomen and legs are yellow in colour. Abdominal segments marked with two rows of six dark spots in female and four dark spots in male. The preoviposition period is 3-5 days long. Single female fly lays 40 eggs with an average incubation period of 3 days. Larva about 6.5 mm long and has 2 posterior black spiracular lobes. 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 females live an average of 30 days and the males about 20 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.

Table: Insect pests of sorghum and their status

	Common name	Scientific name	Damaging stage	Status
Seedling pests	Shoot fly	*Atherigona soccata*	Maggot	Major
	Flea beetle	*Cryptocephalus schestedii* *Monolepta signata*	Adult	Occasional
Foliage pests	Grasshopper	*Colemania sphenaroides*	Nymph & Adult	Sporadic
	Hairy caterpillar	*Amsacta albistriga* *A. moorei*	Caterpillar	Occasional
	Cutworms	*Mythimna separata*	Caterpillar	Occasional
	Weevils	*Myllocerus maculosus* *M. discolor*	Grub	Occasional
Stemborers	Spotted stem borer	*Chilo partellus*	Caterpillar	Major
	Pink stem borer	*Sesamia inferens*	Caterpillar	Major
Sucking pests	Shoot bug	*Peregrinus maidis*	Nymph & Adult	Major
	Aphids	*Rhopalosiphum maidis* *Melanaphis sacchari*	Nymph & Adult	Major
	Spider mites	*Oligonychus spp.*	Nymph & Adult	Sporadic
Panicle pests	Earhead bug	*Calocoris angustatus*	Nymph & Adult	Major
	Midge	*Stenodiplosis sorghicola*	Maggot	Occasional
	Earhead web worm	*Cryptoblabes gnidiella*	worm	Occasional
	Gram caterpillar	*Helicoverpa armigera*	Caterpillar	Occasional
Soil dwelling insects	Root grubs	*Holotrichia. consanguinea*	Grubs	Occasional

Damage symptoms: The shoot fly females lay white, elongated, cigar-shaped eggs singly on the abaxial leaf surface of sorghum seedlings at 5-30 days after seedling emergence. Most of the eggs are laid between 08.00 to 12.00 h, and they hatch between 04.00 to 06.00 h. On emergence, the neonate larvae crawl to the plant whorl and move downward between the folds of the young leaves. After reaching the growing point, it cuts the growing tip resulting in wilting of leaf and later drying of the central leaf known as 'deadheart'.




Shoot fly adult | Egg | Maggot | Pupa

Deadheart symptom

Deadheart formation leads to the seedling mortality. If the infestation occurs a little later, damaged plants produce side tillers which again are infested increasing the population build up. The damage occurs 1–4 weeks after seedling emergence. The total life cycle from egg to adult is completed in 17–21 days. The shoot fly females prefer second leaf, followed by third, first, and fourth leaves for egg laying under laboratory conditions, while third leaf, followed by second, fourth, fifth, sixth, first, and seventh leaf were preferred for oviposition under field conditions. Sorghum shoot fly is active throughout the year, and there may be 10–15 generations in a year. There is no diapause during the off-season. During the off-season, the insect survives on alternate hosts (*Echinochloa colonum*, *E. procera*, *Cymbopogon* spp., *Paspalum scrobiculatum*, and *Pennisetum glaucum*), tillers of ratoon crop, and volunteer or fodder sorghum. Its severe incidence necessitates re-sowing. 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 deadhearts.

II. Foliage feeders

Grasshoppers

Many species of grasshoppers are present, but only a few have pest potential. Common pest species include: clearwinged grasshopper, *Camnula pellucida*; differential grasshopper, *Melanoplus differentialis*; migratory grasshopper, *Melanoplus sanguinipes*; two striped grasshopper, *Melanoplus bivitattus*; and red legged grasshopper, *Melanoplus femurrubrum*. In India *Hieroglyphus nigrorepletus,* *H. banian, Chrotogonus spp., Colemania spheneroides* are destructive to millet crops.

Biology: Grasshoppers lays eggs in clusters in the soil. Eggs laid in the soil in the form of an elongate shaped pod which contains 20–120 eggs each. Eggs may be white, yellow green, tan, or various shades of brown. Eggs hatch into nymphs in late May and June. Newly hatched nymphs are white. After several hours of exposure to sunlight, they assume the distinctive colors and markings of adults. Nymphal period is 35 to 50 days. Adults are stout, greenish brown colour with yellow stripe on the sides.

Damage symptoms: The nymphs and adults mostly feed on leaves during the day. Nymphs and adults of several species of grasshopper may chew holes in leaves causing a ragged appearance in sorghum. Grasshoppers buildup at the boarder and move into sorghum fields causing damage along field margins. In case of severe infestation, they defoliate entire leaves and the field looks like grazed appearance. Their population usually is greater in dry than wet years.

Grasshopper damage

Weevils

Ash weevils: *Myllocerus maculosus*, *M. viridanus*, *M. subfasciatus* & *M. discolor;* (Curculionidae: Coleoptera)

Distribution: Throughout India

Host range: Bajra, maize, sorghum

Bionomics

M. viridanus: Adult weevil with greenish white elytra

M. maculosus: Adult weevil with greenish white elytra having dark lines.

M. discolor: Adult weevil is brown in color with white spot on the elytra. Grub is small, white apodous and found feeding on roots. Weevil appears during summer and lays ovoid, light yellow eggs in the soil. Female lays on an average 360 eggs over a period of 24 days. Eggs hatch in 3–5 days. Grub period is 1–2 months, pupation takes place in soil inside earthern cells and pupal period is 7–10 days. Life cycle is completed in 6–8 weeks, thereby completing 3–4 generations in a year. Adults live fairly long for 4–5 months in the winter.

M. subfasciatus: The adult weevil is light grayish to white with four black spots on the wing covers. The eggs are light yellow and laid deep in the soil. The grubs are fleshy, yellow-colored. Pupation occurs in earthen cells in the soil. The egg, larval, and pupal periods last for about 3–11, 3–42, and 5–7 days respectively.

Damage symptoms: Leaf margins are notched resulting in wilting of plants in patches. Roots are eaten away by grubs as a result plants come off easily when pulled. Adult feed on the leaves.

Hairy caterpillars

High incidences of hairy caterpillars, *Amsacta albistriga, Estigmene lactinea*, *Spilosoma oblique* in north, south and western India have been recorded. It infests young sorghum, maize, cotton, castor, cowpea, bajra. Red soils are more suitable.

Biology: The adult moth is medium sized having white fore wings with brownish markings and streaks and white hind wings with black spots. There is a yellow band on the head and a yellow streak along costal margin of the forewings in *A. albistriga* while the band on the head and streak along costal margin of the wing are red in *A. moorei*. Moths emerge with the onset of monsoon from diapausing pupae in June-July. The emergence occurs in waves following rains. Adults pair almost immediately after the emergence and oviposit the same night. Oviposition is spread over 2-3 days. Eggs are cream or bright yellow and are laid in masses on young foliage or on the soil, clods of earth, stones or occasionally on other vegetation. A single female lays about 1000 eggs in clusters of 50-100. Larvae hatch in about 3-4 days.

Redhairy caterpillar Amsacta albistriga

Blackhairy caterpillar Estigmene lactinea

Damage symptoms: The dark hairy larvae feed gregariously on the lower surface of leaves, scrapping them for 4–5 days. In about 10 days larvae become ashy-brown and move slowly from plant to plant, and field to field, feeding voraciously. In about 40–50 days the larvae become fully grown. They are about 5 cm long and have white spots on the body, dense tufts of long hair, and a red head. The larvae, which often group in large numbers, are voracious leaf feeders. Due to gregarious habit and voracious feeding, complete defoliation of sorghum plants or destruction of seedlings may occur in a short time. The large larvae have many blackish hairs on a reddish body. They pass the hot summer as diapauses pupae in soil. Moths emerge about a fortnight after first showers. According to the rainfall distribution, there are one to two generations.

Cutworms and Army worms

Caterpillars are defoliatiors of Sorghum, ragi, maize, and bajra. *Mythmina separata* has been reported feeding on foliage. Outbreaks of the noctuids *Mythimna separata*, *M. albistigma* and *Mocis frugalis* were noticed during kharif 1987 in Bangalore and Kolar districts, Karnataka, India.

Biology: The larvae of *Mythimna albistigma, Agrotis basiconica, A. flammatra, A.ipsilon, A. spinifera, Mythimna separate* and *Mocis frugalis* migrated even during the day. The average numbers of pupae were estimated to be 26.75, 18.5, and 15.0/m^2 in fields of finger millet, maize and grasses, respectively. They cut tender stems of young and growing plants. Larvae hide during day time in the soil and become active at dusk. In severe cases, entire leaf is eaten. The field looks as if grazed by cattle. The caterpillars of *Spodoptera exigua* are serious pests in ragi nurseries feeding on leaves causing extensive defoliation. The grown up larva coils with slightest touch and drops down.

Damage symptoms: The larvae feed on the leaves. It scraps the green matter of the leaf tissue and the leaves shows as skeletonized appearance. The young cutworm feeds on plant without cutting off the stems or leaves. Later it begins to cut off foliage. The larvae hide during day time in the soil and feed on the foliage at night.


Armyworm damage

Borers

Spotted stemborer, *Chilo partellus*

Distribution: India, Pakistan, SriLanka, Indonesia, Iraq, Japan, Uganda, Taiwan, Sudan, Nepal, Bangladesh and Thailand.

Host range: Maize, sorghum, sugarcane, bajra, rice, *Sorghum halepense*, finger millet, etc.

Biology: The moth is medium size and straw colored. A female lays up to 500 eggs in batches of 10 to 80 near the midrib on the under surface of the leaves. Eggs hatch in 4 to 5 days. The larval development is completed in 19–27 days. Pupation takes place inside the stem and the adults emerge in 7–10 days. During the off-season, the larvae undergo diapause in plant stalks and stubbles. With the onset of rainy season, the larvae pupate and the adults emerge in 7 days.




Damage symptoms: It infests the crop a month after sowing and the damage continues upto emergence of earheads. The first indication of stemborer infestation is the appearance of small-elongated windows in whorl leaves where the young larvae have eaten the upper surface of the leaves. Later, the plant presents a ragged appearance as the severity of damage increases. The third-instar larvae migrate to the base of the plant and bore into the shoot. Central shoot withering leading to typical deadheart' symptom. Normally, two leaves dry up as a result of stemborer damage.




Leaf feeding symptom *Deadheart* *Stem tunneling* *Exit holes*

Larvae continue to feed inside the stem throughout the crop growth. Extensive tunneling of the stem and peduncle leads to drying up of the panicle, production of a partially chaffy panicle or peduncle breakage. Stemborer infestation starts about 20 days after seedling emergence, and deadhearts appear on 30–40 day old crop.

Pink stemborer *Sesamia inferens* (Noctuidae: Lepidoptera)

Geographical distribution: India, Pakistan, Malaysia, Taiwan, Burma, Bangladesh, Sri Lanka, South East Asia, China, Korea, Japan and Indonesia.

Host range: Sorghum, maize, rice, wheat, sugarcane, bajra, ragi, barley, guinea grasses.

Bionomics: The adult moth is fawn-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 lasts for 7days. The fully grown larvae measures about 25 mm and has pale yellow with a purple pink tinge and a reddish-brown head. Usually the larval period is 25 days but in cold months it may be extend to 75 days. Pupation occurs in the larval tunnel in the stem and the adult emerges in 12 days. One generation may take 6–7 weeks. The life cycle is completed in 45–75 days. There are 4–6 generations per year.

Adult

Eggs of Sesamia

Larvae feeding inside the stem

Damage symptoms: The pink larva bores into the stem and damages the central shoot resulting in dead heart. Borer holes are visible on the stem near the nodes. Faeces (frass) and empty grains are visible due to damage.

Sucking pests

Shoot bugs: *Peregrinus maidis* (Delphacidae, Hemiptera)

Geographical distribution: Karnataka, Tamil Nadu, Andhra Pradesh and Madhya Pradesh in India

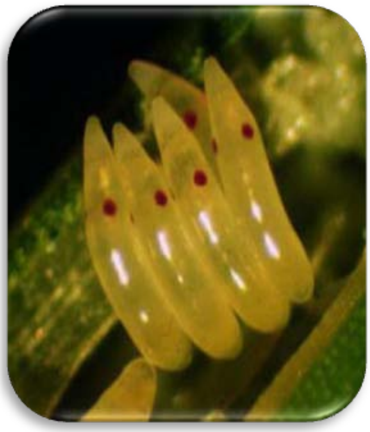
Host range: Sorghum, maize, rice, millets

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. It lays eggs in groups of 1–4 inside the leaf tissue, which remain covered with a white waxy substance. The fecundity of the bug is 97 eggs female^{-1} and 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.



Nymphs and adults live in group in plant whorls and on the innerside of leafsheaths

Damage symptoms: Shoot bug pierces the vascular tissues and suck sap from the leaves, leaf sheaths, and stem during exploratory feeding. Adults and nymphs suck the plant sap, which causes reduced vigor, stunting, and yellowing of leaves. Under severe condition the leaf damage spreads downwards resulting in complete death of the plant. The infestation prior to pre-boot leaf stage usually causes girdling/twisting of top leaves, which bend downwards and prevent panicle development and emergence. The damage is caused between 30–60 days (knee high to pre-flowering stage). Excessive oviposition in the midrib causes eventual drying up of leaves and the tissue surrounding the ovipositing site becomes septic and turns reddish. The feeding punctures and wounds produced by ovipositor predispose sorghum plants to fungal infections. The copious excretion of honey-dew by the insect, encourages sooty mold development. Further, it indirectly reduces the quality and quantity of plant biomass. Moreover, it is also a vector of several important viral diseases like maize mosaic, maize stripe, freckled yellow, and male sterile stunt virus.



Oviposition site after emergence will turn to red




Leaves devoid of chlorophyll *Twisting of top leaves* *Inhibition of panicle formation*

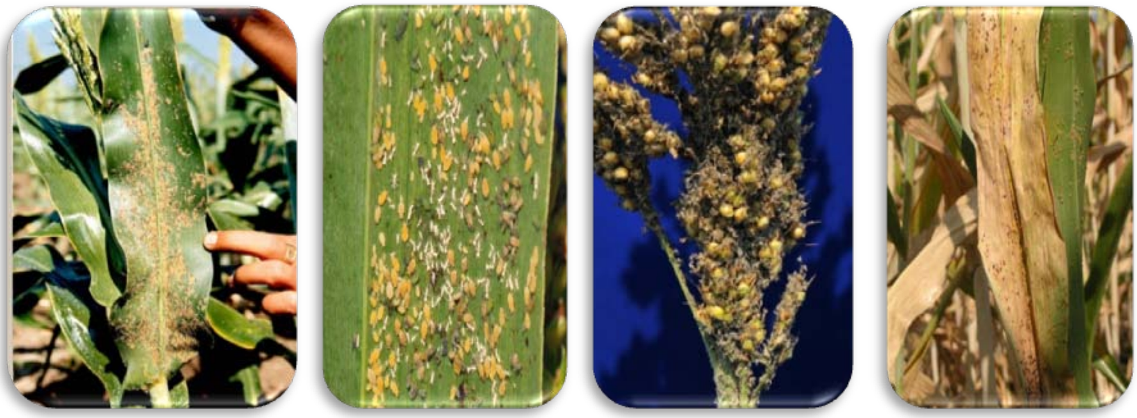
Under favorable conditions, shoot bug completes several generations on sorghum within a season, and so can cause heavy damage. During off-season, it survives on wild grasses like itch grass (*Rottboellia cochinchinensis*), goose grass (*Eleusine indica*), barnyard grass (*Echinochloa crusgalli* L.), bristle grass (*Setaria parviflora*), jungle rice (*Echinochloa colona*), Eastern gama grass (*Tripsacum dactyloides*), and wild Sudan grass (*Sorghum bicolor* subsp. *drummondii*). In addition, maize, triticale, rye, sugarcane, and oats were also observed as alternate hosts to shoot bug. Initially, the macropterous adults emigrate to a healthy crop and colonize for oviposition. The progeny emerging from these eggs may become either brachypterous (wingless) or macropterous (winged) adults under low and high populations. The adults discriminate and preferentially lay eggs on the abaxial surface of the midrib of mature leaves of the sorghum plants. Both adults and nymphs feed on sorghum plants by inserting their stylets into vascular tissue and sucking the plant sap. Repeated stylet insertions into the leaf and stem frequently result in a ring of damaged tissue known as 'girdle'. Girdled regions are characterized by necrotic epidermal tissue and disorganized vascular bundles. In addition, girdling also appears to interfere with translocation of photosynthates.

Aphids: *Rhopalosiphum maidis, Melanaphis sacchari* (Aphididae: Hemiptera)
Geographical distribution: All sorghum-growing areas of the world.
Host range: Sorghum, maize, fingermillet
Bionomics
Rhopalosiphum maidis
The aphid is dark bluish-green. 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. The adult is yellow in color and has dark green legs.
Damage symptom: 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 transmits maize dwarf mosaic virus.

Melanaphis sacchari

The sugarcane aphid is yellow to buff in color. Their number increases rapidly during a dry spell 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. The winged form produces slightly fewer nymphs. The life cycle is completed in about 5.5–7.0 days during the dry season. The honeydew excretion hinders harvesting process and result in poor quality grain. 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 suck the plant sap and cause stunted growth.



Aphids, Melanaphis sacchari damage

Spider mites (*Oligonychus indicus*)

Host range: Sorghum, maize, rice, millets,

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.

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. 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.


Spider mites




Mite damage

Panicle pests

Midges: *Contarinia sorghicola* (Cecidomyiidae: Diptera)

Geographical distribution: India, Pakistan, Bangladesh, West Iran, Sri Lanka, Sudan, Java, Africa, South East Asia, South China, South America, West Indies, USA and Italy.

*Hosts***:** Sorghum cultivated and wild species.

*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. A female lays 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 in color. Larval period is about 9–11days. The larval stage undergoes diapause in a cocoon during December-January within a spikelet. They pupates beneath the glume for about 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 in a year.

*Damage symptoms***:** A maggot feeds on the developing grains and pupates there. Damage symptoms appear as white pupal cases protruding out from the grains and formation of chaffy grains with holes. Pupal cases can be seen attached to the glumes of damaged spikelet. The completion of one generation in a fortnight helps the pest to complete four to five generations in a season with overlapping generations especially when flowers are available. Some larvae pass the dry season by entering diapauses which may last 8-9 months and is terminated by warm and humid conditions in August/September.

Midge damage symptoms

Earhead bugs: *Calocoris angustatus* (Miridae: Hemiptera)
Geographical distribution: South India
Host range: Pearl Millet, maize, tenai, sugarcane and grasses
Bionomics: Adult male is green in colour and female is green with a brown margin. Blue cigar shaped eggs are laid under the glumes or into the middle of the florets. Each insect lays between 150–200 eggs in about seven days. Nymphs are slender, green in colour. First instar larva is orange in colour. 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.

Ear headbug damage

Damage symptoms: 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. 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.

Caterpillars

Earhead web worm: *Cryptoblabes gnidiella* (Pyraustidae: Lepidoptera)
Host: Sorghum, Maize
Bionomics: The adult moth is small with brown fore wings and light brown hind wings. Creamy white, round or conical eggs are laid singly on the spikelets and on grains in a panicle. The egg period is 3–4 days. The larva is light brown with dark head and has dark lateral lines on the body. The larval duration is 9–10 days and pupal period is 7 days. Larva constructs silken cocoon and pupates within the silken webs. The life cycle is completed in 23–24 days.
Damage symptoms: The larvae destroy the grain in the earhead. They produce webs of silken thread that remain on and inside the earhead. Heavily infested heads may be covered with webbing.

Gram caterpillar: *Helicoverpa armigera* (Noctuidae: Lepidoptera)
Geographical distribution: World wide. It is a major pest on cotton, lablab, chillies, tomato, pulses, maize and minor on sorghum.
Host range: Cotton, sorghum, lab lab, soybean, pea, safflower, chillies, tomato, groundnut, tobacco, gram, okra, maize etc.
Bionomics: Adult is a brown color moth with a ‘v’ shaped speck on forewings and dull black border on the hind wing. Larva is green with dark broken grey lines and dark pale bands. It shows colour variation of greenish to brown.
Damage symptoms: Larvae hide within the earheads and feeds on the grains. Earheads are partially eaten and appear chalky. Feacal pellets are visible within the earhead.

Helicoverpa damage

Thrips: Thrips are regarded as minor pests either on millets or sorghum. There are two species found in India. They are *Haplothrips ganglebauri* Schum. and *Thrips hawaiiensis* Mor.

Soil dwelling insects

White grubs

Several species of *Hototrichia* and *Anomala* have been reported.

Host Plants: White grubs feed on the roots of sorghum, corn, soybean, strawberry, potato, barley, oat, wheat, rye, bean, turnip, and to a lesser degree, other cultivated crops.

Bionomics: In spring, overwintering May beetles emerge from the ground at dusk, feed on the leaves of trees, and mate during the night. At dawn, they return to the ground, where the females lay 15–20 eggs in earthen cells several centimeters below the surface. Most of the May beetles lay eggs in grassy sod. Eggs hatch in about 3–4 weeks. The young grubs feed on plant roots throughout the summer; in the fall, they burrow below the frost line (to a depth of 1.5 meters) and hibernate. The following spring, they return near the soil surface to feed and grow. In fall, the grubs again migrate downward to overwinter. The third spring, they move upward to feed on plant roots. By late spring, they are completely grown. These large grubs form earthen cells and pupate. In late summer, adults emerge from the pupal stage, but they do not leave the ground. These beetles overwinter, emerging the next spring to feed and mate. The usual length of time for one complete generation (adult to adult) is 2–4 years depending on latitude. Generations, however, are staggered so that the grubs and the beetles are present every year. Grubs are usually most numerous and damaging the second season following a large beetle flight.

Damage symptoms: The C shaped grubs devour roots and plants wither and die. Infested seedlings remain stunted and produce no seeds. Even three to four grubs may attack the same plant. In general eggs hatch in 1-3 weeks and grubs develop in 8-22 weeks. Pupal period lasts for 1-8 weeks and 13- 20 mm long beetles emerge by November-December if climatic conditions are favourable, otherwise the pest overwinters and adults are active during May-July of the following year.

Management of sorghum insect pests

Cultural management

A number of crop husbandry practices which diretly or indirectly help reduce pest damage have become an integral component of farming systems. The need for ecologically sound, effective and economic methods for pest control has promted renewed interest in cultural methods. Cultural practices to suppress pest populations are best suited for sorghum growing regions because they involve no extra cost and do not disturb the natural ecosystem.

Time of sowing: Sowing time considerably influences the extent of insect damage. Normally, farmers plant sorghum with the first good monsoon showers. Synchronous sowing of cultivars in similar maturity groups over large areas in a short span of time helps reduce yield losses caused by shoot fly, midge and head bug.

Tillage: Ploughing before planting and after harvest greatly reduces the carryover of pests like white grubs, grasshoppers, hairy caterpillars and stemborer by exposing them to parasites, predators and adverse weather factors such as high temperatures and low relative humidity.

Plant density: High seed rate @ 10 kg ha^{-1} and destroying the deadhearts after removal to maintain an optimal plant stand.

Intercultivation: Intercultivation exposes the pupae of shoot fly, grubs and armyworm to parasites, predators and other adverse environmental factors and reduces the damage caused by these insects.

Timely weeding: Timely weeding reduces the extent of damage by pests as many common weeds act as hosts for oviposition by shoot fly, stem borers, armyworms etc. and provide better ecological niches for the insects to hide and thus shielding them from natural enemies and insecticide sprays. Crops that are free from weeds suffer lower armyworm damage than weed-infested crops.

Field sanitation: Collecting and burning stubble and chaffy earheads reduces the carryover of stemborer. Stalks from the previous season should be fed to cattle or burnt before the onset of monsoon rains to reduce the carryover of stemborer.

Removal of volunteer sorghum and alternate hosts: Destroying volunteer and alternate hosts eliminates shoot fly, stem borer, midge, sugarcane aphid, shoot bug and other panicle pests.

Fallowing: Fallowing reduces the carryover and build up of pest populations from one season to the next. Strict observance of a closed season during summer can possibly reduce the carryover of shoot fly.

Crop rotation: Breaks the continuity of the pest over seasons. Sorghum is generally rotated with cotton, groundnut or sugarcane. Most effective against shoot fly, stem borer, midge, sugarcane aphid and shoot bug.

Intercropping: Intercropping of sorghum with pigeonpea, cotton, soybean, cowpea, safflower and other leguminous crops reduces the pest pressure. Shoot fly damage is reduced when sorghum is intercropped with leguminous crops. Intercropping of sorghum with cowpea, lab-lab, or molasses grass (*Melinis minutiflora*) and silverleaf desmodium (*Desmodium uncinatum*) reduced the stem borer incidence to a greater extent over sole crop.

Trap crop: Planting an outer encircling row of highly preferred Napier grass (*Pennisetum purpureum*) which is attractive with few larvae completing their life cycle due to gummy substance produced by these plants causing mortality of larvae and Sudan grass provides natural control of stem borers by acting as a trap crop.

Mechanical method

Light traps: Set up light traps to monitor adults of stem borer, grain midge and earhead caterpillars.

Pheromone traps: Set up sex pheromone trap at 12/ha to attract male moths *Helicoverpa* sp., *Chilo partellus* and *Sesamia inferens*

Fishmeal traps: Set up the fishmeal traps @ 12/ha till the crop is 30 days old.

Biological control

Parasitoids: Release egg parasitoids: *Trichogramma chilonis*; Larval parasitoids: *Cotesia flavipes*
for stemborer

Host-plant resistance

Host plant resistance should form the backbone of pest management in sorghum. Over the past five decades, a large proportion of the world sorghum germplasm collection has been evaluated for resistance to insect pests, and a number of lines with resistance to major insect pests have been identified. Plant resistance as a method of pest control offers many advantage in sorghum growing regions. For some insect species it is the only way of effective pest control. The most attractive feature of using resistant cultivars is that virtually no skill in pest control application techniques or cash investment is involved.

Sources of resistance

A number of germplasm lines resistant to important insect pests have been identified. Reasonable levels of resistance to shoot fly, stem borer and midge have been reported. Many of these are currently being utilized in the All India Co-ordinated Sorghum Improvement Project (AICSIP) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to develop crop varieties with acceptable levels of yield and resistance. Some of the morpho-physiological traits such as seedling vigor, trichomes, erect and narrow leaves for shoot fly, early panicle initiation, faster internode elongation and shorter peduncle for stem borer, short and tight glumes for midge, semicompact panicle type of cultivars (SPV 462, CSH 6, CSH 11, and CSH 14) for panicle pests are resistant.

There is an increased awareness to breed for resistance to shoot bug in high yield background. The rise in the key pest status of shoot bug has led to concerted efforts directed at identifying promising sources of resistance, and the mechanisms involved therein. Few stable sources of resistance across locations have been identified such as IS 18557, IS 18676, IS 18677, PJ 8K(Y), and Y 75. IIMR scientists both at Hyderabad and CRS, Solapur are actively involved in intensifying the research activities to contain the potential threat from this pest.

Use less susceptible varieties: CSV 20, CSV 15, CSV 17, M 35-1, Phule Yashoda, for shoot fly /stem borers.

Chemical control

Seed treatment: Treat seeds with 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 sucking pests.

Spray/Whorl application

Shoot fly: 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).

Stemborer: For stem borers, Carbofuran 3G can be applied in the whorl leaves of plants @ 8 - 10 kg/ ha or the entire field can be sprayed with Quniolphos 25 EC (400 g ai/ha)

Shoot bug, aphids: Dimethoate 30 EC, 1.5 ml/lt

Mites: Dicofol 18.5 EC @ 2 ml / liter.

Cut worms (*Mythmina*, *Spodoptera*), red hairy caterpillars, semilooper : Apply poison baits comprising 10 kg rice bran + 1 kg jaggery + one liter Quinolphos (25 % EC).

Midge: For sorghum midge, the crop may be sprayed at the 50% flowering stage (1 midge/panicle) with Cypermethrin 25 EC @ 1.0 ml/liter .

Earhead bug: Carbaryl 10% or Malathion 5% dust @ 20 - 25 kg/ha

Web worms (*Helicoverpa*, semilooper): Carbaryl 10% or Malathion 5% dust @ 20 - 25 kg/ha

Termites: Mix soil with Chlorpyriphos 5 D @ 35 kg/ha at the time of sowing.
When the incidence of pest is noticed in standing crop dilute Chlorpyriphos 20 EC in 5L of water and mix it with 50 kg of soil and broadcast evenly in 1 ha followed by light irrigation.

White grub: Soil drenching of Imidacloprid 17.8 SL @ 300 ml/ha or Chlorpyriphos 20 EC or Quinolphos 25 EC @ 4 liter/ha with irrigation in standing crop around 3 weeks

Conclusion

Thus an effective integrated control should be followed to reduce the damage caused by the pests in sorghum. Insect pest resistant varieties and cultural practices should form the backbone for pest control programs in sorghum agro-ecosystems. Insecticides may be used when necessary based upon economic thresholds.

3. Improved genotypes and heterosis in rabi sorghum

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal crop after wheat, rice, maize and barley across the world. It is mostly cultivated in the arid and semi-arid tropics for its better adaptation to drought, heat, salinity and flooding. It is the main staple food for the poorest and most food insecure people of the world. Sorghum is reported to be cultivated across 105 countries representing 41.1 million hectares with an average production of 58.6 million tonnes. Among the sorghum producing countries, the top 10 sorghum producers are the United States of America (USA), India, Mexico, Nigeria, Sudan, Ethiopia, Australia, Brazil, China and Burkina Faso. These countries together represent nearly 77% of the world sorghum production and 70% of world sorghum harvested area. In India the crop was a major staple food in 1950s occupying an area of more than 18 million hectares. However, currently in India the area under sorghum has come down to 6.3 million hectares with an annual production of 6.4 million tones. Two adaptive types of sorghum, *viz*., *kharif* and *rabi* are cultivated in India. The *kharif* sorghum represents around 40% of the area and nearly 50% of total sorghum production in India. Over last four decades the yield gains in *kharif* sorghum is at 12.4 kg ha^{-1} $year^{-1}$ and that in *rabi* sorghum is 8.7 kg ha^{-1} $year^{-1}$. This has been achieved both through genetic gains as a result of breeding efforts and improvement in crop management. Over last four decades yield gaps in sorghum in India has come down from above 80% to current level of 72.7% and 71.5% in *kharif* and *rabi* sorghum, respectively. However, the gains in sorghum yield have not been represented in proportionate increase in total production due to rapid loss in sorghum area. The loss in area has been more conspicuous in *kharif* sorghum (~70% of 1970 level) than the *rabi* sorghum (~32% of 1970 level). From mid 1980s *kharif* sorghum area dropped more drastically than the preceding period. Rabi productivity over last five decades has increased by 107%, while the area dropped by 44% (Fig. 1).

Fig. 1. Rabi sorghum area and productivity dynamics

Historical perspective of sorghum improvement in India

Focused sorghum research in India started with the establishment of the Project on Intensification of Regional Research on Cotton, Oilseeds and Millets (PIRRCOM) in 1958. The PIRRCOM was located at 17 different centres spread throughout the country, with sorghum research being led from the Indian Agricultural Research Institute (IARI), New Delhi with isolated efforts on sorghum improvement among the state agricultural universities in sorghum belts of Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Gujarat. In 1966 the sorghum research was shifted from Delhi to Hyderabad as a part of Regional Research Station of the IARI. During this period the center was engaged in research on important dryland crops such as sorghum, castor, groundnut, pigeonpea and cotton as well as sorghum-based cropping systems. Realizing the success of hybrid sorghum in the United States of Ameriaca in 1962 the Indian Council of Agricultural Research (ICAR) launched the Accelerated Hybrid Sorghum Project to initiate hybrid breeding in sorghum. In December 1969, All India Coordinated Sorghum Improvement Project (AICSIP) was launched from the existing IARI RRS in Hyderabad. Subsequently on November 16, 1987 a full fledge institute named National Research Centre for Sorghum (NRCS) was established at the place. The institute extended its research with an additional regional station exclusively for *rabi* sorghum at Solapur in 1991. In 2009 NRCS was upgraded to Directorate of Sorghum Research. Under XII Plan in 2015 the Directorate was further upgraded as Indian Institute of Millets Research by bringing all the millet crops under its preview of research and development. Currently AICSIP functions with a total of 20 centers spread across nine states. During the initial period of sorghum improvement since 1960s efforts were focused on mass and pure line selection towards both improved grain and fodder yields. However, with demands of sorghum as forage crop and in recent past as sweet sorghum, an alternate source of bioethanol, efforts towards these directions have also been initiated.

Grain sorghum improvement

Focus on sorghum improvement till 1960s was on selections from local land races, which were tall with low harvest index, photosensitive, late maturing after seize of monsoon and with localized adaptation. Notable varieties of this period are Saonar, Ramkel, Aispuri, PJ, Maldandi and Dagdi selections from Maharashtra; Bilichigan, Fulgar white, Fulgar yellow, Kanvi, Nandhyal, Hagari, Yanigar varieties from Karnataka; Nandyal (N), Guntur (G) and Anakapalle series from Andhra Pradesh; Co series from Tamil Nadu; Budh Perio (BP 53), Sundhia and Chasation from Gujarat; Gwalior and Indore selections from Madhya Pradesh; and RS selections from Rajasthan. All these varieties carried mentioned undesirable traits of local landraces. With the launching of Accelerated Hybrid Sorghum Project through the Rockfellar Foundation a wide range of germplasm was made available in India, including male sterile (MS) lines and converted lines from temperate × temperate and temperate × tropical crosses from the USA, tropical landraces from African and Indian subcontinent. This led to significant improvement principally through manipulating plant height and maturity resulting into production of relatively photo-insensitive cultivars with short stature, duration and higher harvest indices. Though the emphasis of Accelerated Hybrid Sorghum Project was on hybrid development, realizing the limitations associated with seed chain of hybrids focus on variety development retained till date.

Varietal improvement in Rabi sorghum

The variety M35-1 is a popular landrace grown by farmers of *rabi* tracts of Maharashtra, Karnataka and Telengana during *rabi* season since many decades. The variety M 35-1 proved its merit by stable performance under rainfed situations over years with above average yield and bold lustrous grains. It was released in 1969 from Mohol station in Maharashtra for cultivation in *rabi* sorghum tracts across the country.

Focused breeding on *rabi* sorghum was initiated in the early seventies which over the years led to the release of several cultivars at state and central levels. Most of the present-day improved varieties are the result of pure-line selection practiced among the local/popular varieties and their crosses. The varieties for specific soil situations (shallow, medium and deep) have been released. The popular varieties have lustrous, bold and globular grains. At the national level, the variety CSV 7R was released in 1974, CSV 8R in 1979, Swati in 1984, CSV 14R in 1992, Sel 3 in 1995, Phule Yashoda (CSV 216R) in 2000, CSV 18 in 2005, CSV 22 in 2007, CSV 26 in 2012 and CSV 29R in 2013. Several varieties were released at the state level as well. Some of popular varieties released for the state of Maharashtra are Phule Maulee, Phule Anuradha, Phule Revati, Phule Vasudha, Phule Chitra and Phule Suchitra from Rahuri centre; Mukti, Parbhani Moti (SPV 1411) from Parbhani center and PKV Kranti from Akola. Similarly popular varieties released for Karnataka state are DSV 4 and DSV 5. NTJ 2 and NTJ 3 were released from the Nandyal station for Andhra Pradesh state. Many of these varieties have yielding ability better than five decade old local variety M35-1, with roti making quality at per or even better.

Much of the *rabi* season sorghum is grown on residual and receding soil moisture on shallow and medium-deep soils. A selection from local landrace was released at national level as Phule Yashoda (CSV216R) in the year 2000. It had grain and fodder yield superiority of 18.2% and 8.3% over M 35-1, respectively. This particular variety finds its place as a parent in several subsequent releases, *viz*., CSV 22, Phule Revati and Phule Suchitra. Breeding varieties suitable for varying soil depths was emphasized at Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra. The variety Phule Maulee was released in 1999 for shallow to medium soils , Phule Chitra was released in 2006 for medium soils, Phule Vasudha was release in 2007 for deep soils and Phule Anuradha got released for shallow soils in 2008.. The variety Phule Revati was released for medium to deep soils in 2010 and Phule Suchitra for medium soils in 2012. These varieties have been performing well in specific soil situations Therefore there is a need for the development of specifically adapted varieties adapted in *rabi* season to enhance production and productivity levels.

Hybrid improvement in rabi sorghum

Commercial exploitation of hybrid vigour has paid rich dividends in *kharif* sorghum leading to quantum jump in productivity. However, the progress in hybrid *rabi* sorghum breeding is limited. Some of the early *rabi* hybrids released are CSH 7R and CSH 8R in the year 1977 and CSH 12R in 1986. However, the *rabi* area covered with hybrids is almost negligible. Lack of acceptable grain quality with adaption to different *rabi* agro-ecological situations among release hybrids was the principal reason behind low popularity of *rabi* hybrids among farmers.

The second phase of *rabi* sorghum breeding with emphasis on hybrid cultivars was initiated in the late eighties. During this period, 250 experimental hybrids were evaluated in the AICSIP trials. These trials resulted in t central release of CSH 13R and CSH 15R. CSH 13R released in 1992 has significant yield superiority over M 35-1. However, as the female parent (296A) of this hybrid was of *kharif* adaptation it failed to meet the acceptable grain quality of *rabi* sorghum. Further it was highly vulnerable to shoot fly and low temperature as well. Concentrated focus on development of MS lines under *rabi* background led to development of several promising female parents. One among them is 104A developed at Mohol center. Using this female parent two hybrids, *viz*., CSH 15R and CSH 19R were released in 1995 and 2000, respectively with a marginal yield advantage over M 35-1. However, none of the hybrids gained popularity due to inferior grain and fodder quality as compared to M35-1. Though this and other new CMS lines in *rabi* background have got good grain trait and yield potential, they are poor combiner for yield and lack resistance to shoot fly and charcoal rot. Lack of diversity, grain luster and sensitivity to low temperatures and terminal moisture stress of the parental line are the principal bottleneck in *rabi* hybrid breeding.

Contrary to *kharif* hybrids, the heterosis in *rabi* hybrids is insignificant because the landraces are used in the development of both parents. It is envisaged that introduction of larger grain size and lustre in the female parents of *kharif* hybrids by novel methods and hybridizing such female parents with *rabi* based R lines would increase the yield levels of *rabi* hybrids to fetch better farm incomes to the farmers. For *rabi* hybrid development, CMS-based seed parents and restorers need to be diversified by creating separate gene pools through crossing between guinea-based B-lines and durra-based B-lines and between caudatum-based R-lines and guinea/durra-based R-lines for various selected traits.. Seed setting ability in hybrids at low temperatures is critical to the post rainy season hybrids and requires greater attention to ascertain the differences among the landraces for their ability to restore fertility in hybrids.

A Mission Mode Project on Development of Hybrid crops under National Agricultural Technology Project funded by World Bank was in operation specifically to develop *rabi* sorghum hybrids at NRCS and 7 AICSIP centres working on *rabi* sorghum at National level from 1999 to 2005.Several promising hybrids and diverse parental lines were identified. In recent years, very few hybrids are being tested in AICSIP trials, but promising hybrids with accepatable grain and fodder quality are in pipeline.

Future outlook

Sorghum improvement efforts have succeeded in increasing productivity of *kharif* sorghum but could not impact much in *rabi* sorghum. In *rabi* sorghum efforts need to improve parental lines with better combining ability, desired levels of resistance to biotic and abiotic stresses and acceptable grain qualities. Though hybrids have not gained much popularity in *rabi* sorghum, to enhance productivity of *rabi* sorghum concerted efforts need to be focused on development of hybrids with acceptable grain quality. Alternate use is another area of focus needed in *rabi* sorghum breeding programme particularly to breed cultivars suitable to specific end uses.

Disclaimer: The article is adapted from earlier publication of the author, Rakshit et al. 2015. *Indian Farming*, **65**(4): 12-19.

List of popular rabi cultivars released at national level through public sector breeding efforts

S. No.	Cultivar	Year of release	Grain yield (q/ha)	Fodder yield (q/ha)	Plant height (cm)	Maturity (days)	Recommended for
Hybrids							
1.	CSH 13R	1992	39	144	210	105-110	*Kharif* and *rabi* sorghum growing areas of Andhra Pradesh, Gujarat, Tamil Nadu, Karnataka Madhya Pradesh, Haryana, Rajasthan, Maharashtra and Uttar Pradesh
2.	CSH 15R	1995	32	56	190	110	All *rabi* sorghum growing areas of Maharashtra, south Karnataka and north-western Andhra Pradesh
3.	CSH 19R	2000	30	58	225	117	All *rabi* sorghum growing areas of the country
Varieties							
1.	M 35-1	1969	21	61	170-210	119	*Rabi* tracts of Deccan, Maharashtra, Karnataka and Andhra Pradesh

S. No.	Cultivar	Year of release	Grain yield (q/ha)	Fodder yield (q/ha)	Plant height (cm)	Maturity (days)	Recommended for
2.	CSV 14R	1992	23	55	180-200	110-120	All *rabi* sorghum growing areas of the country
3.	CSV 216R	2000	20-25	70-80	240-270	120-125	Andhra Pradesh, Gujarat, Karnataka, parts of Madhya Pradesh, Maharashtra and Tamil Nadu
4.	CSV 18R	2005	35-38	87-90	225-230	120-126	Maharashtra, Karnataka and Andhra Pradesh
5.	CSV 22R	2006	23-24	70-72	180-200	116-120	All *rabi* sorghum areas of Maharashtra, Karnataka, Telangana and Andhra Pradesh, Suitable for medium to deep soils
6.	CSV 26R	2012	13-16	45-60	180-200	112-115	All *rabi* sorghum areas of Maharashtra, Karnataka and Andhra Pradesh, Suitable for shallow soils

GFY – green fodder yield; DFY – dry fodder yield

4. Extension approaches in India: Prospects and challenges

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Introduction

Farmers require a diverse range of information to support their farm enterprises. Information is needed not only on best practices and technologies for crop production, but also for post -harvest aspects. Agricultural Extension is an essential pillar for research and development in agriculture. Despite a wide range of reform initiatives in agricultural extension in India in the past decades, the coverage of, access to, and quality of information provided to marginalized and poor farmers is uneven. Approaches to agricultural extension in India and worldwide continue to evolve. Since the Green Revolution the agricultural extension, with its focus on increasing production via technology transfer, has adopted decentralized, participatory, and demand driven approaches in which accountability is geared toward the users (Kokate , 2009). While the call for demand driven agricultural extension has existed for several decades now, new modes of reaching out to farmers could have significant impact in India, as they might better reflect the local information needs of farmers. The diverse nature of the Indian subcontinent, with its wide variety of agro climatic regions and broad range of socioeconomic conditions in the rural population, calls for agricultural extension approaches that are context and situation-specific(Singh and Sharma,2004)

In India, the role of agricultural extension in improving agricultural growth is today being recognized with increasing investment. India's 10th and 11th five-year plans emphasize agricultural extension as a key to increasing agricultural growth by reducing the yield gap in farmer fields, and therefore stress the need to strengthen agricultural extension in India (Planning Commission 2001, 2005, 2006). However, despite the renewed interest and investment in agricultural extension in India, the coverage of such services is inadequate.

Review of Extension Approaches

Over the years, the country has tried many extension and development strategies that helped increase and enhance farm production, productivity and overall quality of human life. After the independence, first extension direction to agricultural development was Community Development approach (1952). Besides land reforms, the programme tried to assure cooperative credit, improved marketing facilities, large scale labour- intensive irrigation projects and the efficient use of resources with the help of National Extension Service agency(1953). Though the basic idea of CD programme was to bring overall development of the rural community through community participation but not many positive results were seen due to lack of conviction, commitment and expertise and the compelling situation of food shortages.

During sixties, the agricultural production situation was very critical and intensification of agriculture with the use of high yielding varieties became must and agricultural development became the sole indicator and measure of rural development. The programmes such as Intensive Agriculture District Programme(1960), Intensive Agriculture Area Programme(1964),National Demonstration(1966) and High Yielding Varieties Programme gained momentum. At this point, the sole purpose was of increasing crop yields by using modern means of production like fertilizers, irrigation and high yielding seeds in particular. The strategy was found generally to be unsuitable for the conditions and needs of complex, diverse and risk prone agriculture. These approaches, though paid good dividend, generally failed to help especially the poor farm households and reduce inequity.

During seventies, the emphasis was broadened from agricultural development to rural development and various programmes like Small Farmers Development Agency, Marginal Farmers and Agricultural Labour development agency,Drought Prone Area Programme, Integrated Rural Development Programme etc. were launched.These programmes laid substantial emphasis on participatory approach for organizing and mobilizing poor farmers to enable to take advantages of the technology and services on a continual basis.

Superimposed on TOT approach was the T & V system (1974) with emphasis on the role of extension in technology transfer to encourage utilization of research results. T & V approach was found to be too narrow in its approach and not suitable for small farms and rain-fed areas, which are surrounded with so many uncertainties. Mean while, the ICAR launched its extension programmes namely, Operational Research Project (1975), KrishiVigyan Kendra (1974) and Lab to Land (1979). During 7th plan,all these programmes including National Demonstration (ND) were later merged under the programme of KVK. The farming system research and extension programme was also started through KVKs. These programmes did receive some success, but could not make much impact, particularly in ensuring people's participation. It was realized that the modern technologies did not match with the farmers' need and resources, and therefore, farmers' participation was partial in the programmes. The situation demanded an emphasis on farmers' need-based and problem-oriented technology generation with active participation of the farmers. The need for technology assessment, refinement and transfer was felt and IVLP (Institute Village Linkages Programme) based on participatory methodology was launched (1995) in selected locations in the country. In addition, National Watershed Development Programme for Rain-fed Areas was also launched by Govt. of India in selected states with basic consideration of people's participation. National Agriculture Technology Project (NATP)integrated the activities of public and private agencies in some selected districts under Agriculture Technology and Management Agency (ATMA) using bottom up planning approach(1999).The project continued upto 2005 with refinement based on field experiences.This has resulted to launch Centrally Sponsored Scheme of "Support to State Extension Programmes for Extension Reforms) during 2005-06 and continuing till date in 630 districts of India.

POLICY GUIDELINES FOR EXTENSION PROGRAMMES

The extension programmes are implemented on the basis of National Agricultural Policies, National Policy for Farmers and Five-Year Plans of Planning Commission. The following are the action points were highlighted under agricultural extension in National polices (Chandre Gowda,2013)

National Agricultural Policy, 2000

- Strengthen R-E-F linkages
- Broad-base and revitalize the extension system.
- Encourage KVKs,NGOs, Farmers Organizations, Cooperatives, corporate sector and para-technicians for organizing demand driven agricultural extension.
- Organise capacity building and skill upgradation programme for all extension functionaries.
- Move towards a regime of financial sustainability of extension services through a more realistic cost recovery of extension services .
- Mainstreaming
- Gender concerns in agriculture

National Policy for Farmers, 2007

- KVKs would take up training and lab-to-land demonstrations to provide skilled jobs in villages.
- Strengthening the State extension machinery and promote farm schools
- Convergence of extension efforts at state level , district level and below .

- Linkage with Common Service Centres (CSCs) of the Department of Information Technology, Government of India for inclusive and broad-based development.
- Empowering farmers with the right information at the right time and place is essential for improving the efficiency and viability of small and marginal holding.

Five-year Plans of Planning Commission, Government of India:

Five Year Plans had many implications particularly for initiating new government programmes, policies and procedures.

The **Sixth Five Year Plan** period coincided with the operations of T&V system.

The **Seventh Five Year Plan**, the World Bank assisted National Agricultural Extension Projects I to III were in operation. A major effort had been to broad-base the extension activity by moving away from the narrow individual crop orientation to farming systems approach.

The **Eighth Five Year Plan** more emphasis were given on development of rainfed areas, using adoption of dry land farming system approach; involvement of NGO and Voluntary organizations in Extension, Women in Agriculture, and integration of six extension schemes of ICAR under KVK.

The **Ninth Five Year Plan** basically addressed the issue of food security. A regionally differentiated strategy based on agro-climatic zones to take into account agronomic, climatic, and environmental conditions to realise the full potential of every region was emphasised.

The Tenth Five Year Plan emphasised on reforms to make extension services demand driven, for which encourage the role of the non-government sector in agriculture extension and an innovative approach in the field of television/ radio broadcast,Communication networking, Strengthen the ACABC scheme to establish agri-clinics / agri-business centres / ventures by the agricultural graduates etc.

The Eleventh Five Year Plan reiterated the key role to be played by Public extension system in educating farmers and helping them to take right decisions. Infrastructure below district level is needed to support capacity building of farmers by up-scaling ATMA to all development districts through convergence. Promotions of research—

extension– farmer -market linkages, .Public-private partnership (PPP) in extension were also envisaged.

The Twelfth Five Year Plan envisaged National Mission on Agricultural Extension and Technology (NMAET) in which amalgamation of 17 different schemes of the Department of Agriculture & Cooperation will be done under the umbrella of Agriculture Technology Management Agency (ATMA).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)

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 Farmers Interest Groups (FIGs) to form Farmer Producer Organizations (FPOs) etc.

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(TV, Newspapers, Booklets, KCC, Internet, SMS) of extension will also be carried out in broadcast or interactive electronic modes in all the four Sub Missions.

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)

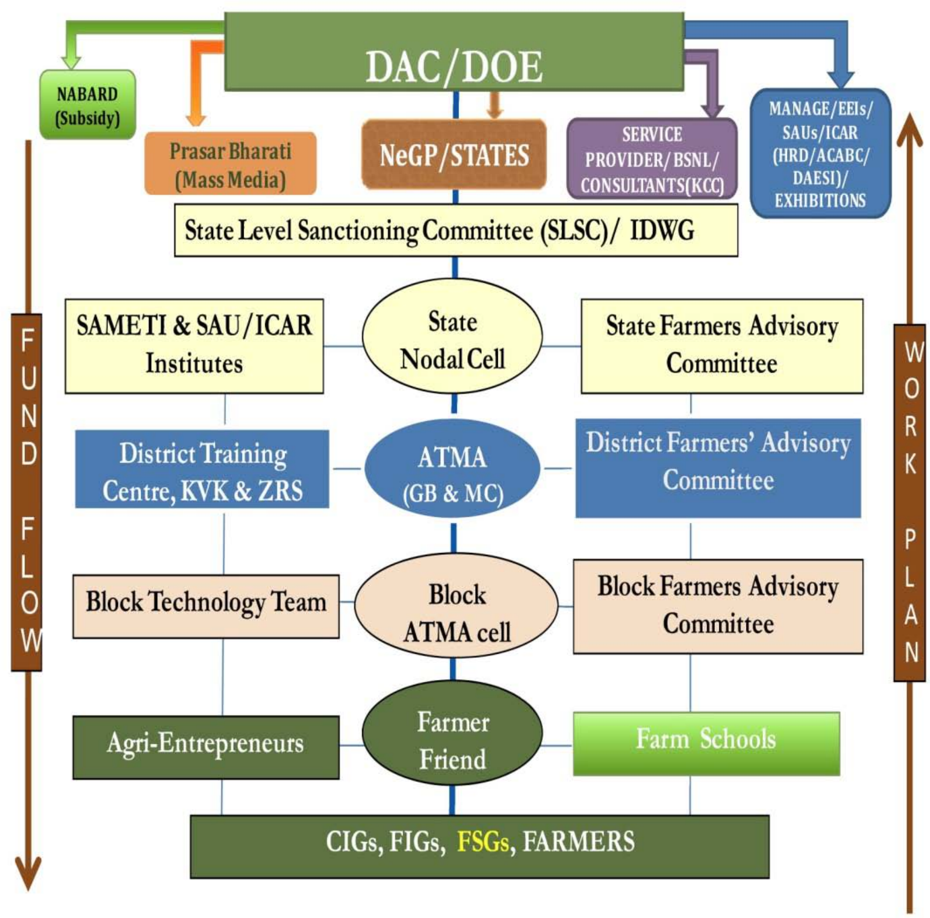
This Scheme shall focus on the following key extension reforms:

- 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:



Extension through Krishi Vigyan Kendra

The Krishi Vigyan Kendra (KVK), or farm science center, is a multidisciplinary educational institution situated at the district level, with funding and technical supervision from ICAR. There are 631 KVKs, almost one for each district in India. Each center is under the administrative control of a state agricultural university, State Department of Agriculture, NGO, or central research institute. The performance of KVKs may vary depending on the administrative control. Each KVK is in one of 15 agro climatic zones and created a niche for themselves as the front line extension system performing the vital role of linking research-extension-farmers systems.

Extension through Private Sector

The private sector is increasingly playing a role in extension services in India.It develops context-specific models and using ICT tools to bring information directly to the farmer. Most of the agricultural input companies have an element of extension through various approaches. A few private companies have initiated 'one-stop farm solution centres ' for their extension services .Some of them are

Mahindra Krishi Vihar: Mahindra and Mahindra Limited has established one-stop solution centres with the establishment of Mahindra Shubhlabh Services subsidiary, since solution centres operate on a franchise basis and provide quality inputs, 2000. The one-stop solution centres operate on a franchise basis and provide quality inputs, rent farm equipment, credit in partnership with banks,farm advice by trained field supervisors who visit fields, and arrange contracts with processors for off-take of crop produce.

Tata Kisan Sansar by Tata Chemicals Ltd. Has a franchise-based 'hub and spokes' model of outlets. The extension services offered by these one-stop shops include soil testing, remote diagnostics and house brands for seeds, cattle feed, pesticides and sprayers.

Godrej Agrovet has chain or rural outlet and run in partnership with other companies to extend its products range. Its 'one-stop solutions ' model offers agricultural equipment, consumer goods, technical services, soil and water testing, veterinary, financial and post office services, and pharmaceuticals

Although few empirical studies have been carried out, the performance of private extension is said to vary widely; it tends to focus its services on areas with sufficient resources and is limited to a few crops and areas where profits can be assured (Sulaiman and van den Ban 2003). The private sector serves a corporate interest, working with individual farmers, so social capital is not built. Moreover, private extension can only work well if farmers are willing and able to pay. One option suggested by Swanson (2008) is that the private sector could serve the needs of medium-size and commercial farmers, while the public sector could work in remote areas, which are currently not serviced well. This sort of system would require public-private partnerships that currently at initial stages in India.

Extension through NGOs

Considering the large number of marginal and small land holdings in India, Farmers organizations and SHGs could play important roles in articulating the needs of farmers to knowledge intermediaries. They can operate side by side with either NGOs or the public sector, but challenges exist in both sectors. Public capacity to build FBOs and SHGs is limited, while NGOs, which are not numerous, rely on donor funds and would need public support to develop the technical skills to facilitate the groups (Swanson 2006; Sulaiman and Hall 2004). Within FBOs or SHGs, problems related to social identity, including gender and caste, mean that these organizations may not be completely inclusive and are subject to elite capture problems. When farmer groups interact with other institutions, social identities and other social status perceptions mean that they may be too weak to articulate their concerns (Sulaiman and Hall 2004). Building the capacity of such groups, and promoting the development of leadership and management skills so that farmers can demand the information they need, is therefore an important component of agricultural extension approaches.

NGOs such as BAIF , Basix and PRADAN operate in numerous states and have been active in extension services for many years.

The Bharatia Agro-Industries Foundation (BAIF) BAIF is a Gandhian organization committed to imparting livelihood opportunities to the rural underprivileged families. BAIF currently works in round 50,000 villages in 12 states of India. BAIF 's areas of work include water resources development, sericulture, agro forestry, post-harvest product management and marketing cattle feed ad forage production. BAIF facilitated the formation of farmers' cooperatives and federations of self-help groups.

Basix: Basix strategy is to provide a comprehensive set if livelihood promotion services which include Financial Inclusion Services (FINS) agricultural/Business Development Services (Ag/BDS) and institutional Development Services (IDS) to rural poor households under one umberall. Extension services for farmers is being provided. According to Basix its services reach around 800,000 farmers and involve productivity enhancement, risk mitigation, local value addition and alternative market linkage for synthetic bio-inputs and outputs.

PRADAN: A majority of the families that PRADAN works with belongs to the Schedule Tribes and Schedule Castes. PRADAN promotes the Integrated Natural

Resources Management (INRM) of land, water, forest and biological resources to achieve and sustain potential agricultural productivity

Extension through ICT applications:

Kiisan Call Centres (KCC) to harness the potential of ICT in agriculture, Ministry of Agriculture took the initiative of launching an innovative scheme "Kisan call Centres" on January 21, 2004 aimed at offering solutions to farmers' queries on a telephone call.

aAqua ('Almost All Question Answered') is an internet based discussion portal initiated in 2003 by the Developmental informatics Lab of the Indian Institute of Technology in kiosks and cybercafés in Pune. A farmer can ask a question on aAqua from a kiosk or cybercafé other farmers or experts view the question and reply (in English, Hindi or Marathi).

Avaaj Otalo is a voice-based system for farmers to access and discuss relevant and timely agricultural information by phone. The system itself is a voice-XML based interactive Voice Response system. When a farmer calls iin, he/she hears audio prompts and is asked to enter a number from the keypad or say a word in order to navigate.

Digital Green is a non-profit organization with funding firm the Bill and Melinda Gates Foundation and the Deshpande Foundation. It disseminates agricultural information to small and marginal farmers through digital video.

e-Choupal is an intiative by the agri-division of ITC Ltd, the Indian Tabacco Company, Each e-Choupal is equipped with a computer connected to the internet. A local person acting as a sanchalak (coordinator) runs the village e-Choupal. Farmers can obtain daily updates on crop prices in local mandis, procure seed, fertilizer, and other products including consumer goods, and sell their crops for prices offered by ITC.

Extension through Farmers Organizatgtions and Agri-preneurs

Agri-Clinics&Agri-Business Centres (ACABC) is a Central Sector Scheme under implementation since 2002. The scheme promotes the involvement of agri-preneurs to supplement the efforts of public extension system by way of setting up of agri-ventures in agriculture and allied areas. Agri-Clinics are envisaged to provide expert advice and services to farmers on various technologies, Agri-Business Centres are commercial units of agri-ventures established by trained professionals.

Mahagrapes It is a Partnership firm of 15 co-operative societies, the main aim being to export grapes and other fresh produce to different parts of the world. Formation of co-operative societies has helped to reach every farmer.

Producers Companies: Producer Companies are the legal institutions, registered under GOI's Producer Company Act, or Companies (Amendment) Act, 2002. It is a hybrid of cooperative and private Company Act, 1956. Members have to be necessarily primary producers i.e., persons engaged in an activity concerned with or related to primary produce. Minimum 10 members must come together to form the producer company and there is no upper limit for number of members.

Vegetable and Fruit Promotion Council Keralam (VFPCK) is an ISO 9001-2000 certified company registered under section 25 on Indian Companies Act 1956 and has been established to bring about overall development for fruit and vegetable sector in Kerala. VFPCK is managed by a result oriented multidisciplinary team of professionals. VFPCK is a company with majority stake of farmers and the government an financial institutions as the other major shareholders.

Farm School to promote Farmer-to-Farmer Extension: Farm School under ATMA scheme is an attempt to institutionalize the concept of farmer-to-farmer-extension. These 'Farm Schools' are to be operationalized at Block/Gram Panchayat level and are set up in the field of achiever farmer who are the 'Teacher ' in the Farm School.

Conclusion

Due to changing agricultural conditions—including climate change, increasingly degraded and marginalized land coming into production, limited water availability, increasing use of inputs, rising fuel costs, and unknown market opportunities—farmers require access to timely, reliable, and relevant information that can support the complexity within which their farm enterprises operate. Although agricultural extension today has a broad mandate, this review shows that despite pluralistic extension approaches in India, the coverage and use of these services are limited. Considering the large number of marginal and smallholder farmers, particularly in rain fed regions, a major need is to build the capacity of farmers to demand and access information to increase their productivity, profitability, and incomes. The information must be reliable and timely. The public-sector extension system still receives significant investment from the central government and is increasingly pushed as the major source of knowledge through a presumed transfer of technology. ATMA is a key component of the system. The KVKs also face challenges that limit their ability to meet farmer's needs. Pluralistic extension system in India; with the public sector, private sector, and third sector all playing some roles. Public-private partnerships; for example, through the agri-clinic and agri-business center (ACABC) scheme; are one aspect that could be strengthened and encouraged. The public extension system dominates the provision of knowledge and information to smallholder farmers, especially in rainfed agricultural communities and largely concentrates on on-farm activities. The private-sector e-Choupal initiative and various small-scale models have tried to provide farmers with information not only regarding on-farm production but also regarding prices and accessing markets. However, these approaches work only for specific crops and regions where farmers have the incentive to take risks and are willing to pay for services. The impacts of the multiple ICT approaches are not documented and tend to work in small communities. Despite the variety of agricultural extension approaches that operate in parallel and sometimes duplicate one another, the majority of farmers in India do not have access to any source of information. This severely limits their ability to increase their productivity and income and thereby reduce poverty. Understanding the behavior of farmers in seeking information for their enterprises and communication through social networks will assist in the development of appropriate agricultural extension strategies. The existence of context-specific and relevant information for farmers also needs to be considered.

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5. Sweet sorghum - An important biofuel crop and technologies for enhancing crop productivity

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Introduction

In view of the rapid increase in the global population and the consequent increase in energy requirement, depletion of natural energy sources is rapid with atmospheric pollution reaching highest levels. Therefore, worldwide, the demand for renewable energy sources is continuously on the rise to cater to the needs of increased population and to reduce carbon dioxide emissions along with associated risks of climate change, and global warming**.** 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. Use of renewable, easily available, consistent photosynthetic biomass for production of biofuel plays significant contribution in development of environment friendly technologies. Biofuel include fuel 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.

In India, ethanol is produced from sugarcane molasses which is a by-product of sugar industry and used as a biofuel for blending with petrol. In January 2003, Government of India (GOI) mandated 5% blending of ethanol with gasoline through its ambitious Ethanol Blending Program (EBP). Ever since the blending program has been initiated, the trade balance for ethanol has been generally negative as the need for ethanol is greater from industrial sector (Chemical industry, potable alcohol industry, etc) and less quantity is available for blending programme. To promote biofuels as an alternative energy source, the GOI in December 2009 announced a comprehensive National Policy on Biofuels formulated by the Ministry of New and Renewable Energy (MNRE), calling for blending at least 20% of biofuels with diesel (bio-diesel) and petrol (bio-ethanol) by 2017. The policies are designed to facilitate and bring about optimal development and utilization of indigenous biomass feedstock for biofuel production. In the last few years, the country could achieve only closer to 2% blending of petrol with ethanol against the envisaged 5% blending. The fact remains that ethanol production from sugarcane molasses alone does not ensure optimum supply levels needed to meet the demand at any given time owing to reasons such as cyclical nature of sugarcane cultivation, difficulty in increasing sugarcane area due to high water intensiveness of the crop, erratic monsoon and power supply. Increasing the area under sugarcane at the cost of diverting land from other staple food crops is undesirable. 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: promising 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.

Sweet sorghum breeding efforts (Research & Development)

Early R & D efforts were made at Nimbkar Agricultural Research Institute (NARI), Phaltan, and 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 Indian Institute of Millets Research (IIMR), Hyderabad, and at other All India Coordinated Sorghum Improvement Project (AICSIP) centers in Rahuri, Phaltan, Parbhani, Akola, Coimbatore and other places. IIMR 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 IIMR 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

Fig.1.Sweet sorghum cultivars released at national level

Available sweet sorghum technology

Concerted research efforts utilising the wide variability in the germplasm during last two decades at IIMR and its cooperating centres in different State Agricultural Universities and at ICRISAT have resulted in development and commercialization of excellent sweet sorghum genotypes for use in ethanol production by the sugar industries/alcohol distilleries and for use as green/dry fodder. Promising nationally released varieties/hybrids are 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 yields of these genotypes 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.

Characteristics 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 for enhancing bioenergy production

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) biofuelfeed 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 (Sarathet 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:

- High suitability for genetic improvement
- High biomass accumulation
- High harvest index
- High fraction of biofuel in harvested biomass
- being able to be grown on marginal lands
- harvested material able to be stored in the field
- high bulk density
- high water use efficiency
- high N use efficiency
- low potential as a weed
- high coproduct potential
- optimal biomass composition
- large-scale potential production
- 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-bmrstover 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%, and 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 theWT. 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 Indian Institute of Millets 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.

Table2. 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 – neutraldetergent 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 xRTx430[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.

Sweet Sorghum Production Technology

Land preparation and manuring:

1. Two ploughings followed by leveling for good soil tilth
2. Apply 10 t farm yard manure (FYM) along with last ploughing.

*Plot***:** Six rows as gross and four rows, as net plots were generally followed in AICSIP coordinated trials. Please do not leave the gap between the plots while planting (continuous planting) in flat or ridge planting.

Soil type: Medium to deep black soil (Vertisol) or deep red loamy soil (soil depth ≥ 0.75 m deep) holding at least 500 mm of plant available water (PAW).

Sowing time: Kharif season crop (June –October): Sowing should be taken immediately after the onset of monsoon, preferably from second week of June to first week of July, depending on the onset of monsoon at your location. Record the date (s) sowing. Sow about three seed per hill by hand dibbling or planter at 5-cm deep. Please make sure that soil has fully charged with rainwater at least in the top 30 cm soil layer to ensure uniform germination. Soil moisture should be above equal or above field capacity at the time of sowing the crop.

Fertilizer management:

1. 80 kg N, 40Kg P_2O_5, and 40 kg K_20
2. Apply 50% N, full P_2O_5,and K_20 at sowing as a basal
3. Apply remaining 50% N as side-dress at two equal installments at about 25-30 DAS (i.e., at final thinning) and at about 50-55 DAS after ascertaining the availability of soil moisture.

Seed rate: 8 kg/ ha (or 3 kg /acre)

Spacing: 60cmx15 cm; (Row to row distance: 60cm; & plant to plant distance: 15cm)

Plant population: 1.10 to 1.20 lakh plants/ha (40 000 to 48 000 plants /acre)

Thinning:

1. First thinning at about 10-15 DAS and retain two seedlings per hill at 15 cm apart.
2. Final thinning at about 20-25 DAS. Retain a single plant per hill at the time of final thinning. Record the date (s) of first thinning and final thinning.

Weed management:

1. Apply pre-emergence spray of atrazine @1.0 kg a.i ha^{-1} one day after sowing but before weed emergence
2. Mechanical weeding twice up to 35 -40 days age of the crop will check the weed growth

Intercultivation or hoeing:

Intercultivation with blade harrow or cultivator once or twice between 20 and 35 days after sowing will not only check the weed growth but also conserve soil moisture by providing surface soil mulch.

Irrigation/rainwater management (Kharif):

1. Normally the crop is raised under rainfed condition in areas receiving rainfall of 550-750 mm. In case of late onset of monsoon and its erratic distribution, plant the crop and irrigate immediately.

2. Irrigate the crop if the dry spell (drought) continues for ≥ 20 days on deep soils and ≥ 15 days on medium/sandy loam soils especially at critical crop growth stages such as panicle initiation (35-40 DAS) and boot stages (55-65 DAS).
3. Please ensure that crop does not suffer from moisture stress especially during pre-flowering stages of crop development. Sweet sorghum is aimed at maximizing the cane yield similar to sugarcane.
4. Hence, maintain soil always at field capacity. On the other hand, drain out the excess irrigation water or rainfall from the field to avoid water logging.
5. Decide when to irrigate sweet sorghum based on the soil type and rainfall distribution at your location. Finally record the dates (s) of irrigation if given in the data book let.

Tillering: Remove the side tillers (basal) manually, if they occur before 20-25 DAS from the base of the mother plant.

Crop protection: Take minimum and need-based protection against shoot fly, stem borer and shoot bug, aphids etc. and other diseases as per recommendation based on visual damage symptoms.

Pest & disease incidence: Record as partial/low/medium/heavy etc. and the name of the pests & disease .The important insect pests and diseases that need attention and their management are given below.

Biotic constraints	**Management**
1. Pest	
Shoot fly	Application of carbofuran 3 G (@ 20 Kg ha^{-1})or phorate 10 G (@15 kg ha^{-1}) as basal at the time of sowing in soil furrows
Spotted stem borer	Application of carbofuran 3 G inside the whorl, based on leaf feeding damage symptoms
Shoot bug	Application of or metasystox 35 EC (@ 2ml/ L of water) in the whorls based on the damage symptoms.
Sugarcane aphids	Spraying of metasystox 35 EC (@ one Lit/ha in 500 Lit of water) at boot stage based on the damage symptoms.
Spider mites	Spraying of kelthane 35 EC or dimethoate 35 EC (@ one Lit/ha in 500 Lit of water) at panicle emergence based on damage symptoms.
2. Diseases	
Downy mildew	Seed treatment with apron excel (@ 3 ml /kg seed)
Foliar diseases	Spray dithane M 45 (@ 2 g /Lit of water) at stage panicle initiation (35 DAS)

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6. Sorghum production technology

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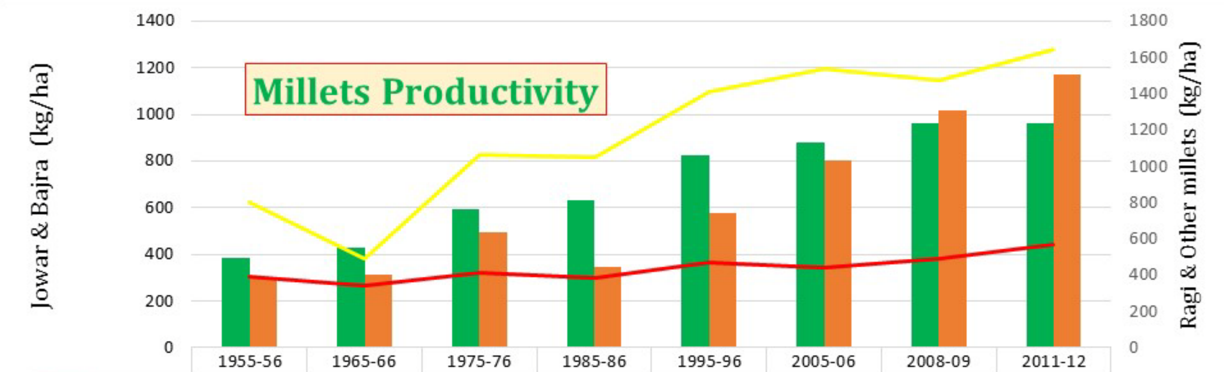
The term millet includes a number of small-grained cereal grasses. Based on the grain size, millets have been classified as major millets which include sorghum (jowar) and pearl millet (bajra) and several small grain millets which include finger millet (ragi), foxtail millet (kangni), kodo millet (kodo), proso millet (cheena), barnyard millet (sawan) and little millet (kutki). Productivity of sorghum and other millet crops (Fig 1) can be modeled through the interactive components of a given cropping system, which are the environment (E), the genotype (G) and their management (M). A rainfed production system, is basically dependent on environment, which influences the crop yield both through the above ground climatic and below ground soil related factors. Genetic advances across millet genotypes (hybrids & varieties) in terms of yield improvement have been brought about through two most important features, which has been their response to inputs and increased harvest index. Management facilitates in bringing about an ideal environment by genotype interaction, wherein the potential of the genotype is attained across millet growing drylands.



	1955-56	1965-66	1975-76	1985-86	1995-96	2005-06	2008-09	2011-12
Jowar	387	429	591	633	823	880	962	962
Bajra	302	314	496	344	577	802	1015	1171
Ragi	800	492	1064	1049	1410	1534	1477	1641
Other millets	388	341	412	386	469	443	491	565

Figure 1 Productivity trends in millets

Environment

Sorghum farming in India has two distinct seasons driven by the monsoonal rainfall, which are the *kharif* and *rabi*, while during the third season which is the *summer,* cropping is feasible, only where an irrigation water source is prevalent. Indian monsoonal rains are spread across four months (Table 1) i.e., from June to September, that are crucial for the *kharif* cropping system. The second cropping season i.e., *rabi* season commences during the withdrawal phase of the monsoon and extends through the winter period of the year. The crop survives on stored soil moisture which is a function of soil depth and the duration/intensity with which the rains are received during the withdrawal phase of the monsoon (September-October).

Table 1. Normal rainfall distribution pattern across winter, summer, monsoon, and post-monsoon months at Akola in Maharashtra.

Rainfall (mm)	Winter (DEC-FEB)	Summer (MAR-MAY)	Monsoon (JUN-SEP)	Post-Monsoon (OCT-NOV)
1^{st} Month	7	13	142	51
2^{nd} Month	10	3	201	21
3^{rd} Month	8	12	205 & 116	-

Above ground climatic features primarily influence through the evapotranspiration demand set on the field crop by its canopy, while the below ground supply system helps meet this demand through the crops root activity. All the three seasons differ in their characteristic environmental (atmospheric) features which ultimately influence crop growth, development and yield.

Table 2. Temperature range and mean across winter, summer, monsoon, and post-monsoon months at Akola in Maharashtra.

Temperature (^{0}C)	Winter (DEC-FEB)	Summer (MAR-MAY)	Monsoon (JUN-SEP)	Post-Monsoon (OCT-NOV)
Min Temp	11	22	23	17
Mean Temp	21	31	28	25
Max Temp	31	40	33	33

During the monsoon season the range of temperature (Table 2) is ideal or optimal, while during the post-monsoon it's the winter temperature extreme on the minimum side that sets the limitation on pollen viability. While during summer it's the other extreme of the maximum which influences the seed setting physiological phase. Growing degree day (GDD) concept takes into account the ambient temperature (Maximum temperature –T_{max} as well as minimum temperature – T_{min}) and the base temperature (T_{base}) specific to a given crop, to model the progress of crop growth from emergence to maturity. It is calculated by using a mathematical equation and cumulated over time to predict the crop phenological phase:

$$GDD = \frac{T_{\max} + T_{\min}}{2} - T_{\text{base}}.$$

Predicting the crop phenology using the prevalent climate helps split the nitrogen management option in tune with the crop physiological phase which sets the demand for the said nutrient. In some millets like Sorghum and Pennisetum (pearl millet) that are photosensitive, the photoperiod based on the latitude of a given region, is another environmental element that drives the developmental process like the transformation from vegetative to reproductive phase. Seasonal photoperiod length which is characteristically shorter during *rabi* season influences cultivar selection especially in sorghum. Maldandi cultivar M 35-1 is a classic example of photosensitivity that flowers normally (60-65 days) during post-monsoon season (*rabi*-shorter photoperiod), while grows tall and flowers late (75-80 days) during monsoon season (*kharif*-longer photoperiod).

Table 3. Relative thermal time[1] required for millets growth and development.

Crop Phenology	Sorghum	Pennisetum
Crop Emergence	-	10.7 °Cd
Flag leaf to Flowering	100 °Cd	66.1 °Cd
Flowering to Maturity	695 °Cd	457 °Cd

Agricultural Production Systems Simulator (APSIM Model) https://www.apsim.info/

Below ground soil factors that influence sorghum growth and yield can be categorized primarily into those that help optimize water use and those that balance nutrient supply. The physical characteristics including the soil depth primarily influence the water holding capacity which have a greater bearing on crop yield during *rabi* season (Table 4 –soil moisture replenished at the start & later recede) as compared to *kharif* season (intermittent replenishing of soil moisture by monsoonal rains).

Table 4. Typical mean rainfall distribution pattern during post-monsoon (*rabi*) season.

Crop Growth Phase	Rainfall (mm)
Early establishment stage (0-30 days)	103
Panicle initiation to boot leaf stage (30-55 days)	23
Boot leaf to 50% flowering stage (55-70 days)	3
Grain filling stage (70-90 days)	3
Grain maturity stage (90-110 days)	2
Crop seasonal rainfall (mm)	134
Annual rainfall (mm)	575

Soil biology (humus content) is also important which helps bind the soil clods and thus facilitating a high infiltration rate especially with reference to sudden rainfall events that exceed 50mm at times. Minimum tillage and green manuring are two management practices that help improve the soil biology. Balancing nutrient supply is the second most important below ground feature that helps attain a high harvest index especially with the improved hybrid cultivars across both sorghum and pearl millet. Nitrogen element has a specific role in setting the grain number vis-à-vis the protein content in millets and its management becomes crucial in terms of both grain and fodder quality. Interaction of the two important below ground entities i.e., soil moisture and soil nutrient, thus ultimately drive the productivity of improved millet genotypes especially in dryland regions, which require management options that optimize their utilization efficiency.

Genotype

Carl E Pray and Latha Nagarajan (2009) in their IFPRI discussion paper stated that there was little research on sorghum and pearl millet in the pre-independence period. Even after independence these crops received very little research attention, until the creation and expansion of the All India Coordinated Crop Improvement Projects. In the early 1960s, the Indian Council of Agricultural Research, with Rockefeller Foundation assistance, initiated research on hybrid sorghum and pearl millet. ICAR then initiated the All India Coordinated Pearl Millet Improvement Project (AICPMIP) and the All India Coordinated Sorghum Improvement Project (AICSIP), in 1967 and 1969. These programs organized government research and conducted multi-location testing for improved characteristics of hybrids and varieties, working with state agricultural universities, research institutes, International Crops Research Institute for Semiarid Tropics (ICRISAT), and experiment stations.

Sorghum improvement in India historically commenced with the national release of CSH-1 as the first hybrid for commercial cultivation in 1964 and followed with the spread of high yielding improved seed across the rainfed Sorghum based cropping systems. A number of hybrids and open pollinated varieties have been released till date, for cultivation specifically to suit different seasons, across India both nationally (ICAR) and at the state level by State Agricultural Universities (SAU's). Sorghum genotypes based on their photoperiod response have been bred for longer and shorter photoperiods, so as to exploit the prevailing environmental conditions. Some of the prevalent sorghum hybrids that are adapted to longer photoperiod (*kharif* and *summer* seasons) include CSH 9, CSH 14, CSH 16, CSH 25 and CSH 30, while cultivars that are suitable for shorter photoperiod (rabi season) include CSH 15R, CSH 19R, CSV 14R, CSV 216R, CSV 22R and M 35-1. The only sorghum cultivar that performs in terms of improved productivity across all three seasons is the hybrid CSH 13 K&R.

Gangaiah at IARI in his paper stated that initially, crop improvement in Pearl Millet evolved by selection (mass/pure line) from land races such as RSK, RSJ and Jakrana (Rajasthan), N – 28-15-1 and Avsari (Maharashtra) and Mainpuri (Uttar Pradesh). Some of the introductions from Africa also served as varieties (Jamnagar Giant, Improved Ghana and Pusa Moti). Hybridization was also explored in evolving varieties in the country. HB 1 was the first cytoplasmic male sterile (CMS) hybrid released in 1965 at Ludhiana, Punjab. Since then many varieties and hybrids have been released.

The pearl millet regions in India have been grouped in to two major zones:

Zone A: North Western Zone (Rajasthan, Gujarat, Haryana, Plains of Uttar Pradesh, New Delhi, Madhya Pradesh and Punjab.

Zone B: South Central zone (Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu)

Table 5. The Pearl Millet Hybrids and Varieties recommended for different zones.

Zones	HYBRID	VARIETY
Zone A	MH 518, MH 497, RHB 127, HHB 146, GHB 577, HB 4	MP 258, MP 266, JBV 3, JBV 2, Puas Bajri, Pusa Composite 383, Pusa Safed, PCB 15, CZP 9802
Zone B	MH 515, MH 52, SAMH 166	ICMV 155, AP Composite, Composite 3, BD 163, BD 111, CJ104
ALL INDIA	HC 4, GHB 558, BK 560-230	ICTP 8203, WCC 75, ICMS 7703, Raj Bajra, Chari 2, ICMV 221, Raj 171, Pusa 334

Small millets improvement efforts in India have been in progress since the beginning of the 20 the century and can be divided into two periods, before the formal launching of the coordinated program at Bangalore (Seetharam, 1998).

1940's to 1960's, the crop improvement in small millets was confined to a fewer states such as Tamil Nadu, Andhra Pradesh, Karnataka and Uttar Pradesh. The emphasis was on varietal improvement through selection of better types from local cultivars. The first finger millet variety released in the country was H 22 as early as 1918 in Karnataka. Interest in finger millet improvement got a fillip in Karnataka during 1950-60 and several new varieties such as Aruna, Udaya, K1, Purna, ROH 2 and Cauvery were released. While in the other millets the released varieties were as follows: little millet variety Co 1 (1954); foxtail millet varieties Co1, Co2, Co3 (1943), H1, H2 (1948), T4 (1949); kodo millet varieties PLR 1(1942, T 2 (1949), Co 1 (1953), proso millet variety Co 1 (1954) and barnyard millet varieties T 25, T 46 (1949).

1970' to 1980's, small millets improvement received the major boost during 1978-79 with the establishment of five crop specific lead research centres in the country under International Development Research Centre, Canada (IDRC) assistance. They were Almora in Uttarakhand (barn yard millet), Dholi in Bihar (proso millet), Dindori in Madhya Pradesh (Kodo millet), Semiliguda in Orissa (Little millet) and Nandyal in Andhra Pradesh (foxtail millet.). The "All India Coordinated Small Millets Improvement Project" (AICSMIP) was established in the year 1986 with headquarters at 'The University of Agricultural Sciences', Bangalore. There are 14 centers functioning under AICSMIP spread all over the country that address research needs of small millets.

Table 6. Total number of small millet cultivars released before and after AICSMIP was established.

Small Millets	Prior to 1986	After 1986	Total
Barnyard Millet	4	17	21
Finger Millet	45	67	112
Foxtail Millet	12	20	32
Kodo Millet	11	20	31
Little Millet	6	14	20
Proso Millet	8	16	24
Total	86	154	240

Farmers participatory selection approach in characterizing the cultivar features and as well as its acceptance was validated across introduced Finger Millet cultivars in Karnataka (Table 7). Interaction with farmers helps understand their practical mode of fitting cultivars into their existing cropping system. Earliness an important trait for drought escape whenever there was early withdrawal of monsoon and as well suitable for late sowing with delayed monsoon, were the criteria used by the farming community in the participatory selection process. Short duration cultivars were also suitable to fit into double cropping system in a rainfed crop production scenario.

Table 7. Finger millet cultivar traits preferred by Karnataka farmers apart from higher grain yield. *(http://www.researchintouse.com/nrk/RIUinfo/PF/PSP04.htm)*

Finger Millet Cultivar	Special traits considered by farmers
GPU 28	Earlier to mature, escapes terminal drought under early cessation of rains. Matched farmers' requirement for normal sowing in the second week of July.
GPU 26	Earlier maturing variety and was preferred for late sowing in August when monsoons are delayed
VL 305	Very early to mature in 85 days and fits well as a short duration second crop after sesame or green gram or cowpea.

Table 8. Released cultivars across other millets that are popular among Indian states

Other Millets	Popular Cultivars
Barnyard Millet	VLM 29, VLM 172, VLM 181, VL 207, CO 1, K 1, K 2, PRJ 1
Foxtail Millet	CO 4, CO 5, CO 6, CO 7, K 2, K 3, Krishnadevaraya, PS 4, SIA 326, TNAU 186,
Kodo Millet	APK-1, CO 2, CO 3, DPS 48, GK 1, GK 2, GPUK 3, JK 21, JK 41, JK 48, JK 76, K 1, K 106, RBK 155, Vamban
Little Millet	CO 2, CO 3, CO 4, JK 1, JK 8, JK 36, OLM 3, OLM 20, OLM 203, Paiyur 1, Paiyur 2, PRC 3, TNAU 63, VG 1
Proso Millet	CO 2, CO 3, CO 4, CO 5, GPUP 8, GPUP 21, K 1, K2

Management

Sorghum is grown across two distinct environments, the one where the crop productivity is uncertain with dependencies on monsoonal rainfall, while the other with assured production under irrigated conditions. The potential of released sorghum cultivars that have a high harvest index, could be attained, only when the onset as well as distribution of monsoonal rains were optimal during the crop season. Majorly, management of inputs in terms of nutrient supply and reduction of competition from weeds have greater significance as compared to other components of the production technology. Experiments conducted in the All India Coordinated Research on Sorghum (AICRPS) across centers proved that yield reduction was highest when fertilizer and weed management (Fig 2) were withheld from the recommended package of practices (POP).

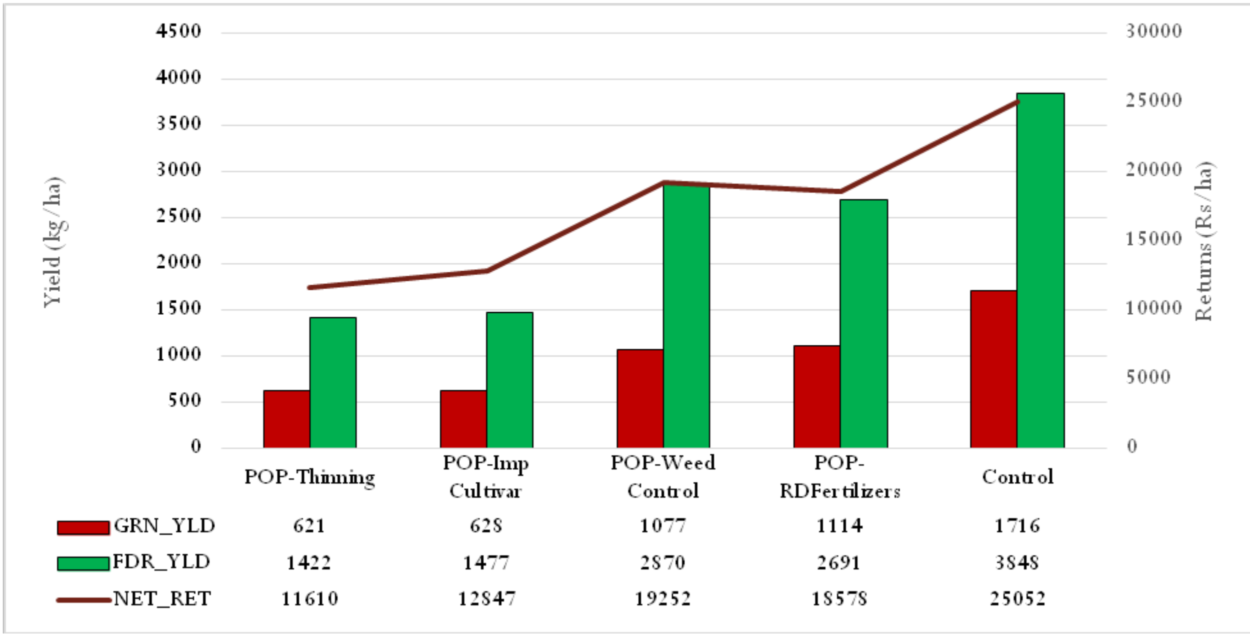


Figure 2 Reduction in net return and yields as influenced by the deficient package of practices (POP) component

Prediction of the monsoonal pattern by Indian Meteorological Department (IMD) ahead of *kharif* season gives a general idea of the likely scenario in terms of deviation from the normal. But management approach under uncertainty has to be in tune with prevalent above ground and below ground features and in response to available resources of a given location. Investment in terms of inputs under dryland farming, where in the producer is averse to risk, sets the limit to millet productivity. Major management options ahead of the season should address the capture and retention of soil moisture, which is primarily important under dryland farming.

Table 9. Field management approach to improve soil moisture content.

Pre-Seasonal Management	Soil Moisture (%)
Compartmental bund formation during kharif	28.23A
Tied ridging during kharif	26.29AB
In-situ mulching with dhaincha during kharif	27.07AB
Opening furrows at 45cm during kharif	26.26AB
Check treatment	
Normal rabi flatbed sowing	23.59C
p-Value	0.0292 *

The others would be to manage the nutrient supply in line with the crop growth phases, increase the resource use efficiency and produce more yield per unit nitrogen input.

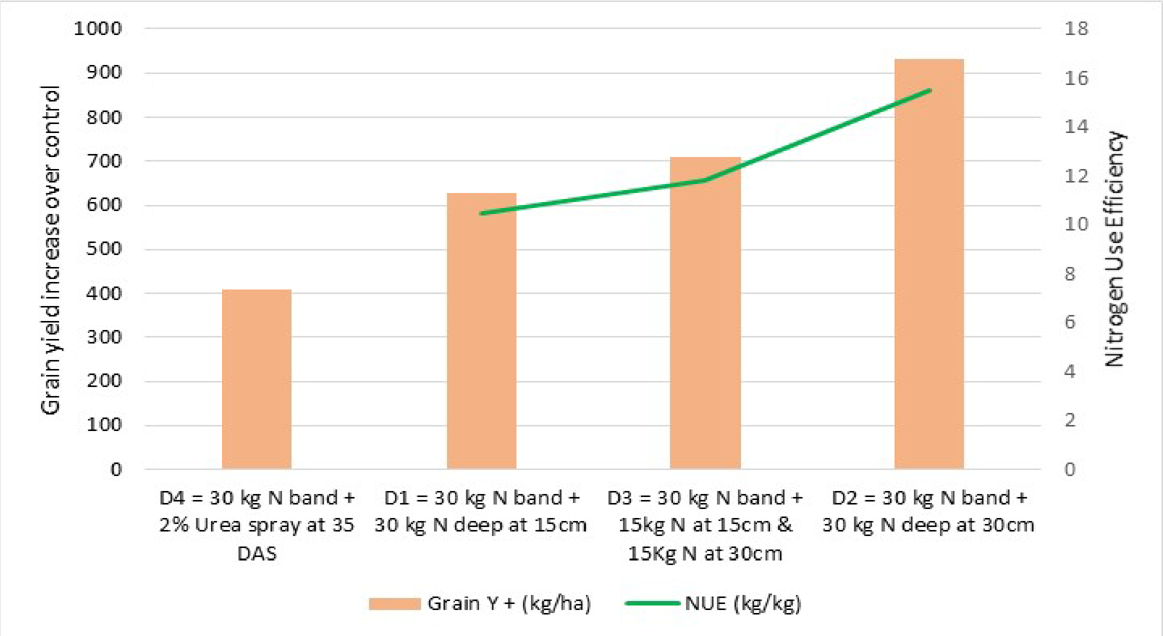


Figure 3 Increased rabi sorghum yield and nitrogen use efficiency with deep placement of fertilizer.

Relative Package of Practices in Jowar, Bajra & Ragi

Component	Sorghum	Bajra	Ragi
I. Time of Sowing	With onset of monsoon during Kharif		
Kharif (K)	Jun - Jul	Jun-Jul	Apr-May Jun-Jul
Rabi (R)	Sep - Oct	-	Sep-Oct
Summer (S)	Jan-Feb	Jan-Feb	Jan-Feb
II. Seed rate per acre	3-4 kg	1.6 kg	4 kg
Row to Row	45 cm	45 cm	22.5 to 30 cm
Plant to Plant	12-15cm	10-15cm	7.5-10cm
Population per acre	72,000 (K&S) 54,000 (R)	50,000 to 90,000	1,60,000 to 2,00,000

Component	Sorghum	Bajra	Ragi
Seed Treatment	Imidacloprid (70ws) 3g/kg seed	Apron 35 SD 6g/kg Seed	Carbendezim 2g/ kg Seed
III. Nutrient input	Per Acre		
Organic (FYM)	4 tons	2 tons	3 tons
Inorganic (K) (N:P=32:16)	36 kg DAP +56 kg Urea OR 100 kg SSP + 70 kg Urea	36 kg DAP +56 kg Urea OR 100 kg SSP + 70 kg Urea	36 kg DAP + 30 kg Urea + 17 kg Muriate of Potash
Inorganic (R) (N:P=16:8)	20 kg DAP + 30 kg Urea OR 50 kg SSP + 36 kg Urea	Irrigated (N:P=48:24) 52 kg DAP + 84 kg Urea	Irrigated 44 kg DAP + 70 kg Urea + 33 kg Muriate of Potash
IV. Weed MGMT (Pre-emergence)	Atrazine 0.5-1.0kg ai ha^{-1}	Atrazine 0.5-1.0kg ai ha^{-1}	Isoprturon 0.5kg ai ha^{-1}
V. Intercropping	Sorghum + P.pea Sorghum + Cowpea	Bajra + Groundnut Bajra+Castor Bajra+Moong	FM + P.Pea FM+Fieldbean FM+Blackgram
VI. Crop Rotation	Sorghum-Chickpea /Safflower /Mustard	Bajra-Barley/Wheat / Chickpea	FM-Greengram /Blackgram /Groundnut

Relative Package of Practices in Kodo, Little, Barnyard, Foxtail, & Proso millets

Component	BARNYARD	FOXTAIL	KODO	LITTLE	PROSO
I. Time of Sowing	Early sowings in the Hills and Normal in the plains				
Kharif (K)	Apr-May (Hills)	Jul-Aug	Jun-Jul	May-Jun	Jul
Rabi (R)	Sep-Oct	Aug-Sep	-	Sep-Oct	Sep-Oct
II. Seed rate (acre)	3 kg	3 kg	4 kg	3 kg	4 kg
Row to Row	25cm	25-30cm	22.5-30cm	22.5cm	25cm
Plant to Plant	10cm	8-10cm	10cm	10cm	10cm
Population	1,60,000	1.6 to 2.0 lakhs	1,80,000	1,80,000	1,60,000
Seed Treatment	Carbendezim 2g/ kg Seed	Ridomil 2g/ kg Seed	Carbendezim 2g/ kg Seed	Carbendezim 2g/ kg Seed	Carbendezim 2g/ kg Seed
III. Nutrient input	Per Acre				
Organic	2 to 3 tons	2 to 3 tons	2 to 3 tons	2 to 3 tons	2 to 3 tons
Inorganic	44 kg DAP + 26 kg Urea	33 kg DAP + 52 kg Urea	44 kg DAP + 26 kg Urea	44 kg DAP + 26 kg Urea	44 kg DAP + 26 kg Urea
IV. Weed MGMT (Pre-emergence)	Isoproturon 0.5 a.i. ha-1				
V. Intercropping	Barnyard Millet + Rice bean	Foxtail Millet + P.Pea / Cotton / Field bean	Kodo millet + P.Pea / Oilseeds	Little Millet + P.Pea / Green gram/ Soybean	Proso Millet + Green gram
VI. Crop Rotation	Millets rotation (seasonal or annual) with Pulses and Oilseeds is recommended				

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

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Sorghum is the indigenous African cereal crop and has become traditional crops of India and many of the Asian countries. The grain represents the major source of dietary energy and protein for more than a billion people in the semi-arid tropics including India. Sorghum is also grown in Australia, Europe and North and South America, mainly for ruminant and bird feed. Not only sorghum is nutritionally important, but also has unique functional characteristics and is potentially the sources of value added products, especially snacks and foods for the population at risk of physiological disorders such as diabetes, obesity and cardio vascular disease. Hence, these minor cereals need to be suitably processed to upgrade their food value as well as consumer acceptability to provide them in the form that are readily acceptable to non-traditional millet consumers.

Like any other cereals, sorghum is neither RTE (Ready-to-eat) nor RTC (Ready-to-cook) grains and need some kind of processing for human consumption. Most commonly followed processing methodologies for these are: milling including decortications or seed coat separation and size gradation in to semolina and flour, popping, malting, fermentation and cold extrusion. In recent years the contemporary food processing technologies such as extrusion cooking for RTE food and breakfast cereals, pasta and vermicelli-noodles and bakery products, malting & brewing, wet milling for starch preparation are employed for these grains.

Processing quality of any cereals is determined predominantly by the morphological features such as kernel shape, size, density, hardness, endosperm texture, nature of pigmented testa and pericarp. Sorghum is not exception to these features; sorghum, pearl millet and finger millet are practically naked grains and resemble wheat and do not have distinct husk tissue covering kernels, except glumes. Hence, processing in general and milling in particular vary for sorghum, other grains.

Milling: In the case of sorghum the term milling refers to preparation of flour as well as decortications or pearling. In sub-Saharan countries, the pestle and mortar as well as hand pounding are still the main tools used to grind sorghum, even though, manually grinding or pounding grains is painful and time-consuming. However, of late mechanical grinders have made inroads. In the Indian subcontinent as well as other part of the world, sorghum is pulverised to flour for food uses without any pretreatment except cleaning. For custom milling, stone, iron or emery disc mills are used where as for large scale milling hammer mills and also roller flour mills are also used. The meal is commonly sieved to separate out a small percentage of coarse seed coat or bran. Hence, the meal is a good source of dietary fibre, minerals and the vitamins derived from the bran but the keeping quality of such meals is low due to oil content from the bran. But to prepare flour with low bran contamination (refined flour), it is recommended that, the grains are moistened with 3-5% addition water, conditioned for 10 -15 min, pulverized and sieved to separate out the coarse bran fraction. Moist conditioning minimizes the bran fragmentation and facilitates its segregation to a larger extent.

Sorghum is also decorticated or debranned to obtain pearled grains, but for efficient operation, the seed coat should be moistened prior to pearling. For the purpose, rice huller or rice polishers could be used. Decorticated grains could be cooked similar to rice or may be flaked or size graded to semolina as well as to flour for conventional food uses and also for value added food products.

Popping: Popping of Sorghum is one of the traditional and popular dry-heat (high temperature short time – HTST) processing methods followed to prepare ready-to-eat products. The popped grains contain pre-gelatinised starch and possess highly desirable aroma and crunchy texture. Since, popped sorghum contain the bran layer, they are good source of dietary fibre and nutraceuticals. Normally, the expansion volume of the popped sorghum ranges from 7 - 18 ml/g, highest being for sorghum and lowest for barnyard millet. The varieties with hard endosperm and medium thick pericarp exhibit superior popping qualities. During popping the lipases enzyme gets denatured and hence, shelf-life of popped products is better than other kinds of sorghum products. HTST treatment ensures that popped foods are generally microbiologically safe. Popped grains serve as snacks after seasoning and also could be used for preparation of sweet meats such as *laddu* or *sattu* and *chikki etc.* Popped sorghum could be blended with toasted or puffed legumes, oilseeds and jaggery or sugar to prepare delicious and nutritionally balanced convenience supplementary foods for growing children and lactating mothers. The possibility of using popped sorghum exists very much in the state sponsored nutrition intervention programmes as substitute or supplement for toasted wheat which is in vogue. The snacks and supplementary foods from them will be nutritionally superior over similar products from rice and wheat.

Popping is practiced by subjecting the grains to HTST treatment using hot sand as a heat transfer media till date in India. The sand particles adhering the product affect the eating quality as well as the food value and hence, hot air popping which is a feasible proposition should be followed. A food machinery fabricator in Coimbatore manufactures hot air toasting machine which could be successfully used for the

HTST treatment for popping sorghum. Alternately, the gun-popping technology followed in East Asian should be popularized in India also.

Expanded grains: Expanded products which resemble rice poori or *murmura* would be the new generation snacks from sorghum. To prepare such a product from sorghum, the grins should be parboiled, pearled, bumped and then subjected to HTST treatment. The recent R&D work at CFTRI Mysore has shown the feasibility of preparation of expanded grains from millets. In fact, such a product from pearl millet is in the Indian market. Expanded grains are novel and high value products and can find application as ingredients for snacks and crispy in confectioneries and also as thickener in soup mixes.

Flaking: Cereal flakes are of three kinds in India and their methods of preparation also differ from each other, namely, using edge runner, roller flaker and extrusion cooker and flaker. Flakes from SORGHUM could be prepared following all these methods.

a. *Conventional method*: sorghum soaked in cold or hot (<70 C) water for hydrating to their equilibrium moisture content (EMC), subjected to HTST treatment using hot air as heat transfer media and flattened in the edge runner. During the process the seed coat (both husk and bran) get pulerised whereas the endosperm gets flattened (IIMR Hyderabad is actively producing such type of flakes from sorghum). These flakes find usage similar to rice flakes.
b. *Roller flaking:* The pearled grains are hydrated to their EMC, steamed to gelatinize the starch and dried to about 20% moisture level and then flattened by single point impact in a heavy duty roller flaker and then dried (sorghum flakes following this method are prepared by a food industry at Bijapur, Karnataka). This type flakes are more suitable to prepare snacks after deep oil frying.
c. *Breakfast cereals:* The technology followed is similar to that followed for preparation of breakfast cereals from corn. It is an elaborate process but the product will have international acceptance. The flour from sorghum will be extrusion cooked and the extrudate will be cut into small bits, and then flattened in the roller flaker, dried, blistered and then coated with sugar and flavouring agents. Normally there flakes are taken along with cold or hot milk as breakfast cereals (Breakfast cereals from finger millet are successfully prepared and marketed by two food industries from Bengaluru).

Currently, cereal flakes are used as ingredients of muesli. Flakes from roller flaking process and also breakfast cereals from sorghum could go well along with oats and other cereals flakes in muesli and add to the nutritional quality of the products.

Pasta/Vermicelli/Noodles: Pasta and vermicelli/noodles are generally prepared from wheat because of the beneficial properties of gluten. But sorghum being non-glutinous cereals, their starch has to act as a binder between the particles to prepare pasta or vermicelli-noodles. Hence, the flours or the fine semolina from sorghum need special pretreatment to partially gelatinize the starch to extrude into strands. Very often some kinds of functional ingredients such as gums are also used to facilitate binding. However, efforts to prepare noodles from these grains have not been fruitful till date and the composite flour consisting of wheat are used for the purpose. Such products are marketed in Karnataka and Tamil Nadu. Such products exclusively from sorghum will have high market potential especially in Europe and North America because of their non-glutinous nature.

Roti/Tortilla: Roties are highly popular traditional food products from sorghum which are normally consumed fresh. But now a days, dry rotis are sold in some places in the country but such products are brittle and need to be softened prior to consumption. Moreover they are not suitable for warming prior to consumption. These factors limit their acceptance.

Bread and Bakery: It has been very well documented that**,** sorghum flours singly are not suitable for preparation of bread and bakery products similar to wheat. But composite flours consisting of wheat blended with 20 - 30% sorghum could be used for preparation of such products without affecting the texture and taste. In fact, the products from the composite flour would be nutritionally superior to wheat based products due to the phytochemical contents of sorghum. However, there is need for developing the processes for preparation of bread and bakery products from sorghum similar to the Scandinavian rye bread. Obviously, such products would be gluten free and find widespread application as health foods.

Malting and Brewing: Malting is one of the very early biotechnological processes adopted for cereal processing for food and brewing. Although, barley has the place of pride for malting, sorghum and finger millet malting is also practiced extensively. Finger millet malting is mostly followed in India for specialty food product formulations. Pearl millet has very limited scope for malting as the malt will have poor keeping quality; likewise, other minor millets are at disadvantage because of the low level hydrolytic enzymes in their malts. Malted finger millet being a good source of amylases and micro-nutrients is termed as “Amylase Rich Food” (ARF). Sorghum malting is carried out on industrial scale in South Africa, Zimbabwe and Nigeria and it serves as principle raw material for brewing. The commercial beers manufactured in Africa are the lactic acid fermented thick brew and also clarified beer similar to barley beer. In India also sorghum are used as adjuncts in brewing to a limited extent by a select few brewing houses.

Starch, Dextrins and Ethanol: Sorghum are basically starchy grains and have potential for industrial level production of starches for food and allied application. Technologically and economically, sorghum has the potential for production of such products. It is learnt that, a substantial quantity of sorghum is diverted for starch production in the country. Very often sorghum caught in rain at pre-harvest situation and also fungal infested due to faulty storage could be profitably for ethanol production. This may find application in the years to come, although, the present regulations of GOI do not permit for this. Despite this regulation, it is learnt that considerable quantity sorghum is diverted for this purpose.

***Papad* and such other meal adjuncts:** *Papad, sandige*, *murukku, chakkuli* and such other products prepared normally at home or cottage industry level are important adjuncts in the Indian diets. *Papads* from finger millet are popular. Utlilisation of pearl and foxtail millets for deep fried adjuncts will be of highly desirable quality, probably because of their inherent lipid contents. Suitably sorghum flours blended with legumes (moong bean or horse gram) could be sheeted and cut into products of required shape and size, and could be toasted or deep oil fried or blistered in hot air to prepare ready-to-eat multi-grain snack products. Low fat and high fibre snacks similar to taco-chips from sorghum will find ready acceptance by one and all.

Parboiling or Hydrothermal Treatment: Parboiling or hydrothermal treatment hardens the endosperm texture and improves the decortication or milling and also the cooking characteristics of cereals. The process also increases retention of vitamins, minerals and some of the antioxidants of the cereals and thus upgrades their nutritional value. Parboiling of rice is carried out extensively whereas parboiling of wheat (bulgur) is done to a limited extent. The R&D work on parboiling of Sorghum is scanty even though the potential has been established. Parboiled grains on cooking form less sticky food and suit preparation of multi-grain food products similar to *Kashipilaf* marketed in US. Parboiled and milled millets could be utilized similar to rice for preparation of convenience foods such as *bilibelebath, puliogare* and ready-to-eat expanded cereals. Very recently, the parboiling technology has been successfully applied to finger millet for production of decorticated ragi (ragi rice), which is altogether a new product. Parboiled millets are also marketed by a food industry in the country.

Extrusion Cooking: Among the various contemporary cereal processing technologies, extrusion cooking is highly popular and are largely followed for corn and rice. Sorghum could also be extrusion cooked to prepare ready-to-eat (RTE) products successfully. The products will have crunchy texture and can be coated with traditional spice and condiments. Alternately, the grits could be mixed with spice and condiments prior to extrusion to obtain RTE snacks of desirable taste and palate. Extrusion cooked products being of ready-to-eat nature will have greater scope for use as weaning and supplementary foods and also as a component of edible films. Adapting these technologies, it is possible to prepare multigrain snacks or supplementary foods or health bars. Extrusion cooking of sorghum has very high potential for production of pet foods, the demand for which is expanding in the country.

Feed Formulations: In most of the developed countries, sorghum find extensive usage as feed components for bird, cattle and pigs. Normally to improve the biological value of the feed formulations are steamed and bumped. Sorghum is excellent sources of carbohydrates, micronutrients and phytochemicals with nutraceutical properties. They contain 7-12% protein, 2-5% fat, 65-75% available carbohydrates and 15-20% dietary fibre. Niacin and pyridoxine contents in pearl millet are higher than all other cereals, whereas, finger millet proteins are unique in that they contain higher levels of sulphur rich amino acids. Impressively, finger millet also contains about 10 times higher calcium than the other cereals. Also, the millets are admirable sources of B-group vitamins. The higher levels of dietary fibre and micronutrient contents and complex nature of starch and also the phytochemicals with nutraceutical characteristics provide a place of pride for these cereals as health grains. Hence, the image of sorghum as a poor man’s food could be overcome by developing nutritionally and texturally improved products that are attractive and appealing even to the elite and affluent population. It may be noted that, the urban consumers want food products that deliver convenience with desirable taste, texture, color and also shelf-stability at affordable price. In view of this innovative methods of processing them to make available in more and more user friendly manner deserves attention.

Case study: Successful Value Chain of millets developed in IIMR, Hyderabad

Millet is a generic term used for small “coarse” grains which are heterogeneous grasses (Weber, 1998). Sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*) and a group of six small millets together constitute the millets family. Millets cultivation offers chief support to rain fed farming on which 60% of Indian farmers depend. Millets cultivation in India covers an area of 15 million ha with annual production of 16.77 million tons. However, there is drastically reduce in area over the year due to inconvenient, cumbersome and time-consuming preparation of food from millets, lack of processing technologies, lack of awareness of nutritional merits and also the government policy of disincentiveness towards millets and favouring of supply of fine cereals at subsidized prices.

In order to revive the demand of millets in India, ICAR-Indian Institute of Millets Research (formerly DSR) led consortium under the NAIP liberal funding, has undertaken interventions to bridge the identified gaps on different aspects of on-farm production, processing diversification, nutritional certification, promotion and marketing of sorghum in the Indian market. The attempt enabled to bring all the stakeholders in production to consumption system value chain on a common platform and link poor dry land farmers with market as well as consumer. In this regard, the IIMR as the lead institute has built linkages with partners NIN, SAUs and ITC, a private institute. Similarly, with DFRL, CFTRI, CIAE and CIPHET.

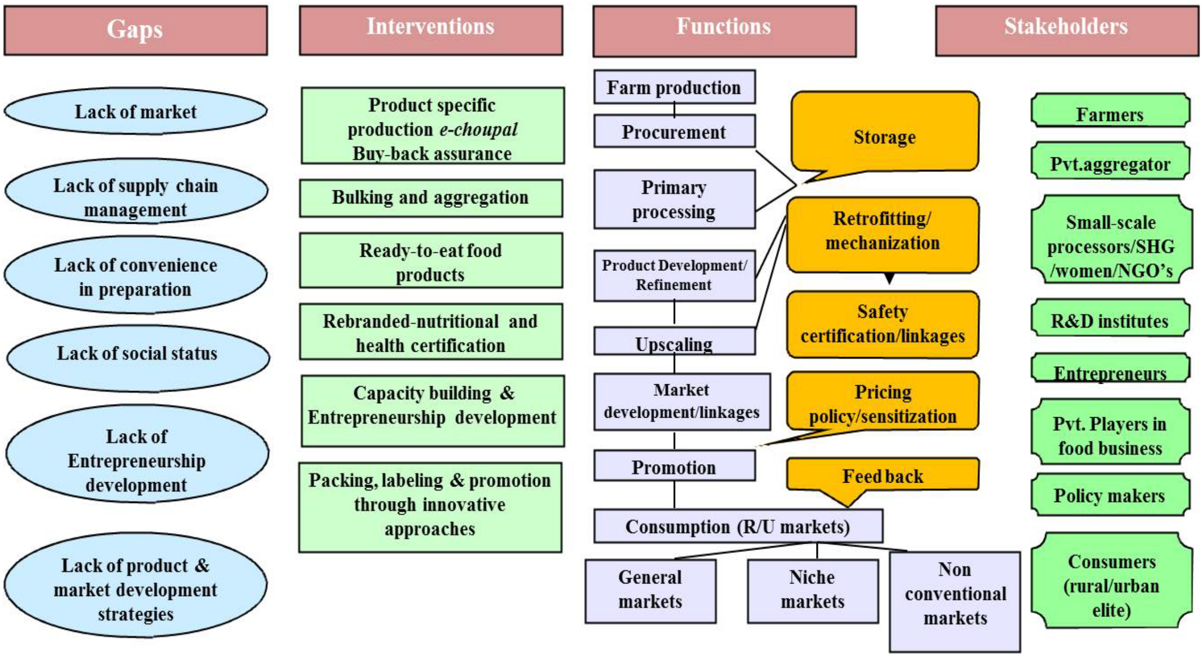

Fig.8. Gaps, Interventions and functions of value chain in millets – NAIP

Fig.9. Successful value chain of millets – IIMR led consortium; Partners: ITC ABD, NIN & PJTSAU (Formerly ANGRAU) an NAIP funded initiative

The individual components of the Sorghum value chain are:

a) On farm sorghum production: The backward integration model of product specific on-farm production covering 3000 acres in Parbhani (rabi) and Nanded (kharif) districts of Maharashtra and Adilabad (kharif for 2 seasons) district in Telangana were tested for 4 successful years under *e-Choupal* market assured model of ITC (ABD). The beneficiaries were technology backstopped by IIMR product specific cultivars (more than 12) bringing change in the mindset of farmers on intensive commercial aspects of sorghum cultivation. The recommended package of practices (PoP) for receiving better yield and quality was extended in PPP mode of farm extension services. The impact is visible through increased farm productivity and assured net incomes over the bench marks determined during the base line survey conducted earlier, which in turn led to shift in allocation of sorghum cultivation from marginal to better soil and water rich environments which is an indicator of stabilization of acreage in the study area.

In fact, backward integration resulted to overall improvement in the crop scenario such as the quality of the produce (sorghum grain), better utilization of fallow land, and commercial colour to the crop through sustainable linkage among all the stakeholders in the value chain.

b) Value Addition through Processing Interventions in Millets (IIMR & PJTSAU): One of the major reasons for declined consumption of Sorghum is due to inconvenience in its product preparation. In this regard, interventions through diversification of processing technologies related to sorghum were attempted to remove the inconveniences and develop, fine tune and standardize sorghum product technologies. For this purpose, the IIMR has installed and retrofitted 30 machineries under NAIP. Primary processing and secondary processing methods have been developed and fine-tuned using those equipment and has come out with good quality of 30 sorghum product technologies such as multi grain atta, semolina, flakes, extruded products (vermicelli and pasta), biscuits etc., similarly PJTSAU has come up with another 10 pearl millet and sorghum product technologies. Of which, 9 IIMR products and 5 PJTSAU products are targeted for commercialization. Interventions are made to improve the nutritional quality as well as the consumer acceptability of Sorghum. Processing interventions is continuing at IIMR to target at niche segment as well as mass marketing at the national level.

c) Nutritional Evaluation and Certification (by NIN): The organoleptic study of 15 sorghum products developed by the IIMR conducted by the NIN show that sorghum products are superior to rice products and on par with wheat based products. This study was followed by nutritional benefits of sorghum products in diabetes and school children. The studies established sorghum offer better nutrition in general over the market available products made from wheat, rice and maize. The amino acid profile of pulse (Soy blend) incorporated *Jowar* products were containing better amount of lysine, which is limiting factor in *Jowar* and also overcome the deficiency of micro nutrients. Glycemic Index of *Jowar* foods was analysed to determine the mean glycemic response for reference and test foods using International standards. The study reported that there was a decrease in the mean incremental area under glucose curve (IAUC) levels after consuming *Jowar* products.

d) Entrepreneurship Development: Entrepreneurship Development (ED) programme on sorghum/millets cultivation, processing, and marketing of jowar based products was jointly organized by ITC and IIMR with active participation from institutes like IIMR, PJTSAU, NIN and College of Home Science, MAU. Machineries of standardized Sorghum products were demonstrated to the farmers. 2000 Rural women and another 3000 SHGs, farmers, urban entrepreneurs are trained on development in Sorghum food processing.

e) Promotion and Popularization: IIMR launched its own brand as "*Eatrite*" and the products are popularized as healthy foods while PJTSAU has branded their products as PJTSAU foods. The sorghum products are fine-tuned and standardized now labelled and branded as health foods based on nutritive value established by NIN studies and targeting separately for urban up marketing (middle and higher income classes) and rural markets. Found a place in shelf space of retail markets in Hyderabad. Thanks for the promotion which was aggressively undertaken by IMR led consortium on awareness of nutritional merits of sorghum covering 360 degree communication strategies. For promotion of *Eatrite* products nutritionists/ doctors/ dieticians were sensitized by IIMR and for commercial portal IIMR launched www.i*eatrite*.com website.

Simultaneously outsourced the event managers for popularization of sorghum products (360 degree communication, brand designing logo, etc with BTL and ATL strategies implemented) in urban markets & New age Media. Massive awareness is created on sorghum as health and nutria food through Road shows (100+) in public parks, malls, and institutes etc in Hyderabad and in exhibitions in imparting awareness of sorghum to across 40000 consumers through fabricated *Jowar* Rath in Pune, Bangalore, Jabalpur, Chennai, Coimbatore, New Delhi etc. Rural consumer drive was undertaken by ITC rural choupal haats to sensitize the convenience and nutritional aspects of the outputs from the sub-project.

f) Commercialization: The pilot commercialization of sorghum products at Hyderabad starts with launching of IIMR brand "*Eatrite*" with a tag line „Eat *Jowar* – stay healthy‟. The range of products under this brand includes: Sorghum Rich Multigrain Flour, Sorghum Semolina, Sorghum Pasta, Sorghum Vermicelli, Sorghum

Flakes& Sorghum Roasted Flakes, and Sorghum Biscuits/Cookies. In this regard, 5 formats of business plans are commercialized for *Jowar* products evolved under their relative merit assessed in terms of farmer„s share in the consumer rupee. Suitable packaging, labeling, marketing and pricing strategies are adopted for targeting them to urban markets (IIMR&PJTSAU). Thus interventions made possible to provide convenient options for consumers among sorghum foods.

g) Policy sensitization: The success story of millets value chain in PPP mode has captured the attention of high profile scientists and agricultural policy makers of the country. The importance of millets have been spoken of in popular TV channels besides giving presentations during important national seminars and conferences such as AERA conference, AMA conference and so on besides NAIP and ICAR meetings. Created awareness through participation in several exhibitions both national and international and setting up *Eatrite* Sales counters at NAFED outlets, Krishi Bhavan, NASC Complex, New Delhi.

In order to draw the attention of the policy makers with regard to millets, the IIMR in collaboration with DMD, Jaipur and NIRD, Hyderabad conducted a National Seminar on Millets in November, 2010. The seminar was ultimately followed by Brainstorming Session in which a task force on millets promotion was set up. Consequently, Initiative for Nutritional and Food Security through Intensive Millets Promotion (INSIMP) project, a Rs. 300 crore under RKVK was launched by DAC with IIMR as the Center of Excellence for disseminating processing technologies to around 200 processing clusters that were set up under the scheme across the country. The Centre of Excellence (CoE) at IIMR is now in full swing disseminating the technologies developed under NAIP to people from across the country. Three pilot Mid Day Meal scheme studies with inclusion of millets diet are initiated in 3 states of Maharashtra, Karnataka and AP by the DAC under technical guidance of IIMR and Government is actively contemplating mainstreaming millets in public funded welfare programmes targeted various groups.

This project developed a model for PCS for millets foods. This led to enhanced consumption levels of targeted groups, income and employment of stakeholders through value-addition and branding of sorghum and millets as health foods. The demonstration of market-linked production, procurement, primary processing and buy-back (procurement) arrangements were done through ITC market assurance model and this was important to establish the confidence of entrepreneurs for Supply chain management. The knowledge base on sorghum grain quality, processing and value addition is now increasing with recent R&D work across the world. Special nutritional and technological features of these food grains has been adequately documented but still a lot has to be done for widening the scope of their food and allied utilization. There exists great potential for production and marketing of identity preserved ready-to-cook convenience products. The prominent food and allied products from SORGHUM that will have consumer acceptance would be shelf-stable roti flour, extrusion cooked and expanded ready-to-eat snacks and supplementary foods, noodles, malt foods, *papad* and such other food adjuncts, flakes, quick cooking cereals, health foods, breakfast cereals. pet foods and bird feeds. Processing technologies may not be the major obstacle to successful production of value added products from sorghum as there is substantial knowledge in that arena. However, consistent supply of good quality sorghum for industrial level processing, suitable marketing strategy for the products and creating awareness about their health benefits need to be addressed. This aspect deserves greater attention as Government of India is contemplating supply of these grains under PDS under the food security programme.

As long as production of fine cereals does not cross the surplus barrier, importance of sorghum, though at reduced level, may persist. Production for feed in domestic use and for international trade and for industrial uses may generate adequate demand for *kharif* grain. In the context of climate change scenario in Asia sorghum cultivation is going to be revived as is evident its come back as food crop in India besides its multiple uses which should arrest the decline in short to medium term and as the profitability is increased with private investment in food processing of sorghum and other industrial uses the crop production will be stabilised and the area will be increasing in the long term. This may require cultivar development with use specific grain quality attributes, high productivity to enhance cost competitiveness and other required standards. Mission oriented R and D activity on these aspects involving client institutions, state of the art know how and appropriate governmental policies promoting this production may provide solution to the problems of sorghum.An awareness of the distribution and flow of profits in the value chain is fundamental to understanding the relationships among and behaviours of each segment, as well as the opportunities for increasing productivity and profit across the chain of activities.

For Further Study

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8. Sweet sorghum - A versatile bioenergy crop its juice quality and diversified uses

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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. Apart from the most commonly used yeast species for fermentation, *Saccharomyces cerevisiae*, six other species viz., *Candida tropicalis, Pachysolen tannophilus, Brettanomyces naardenensis, Kluyveromyces marxianus* var. *marxianus, Schizosaccharomyces pombe* var. *Pombe, Issatchenkia orientalis and a bacterial strain, Zymomonas mobilis* were selected and used to study their potential for ethanol production from sweet sorghum bulk juice. The objective of the study was to determine the best microorganism for maximum ethanol recovery from the fermentation of sweet sorghum juice. Eight strains of yeast (two strains of *Saccharomyces cerevisiae*, one strain each of *Candida tropicalis, Pachysolen tannophilus* (MTCC 1077)*, Kluyveromyces marxianus* var. *marxianus* (MTCC 1389)*, Schizosaccharomyces pombe* var. *pombe* (MTCC 2665) and *Issatchenkia orientalis* (MTCC 643) and one bacterial strain, *Zymomonas mobilis* were evaluated for their ethanol production using sweet sorghum bulk juice. Among the six different species of yeast tested, four species, *S. cerevisiae*, *C. tropicalis, K. marxianus* var. *marxianus and S. pombe* var. *pombe* produced high ethanol (4.5 to 5.2%), the remaining two species (*P tannophilus* and *I orientalis*) produced low alcohol (1.3 to 1.5%). Among the seven strains tested, *S. pombe* var. *pombe* strain MTCC 2665 (0.432), *S. cerevisiae* strain IARI (0.426) and *K*. *marxianus* var. *marxianus* MTCC 1389 (0.411) showed highest ethanol yield (in g/g consumed sugar) followed by MTCC strain of *S. cerevisiae* (0.385) and *C. tropicalis* MTCC 6222 (0.377).

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.

Sweet sorghum Syrup

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.

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 per Litre. 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.

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%).

9. Sorghum diseases - Importance and management options*

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Introduction

Sorghum is infected by many diseases, some of which regularly appear in a severe form and cause considerable economic loss, while others appear sporadically and have less damaging effect to the crop. Fungal diseases are more than bacterial and viral diseases. Important fungal diseases of sorghum are grain mold, ergot, smut, anthracnose, downy mildew, rust, charcoal rot. These diseases infect different plat parts including root, stem, leaves, peduncle or grain and adversely affect yield and quality of the produce. Foliar diseases are special importance 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.

Important Diseases

Grain mold

The first symptoms of mold infection manifest in spikelet tissues. Mold infection at flowering results in poor seed set and production of small, shriveled grains. The severely infected grains become soft and disintegrate under slight pressure. On the mature grains, mold infection become visible as pink, orange, gray, white, or black color fungal bloom on the grain surface. Discoloration of grain is more prominent on white-grain than on brown/red grain sorghum. Many fungi are involved in development of grain mold and the most common species are *Fusarium moniliforme, Curvularia lunata, Alternaria alternate* and *Phoma sorghina*. In addition to these, many saprophytic fungi may colonize mature sorghum grain under the condition of high humidity and rainfall. Moderate temperature (25−35 °C) and high humidity (>90% relative humidity) favors infection and subsequent disease development. The pathogen can be soil-borne, airborne, or carried in plant residue. Plant residues, soil debris and senescing lower leaves produce abundant spores, which are readily disseminated by wind and rain splash.

This disease is a major constraint in the way of improved, short- and medium-duration rainy season sorghum cultivars. Molded grains become discolored and loose appeal in the market and fetches 20-40% less price than the normal grain. Production losses range from 30-100% depending on cultivar and prevailing weather. Economic losses are around US$50−80 million in India. The disease reduces seed value of grain, nutritive value of food and feed and cooking quality of the grain. Molded grains often contain mycotoxins which are harmful to human, animal and poultry birds.

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

It is an important disease causing substantial economic losses to grain, forage and sweet sorghum. Symptoms first appear on the leaf as small, elliptic to circular spots, with straw-color centre and wide margin. Many spots may coalesce to give a blighted appearance on the leaf. A black dot like acervulus is often seen at the centre of the necrotic spot, which is the characteristic symptom for leaf anthracnose. Plants get defoliated and die before maturity when infection is severe. Sometimes pre emergence damping-off may occur and the seedlings wilt and die. The disease is most severe during extended periods of cloudy, warm, humid, and wet weather. The fungus can survive as mycelium in host residue, wild sorghum species, and some weeds and as conidia or mycelium on seed. The fungus has some host specialization on maize, sorghum, sugarcane and a group of grasses.

The disease is caused by *Colletotrichum graminicola* and symptom can appear as seedling blight, leaf blight, stalk rot and head blight. Grain yield losses up to 50% can occur under severe epidemics conditions. The disease has effect on grain and stover yield and stover quality in forage sorghum and sugar accumulation in sweet sorghum.

Ergot

Ergot is an important limiting factor for hybrid seed production. The disease is common on sorghum (c.o. *Claviceps sorghi & C. africana*). First visible symptom appears as exudation of honeydew like droplet from infected floret. The droplets are thin, sticky or viscous, pinkish to brownish in colour and sweet in test. Gradually a wart like fungal structure called sclerotium evolves in an infected floret replacing the grain. The pathogen survives off-seasons in the infected panicles left in the field or via sclerotia that are mixed with the seed during threshing and processing. The sclerotia germinate and produce ascospores which become air-borne and cause infection in the floret. Chances of infection increase when pollination does not happen after emergence of stigma. A low night temperature, high relative humidity and a cloudy weather around flowering favours ergot development.

The disease becomes severe particularly if seed-set in male sterile lines is delayed due to lack of viable pollen or synchrony in flowering between the parents. Ergot infected florets do not produce grain and other grains from an infected panicles show reduced germination, seedling emergence and seed quality. Estimated yield loss in India is about 10‒80% in sorghum depending on severity. Apart from the hybrid, the variety also gets ergot infection when environmental conditions are favorable. Sclerotia of sorghum ergot contain dihydroergotamine, a toxic alkaloid which can affect milk production in cows and pigs, and weight-gain in cattle.

Smut

Sorghum is infected by four types of smuts namely, head smut (c.o. *Sporisorium reilianum*), covered smut (c.o. *Sporisorium sorghi*), loose smut (c.o. *Sporisorium cruenta*), and long smut (c.o. *Tolyposporium ehrenbergii*). Smut disease converts parts or whole of an earhead into fungal structure. In the covered smut, most of the grains of an infected earhead are replaced by the sori covered with a membrane like fungal structure. The loose smut infected plants flower earlier than the other healthy plants in the field. All the spikelets of an infected earhead get malformed and hypertrophied. In case of 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 case of long smut, the sorus is covered by a whitish to dull yellow, fairly thick membrane. Head smut is soil-borne, while loose and covered smuts are primarily carried externally on the seed surface. Spores get adhered to the seed and germinate in the soil along with the seed. In case of long smut the spore balls deposited on the soil surface get air-borne and fall on the flag leaf where they infect the developing florets.

In India smuts are found here and there sporadically and are of minor importance. They can be well managed with seed treatment fungicides.

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.

Charcoal rot

Charcoal rot is an important disease of rabi sorghum in Maharashtra and Karnataka. The pre-mature lodging of plant is the most apparent symptom of charcoal rot. The disease is caused by *Macrophomina phaseolina,* a soil-borne sclerotia producing pathogen. Dry weather, high temperature (35–38°C) and low soil moisture are the important predisposing factors for the disease. The pathogen infects root, destroy cortical tissues and may block water movement through vascular bundles and thus physiologically weaken the plants. Rotting and breaking of the basal internodes cause lodging of the crop, which in turn facilitates further loss of water from the cracks in the stalk. Yield losses vary, depending on weather and the growth stage of the cultivar at the time of infection. Extensive lodging due to charcoal rot can cause 23–64% loss in grain yield.

Leaf spot

Sorghum is infected by a large number of leaf spots and leaf blights. These diseases cause spots or large lesions on the leaf and thus destroy leaf chlorophyll and particularly important for sorghum, which is grown for forage purpose. Few commonly observed such diseases are zonate leaf spot, sooty stripe, gray leaf spot and rough leaf spot in sorghum; *Cercospora* leaf spot, *Curvularia* leaf spot, *Dactuliophora* leaf spot. Generally these diseases occur sporadically and are less damaging, unless they are favored by congenial weather and cultivar susceptibility. A few of them have economic importance, while others assume significance under specific conditions. For example, zonate leaf spot is serious disease on forage sorghum in north India. It can damage up to 85% of photosynthetic area under humid and cloudy weather. Moderate temperature, high humidity, extended periods of cloudy weather and heavy dews favour disease development.

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 4th to 11th leaf. Symptom expression frequency increase from 4th to 7th leaf, reach peak on 7th or on 8th 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.

Management options

Sorghum is grown in marginal soil using little or no input by resource poor farmers. Therefore, the production system has relatively less threat from high use of inputs, or this system is by default an organically managed agro-system with very little use of chemical pesticides, fertilizers, and synthetic plant growth regulators. For such a system disease management through host plant resistance is the most economic method for the farmers. To supplement the host resistance use of bio-agents or their metabolites can be helpful. There a few soil-borne diseases of sorghum for which adequate level of host resistance are not available so far. For such diseases like charcoal rot in sorghum bio-control agents are useful. Seed treatment with talc formulation of *Pseudomonas chlororaphis* SRB127 reduces charcoal rot incidence and increase seed weight. Bio-control agents especially and *Trichoderma* and *Pseudomonas* strains are useful for foot rot and sheath rot diseases.

Host-plant resistance is an important component of eco-friendly management of plat diseases. It provides the most economic and environment friendly method of disease management. For poor farmers it is the only viable practice, as they hardly use any other methods of disease control in sorghum. For grain mold use of a cultivar that matures during a period of no rain is the best option to escape grain mold. Use of mold tolerant cultivar (CSH16, CSH27, CSH30, CSV20 and PVK801) and harvesting the crop at physiological maturity followed by drying of grain is the second best option to avoid grain deterioration due to weathering. High level of genetic resistance is not available for charcoal rot in sorghum and present day cultivars (CSV19R, CSV216R and DSV6) possess good tolerance. Drought tolerant, lodging resistant and non-senescing sorghum genotypes are supposed to have good tolerance to charcoal rot. Agricultural practices like deep ploughing during summer season, cleaning of field bunds after every crop season, removal of crop residues from the field, uprooting the diseased plant from the field and burning, regulating irrigation water from entering into other field, if followed regularly, greatly reduce disease problem in the field. Collateral and alternate hosts, weeds, volunteer crop and wild crop species harbor pathogen and serve as source of inoculums for many diseases. Removal of host plants from the field bund and surrounding helps to control diseases like ergot, downy mildew, rust, blast, leaf spots and bacterial and viral diseases. Deep summer ploughing, destruction of crop residues and crop rotation with non-host plant are helpful for reducing inoculums of soil-borne diseases like downy mildew, smut, charcoal rot and a few fungal and bacterial leaf diseases. Maintaining optimum plant spacing and regulating the amount of nitrogenous fertilizer reduces incidence of blast, downy mildew and charcoal rot. Mechanical removal of sclerotia from seeds, by washing in 30% salt water followed by rinsing in plain water before sowing reduces seed contaminated infection of ergot. In seed production plots, ensuring synchrony of flowering between A and R lines avoids the occurrence of disease. Management of smut diseases requires awareness about the disease among the farmers. Practice of clean cultivation like collecting smutted heads in cloth bags and dipping in boiling water to kill the pathogen will reduce the inoculum for the next year and minimize incidence. Insect acts as vector for many viruses (e.g., maize stripe virus, maize mosaic virus are transmitted by shoot bug, *Peregrinus maidis*) and injects virus inside the plant. Insect control therefore helps in managing such diseases.

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10.Alternative uses of millets and scope of entrepreneurship

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Why alternative uses of millets?

- **Lifestyle diseases** such as diabetes. Cardiovascular diseases, cancer, hypertension etc., are different from other diseases because potentially preventable, can be lowered with changes in diet, lifestyle, and environment.
- **Millet diversity**
    - Little millet, Kodo millet, Foxtail millet, Proso millet, Barnyard millet, Finger millet and Pearl millet and Sorghum
    - In millets there are several verities based on color, taste, texture, pest resistance, crop duration and cultural values.

About 9 million of the 36 million people die every year because of non-communicable diseases die before the age of 60 years, that means the productive age group are effected which indirectly impedes the work efficiency and hits the nation's economy growth. It was reported that India would lose $237 billion over the next decade owing to non-communicable diseases (WHO).

Cardiovascular diseases (CVD) are the number one cause of death globally: By 2030, almost 2306 million people will die from CVDs, mainly from heart disease and stroke and projected to remain the single leading cause of death. It is estimated that by 2020, CVD will be the largest cause of disability and death in India.

Millets are equal or superior to other fine cereals. They are rich in dietary fiber, minerals such as iron, zinc and magnesium etc. They have slow digesting carbohydrates and as very good probiotic. Recent research has shown that sorghum may have several components that could impact human health. Some sorghum lines, those containing a pigmented testa, are high in antioxidants; some lines higher even than blueberries. In addition, the wax surrounding the sorghum grain contains compounds, policosanols, which may have an impact on human Cardiac health.

Millet Securities

- Food security: The World Food Summit of 1996 defined food security as existing "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life". Commonly, the concept of food security is defined as including both physical and economic access to food that meets people's dietary needs as well as their food preferences. In many countries, health problems related to dietary excess are an ever increasing threat, In fact, malnutrion and foodborne diarrhea are become double burden.

- Fodder security and Livelihood security: This note highlights the importance of engaging members of the community in documenting the wealth of traditional knowledge regarding feed and fodder systems across different agro-ecological regions. This process enhanced their self-respect and dignity in terms of their heritage and inspired them to revitalize and reintegrate some of these practices into their ongoing livelihoods strategies. The good practice also focuses on the necessity of developing synergies between scientific and community validation methods regarding nutritive value of traditional species in comparison to improved varieties of grasses and fodder. The similarities in the findings have helped to break the myth regarding the fodder value of traditional species.
  - Nutrition security
  - Health security
  - Ecological security

Advantage Millet

- Grown under completely Rainfed conditions
- Minimum input cultivation
- Accommodates Agriculture bio diversity to a large extent
- Relatively Pest Resistant Crops
- Nourishes soils, animals and Humans
- High periods of shelf life for unprocessed millets

Millet Meals

- Public Distribution System
- Integrated Child Development Services Scheme
- Mid Day Meals program
- National Child Labour Project
- Residential schools and welfare hostels

Enabling Facilities

- Encourage local livestock
- Local Storage and Processing Facilities
- Consumer education
- Farmer Led Agriculture Research in place of scientist led yield approach
- Documentation of associated cultural and agricultural factors of millet farming

INDIA – THE CEREAL FACTS (FAOSTAT data)

	INDIA
Population (billion)	1.21
Cereal production (million tons) (2010 data)	
Total	234.9
Barley	16.0
Maize	14.1
Millets	*10.9*
Oats	0
Rice	120.6
Sorghum	*7.0*
Wheat	80.7
Cereal imports (2007 data)	2.7
Calorie availability (per capita)	2300

FEATURES OF THE INDIAN FOOD MARKET

1. Rapidly growing economies - Approx. 5% per annum
2. Many young consumers - Disposable income
3. Rapid urbanisation - Growing middle class with aspirations
4. Most urban households have two "Bread winners" - Demand for convenience
5. Traditional foods culture – Respect for sorghum and millets
6. High levels of malnutrition – Especially young children (PEM and Micronutrient Malnutrition)
7. Growing problem of Western-type diseases - Especially in the newly urbanised (Obesity, CVD, Type II diabetes)

SORGHUM AND MILLET FOOD AND BEVERAGE PRODUCTS

Increased Technological Complexity

Three levels of value addition to the grains:

1. Clean Grain and Simple Flours

2. *Flours plus Other Ingredients* (Fortified)
– Micronutrients, Other grains, Flavourants

3. *Ready To Eat (RTE) and RT Drink*
(pre-gelatinised starch +/- hydrolysed)
Pre-cooked flours, Snack Foods, Formed Foods, Cookies

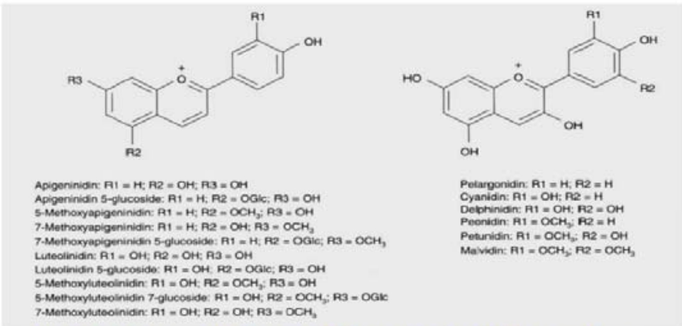
- Beverage powders, Beverages

PHENOLIC CONTENT AND ANTIOXIDANT ACTIVITY OF SORGHUM COOKIES COMPARED TO WHEAT COOKIES

	FLOUR EXTRACTION RATE (%)	TOTAL PHENOLICS (g catechin equiv./g)	ANTIOXIDANT ACTIVITY (micro Mole Trolox equiv./g)
White tan-plant sorghum	70	12	10
	90	20	15
	100	26	102
Red non-tannin sorghum	70	16	78
	90	27	94
	100	30	106
Red tannin sorghum	70	20	145
	90	61	202
	100	65	227
Red bread wheat	75	9	8

Chiremba C, Taylor JRN and Duodu KG 2009 Cereal Chem 85:590

THE SORGHUM AND MILLET ANTIOXIDANT ACTIVITY OPPORTUNITY



(Left) 3-Deoxyanthocyanidins reported in sorghum compared to anthocyanidins in fruits (Right)

From: Dykes, L. and Rooney, L.W. 2006. J Cereal Science 44:236

Scope of entrepreneurship

Cereal technology deals with

The major cereals are: paddy, wheat, maize.Minor grains are: barley, oats, sorghum (great millet), bajra (pearl millet) & ragi (finger millet) are also produced in our country.

Cereal based industries:

Processing/ Milling industries,Bakery industries , Convenience food , Macaroni products, Malting, Brewing, Starch production , Feed manufacturing

Sorghum & Millet-Based Products :

Bread production, premixes, biscuits, rusk,Flakes, Chips, Vermicilli noodles, Stable sorghum flour,Refined millet flour , Jowar Roti, Ready mix for dosa

Ready mix upma, Ready Mixes Savouries, RTE products, Puffing of cereals – FBD, Multi Purpose Food,Energy Food, Weaning food: Balahar, Lactic acid production, Milling by cftri grain mill ,Cattle feed formulations, Some traditional products

JOWAR FLAKES

Sorghum is a coarse grain difficult to pound and make it to flakes. However, with the available modern machines a process for flaking sorghum has been made possible. The flaked sorghum can be used for preparing snack products like chewda. This flakes can be used similar to rice flakes. The units can be established even in rural areas.

SELF STABLE SORGHUM FLOUR

Sorghum is generally ground to whole grain flour as and when required in small quantities by traditional consumers. The major setback of storing of sorghum flour is the development of rancidity within few days of storage. Sorghum is rich in oil containing 3-4 % and due to enzyme action the flour become rancid. The process developed at CFTRI in a standardised way by which the sorghum flour can be stored up to 6-8 months. The flour can be marketed as a regular commodity like maida & ragi flour etc.

Mini Grain Mill

Coarse Grains and millets such as maize, jawar, bajra, ragi are generally used by the economically weaker sections. These cereals and millets contain the non-edible fibrous husk/ bran to the extent of 8-15%. By minimal refining, these can be made tasty, easily digestible, without reducing much of the nutritional factors. It costs about Rs. 1.5 lakh. By this mill, not only the coarse grain, but also wheat can be refined. In a single step the refined suji and flour are obtained from wheat /maize/ jowar/ bajra/ ragi/ and other grains. In this mill, the simple chakki machine has been modified suitably to have arrangement for water mixing, sieving and aspiration.

DECORTICATION OF RAGI

The decorticated ragi cooks within 5 min. in boiling water and the grains retain their shape with soft texture even after cooking. The cooked grains will be slightly brick red and spherical in shape suitable for consumption similar to rice along with sambar, rasam, curd etc., or can be seasoned with spice to prepare tamarind rice. It can be used to prepare traditional sweets also.

Alternately, the decorticated millet could be cracked to soji or semolina to prepare upma, idli, dosa and such other products. The flour from the millet may be utilized for preparation of traditional millet foods and bakery products. The process know-how for preparation of Decorticated Finger Millet (Ragi-Rice) has been tested successfully on industrial scale. The decorticated millet can be puffed to prepare the product similar to 'rice poori' or expanded rice or could be flaked for use as breakfast cereal.

CATTLE AND POULTRY FEED

Animal feed production units have for their options a variety of raw materials like cereals, millets, agricultural waste, oilseed meals, fish/silk worm meal and other nutritive materials for the formulation of an effective balance feed for the proper growth of animals. Small units based on cattle and poultry feed production can be established at rural areas, either in cooperative sector or individually.

The raw materials for the animal feed are Jowar, ragi, wheat brokens, maize, topioca, rice bran (deoiled), rice bran, gram husk, groundnut cake, wheat bran, wheat husk, fish meal, dried fish, niger cake, silk worm pupae, molasses and these are available in plenty in rural areas. According to the availability of the suitable raw material, cattle and poultry feed formulations can be standardised and manufactured on cottage scale.

Some of the health and functional foods from millets

Fiber rich jowar bicsuits in multi taste, Gluten free biscuits with extra protein and calcium, fiber rich gluten free vermicelli, fiber rich gluten free pasta, Omega-3 fortified millet pasta, designer rawa, shelf stable multi grain roti and jowar roti, ashwagandha incorporated millet biscuits, shelf-stable jowar based roti, fat free crunchies, Ready to eat extruded snacks

Process know-how available

Ragi vermicelli noodles, Jawar vermicelli noodles, maize vermicelli noodles rice vermicelli noodles, bajra, navane, samai vermicelli noodles.

11.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.

A March 2015 report of the Indian Council of Agricultural Research (ICAR)—Central Institute of Post-Harvest Engineering and Technology (CIPHET)—in Ludhiana showed that the cumulative percentage of post-harvest losses of cereals was low in the range of 4.65–5.99 per cent while that of pulses was between 6.36–8.41 per cent and oil seeds 3.08–9.96 per cent *(http://www.thehindu.com/business/Industry/government-mulls-fresh-study-on-postharvest-loss-of-farm-produce/article8337371.ece*

As on Nov, 2013 the post-harvest loss in foodgrains in India worked out to six per cent and 18 per cent in case of fruits and vegetables. About two per cent loss of food grains was accounted for storage done by farmers for seed purpose14-17 million tonnes of foodgrains are lost due to storage pests, which if prevented could feed one-third of the population *(http://articles.economictimes.indiatimes.com/2013-11-13/news/44030995_1_food-grains-pests-foodgrains)*

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

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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 stinking odour in flour affecting the dough quality.	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.
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 secretio.	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:

S. 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

S.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.:

- 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.
- 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.
- 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.
- 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.

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.

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

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.

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.

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 and b. Curative treatment.

Prophylactic treatment

- 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.

- 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.
- 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.
- Gunny bag impregnation: Empty bags are soaked in 0.1% malathion emulsion for 10 minutes and dried before using for seed storage.

Curative treatment

- 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
- Decide the need for shed fumigation (entire store house or godown) or cover fumigation (only selected blocks of bags)
- 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”

12.Sweet sorghum for bio-fuel production - Industrial experiences and economics

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Introduction

Blending automotive fuels with ethanol has been mandated in India like several other countries across the globe to meet the energy requirement for transport. The entire blending requirement has to come from molasses (by-product of sugarcane). Molasses based ethanol alone cannot meet the blending target due to cyclical nature of sugar cane production. This has dragged the interest of researchers to augment energy sources that are sustainable and economically viable. Alternate renewable resources can contribute to energy requirements with the added advantage of greater environmental protection, especially in terms of lower CO_2 emissions (Basavaraj et al., 2012). One of the major indicators of the country's economic growth is energy consumption and is one of the major inputs for which use increases with economic growth and development. Over the past two decades Indian economy has grown on an average at the rate of 5-6 % per annum. In terms of energy demand India ranks sixth and accounts 3.6 % of the global energy demand (Prasad et al., 2007) and this is expected to increase by 4.8% annually in the next few years (Gonsalves, 2006). In India, highest demand for energy comes from industry, followed by the transportation sector which consumed about 16.9% (36.5 m of oil equivalent) of the total energy (217 million t) in 2005-06 (TERI 2007).

Coal, natural gas and oil (fossil fuels) are non-renewable energy sources through which India's current energy demand is primarily met. Being short in domestic production, India mainly depends on crude oil imports that have risen from 57.8 million tons in 1999-2000 to 140.4 million tons in 2009-10 which accounts for about 81% of the oil consumption in the country (Ministry of Petroleum & Natural Gas, 2009). This in turn puts pressure on scarce foreign exchange resources (import bill of $75.6 billion in 2009-10). In the near future the imports are slated to rise further with no major breakthrough in domestic oil production and the rise in vehicular population that has grown at 10% per annum between 2001-2006 and is expected to continue in the near future. To meet the energy demand, also growing concerns of energy security and environmental pollution due to high dependence on fossil fuels, the focus has shifted to energy augmentation through renewable alternative sources (GOI, 2009). Blending requirements of automotive fuels with ethanol have been introduced across several countries to accomplish mandatory blending requirements and this has promoted research efforts towards energy sources that are sustainable and economically viable. Several alternative renewable energy sources like wind, solar, hydro and plant biomass are available, energy derived from plant biomass is gaining importance worldwide (Rao et al., 2007). Bioenergy derived from plant based biofuels has been the major thrust across countries to develop alternative energy sources. Bio-ethanol and biodiesel are the two most common biofuels that are commercially exploited. Biodiesel is produced from *Palm, edible oil, Jatropha &* switch grass while sugarcane, corn, and sugar beet are common commercially exploited feed stocks for bio-ethanol. Molasses is commonly used for alcohol and ethanol production in India, which is a by-product in sugar production. However, current estimates indicate that ethanol from molasses alone will not be able to meet the mandated requirement of blending.

National Policy on Biofuels

National Policy on Biofuels is approved on December 24, 2009 by the Government of India (GOI). The policy encourages use of alternate renewable energy resources to supplement transport fuels and had proposed an indicative target to replace 20 % of petroleum fuel consumption with biofuels (bioethanol and biodiesel) by the end of 2017. The Cabinet Committee of Economic Affairs (CCEA) on November 22, 2012, recommended 5 percent mandatory blending of ethanol with gasoline to renew its focus and strongly implement the Ethanol Blending Program (EBP), (GAIN report 2013). Currently, the government's target of 5 % blending of ethanol in gasoline has been partially successful in years of surplus sugar production and unfilled when sugar production declines. The interim (ad-hoc) price of Rs 27 per liter would no longer hold as price would now be decided by market forces. According to CCEA, the EBP is presently being implemented in a total of 13 states with blending level of about 2 %. The net ethanol availability (after accounting for domestic consumption) seems adequate to meet 2.9 and 2.1 % of ethanol blending target for 2013 and 2014, respectively. Presently, the contracted ethanol supply for calendar year 2013 is sufficient to meet 2.9 % blending target. As per the estimation, India would require more than 6.3 billion liters of ethanol to meet its ambitious target of 20 % EBP by end of 2017. Given the current pace of development, a target to meet 5 % blending of ethanol (1.6 billion liters) with gasoline looks plausible. Based on the projections, it is estimated that bio-ethanol requirement would be 3.46 billion liters by 2020 at the rate of 10% blending. Sweet sorghum is one of the first generation biofuel feedstock besides sugarcane, sugar beet and cassava as in the National Biofuel Policy (2009).

Ethanol Production from Sweet Sorghum

Sweet stalked sorghum, popularly referred to as sweet sorghum is a multipurpose crop plant that provides food, fodder, feed, fiber and fuel that addresses food-versus-fuel issue favorably**.** Sweet sorghum (*Sorghum bicolor* [L.] Moench) has the ability to produce both food (grain) and biofuel (from stalk juice) and is increasingly being studied as a potential source of feedstock for bioethanol production and could be a promising biofuel feedstock for ethanol production in India (Hunsigi et al., 2010; Ratnavathi et al., 2010) and around the world (Rooney et al., 2007; Erickson et al., 2011; Whitfield et al., 2012). Sweet sorghum competes well with miscanthus and switch grass in terms of biomass yields (Propheter et al. 2010), can thrive under moderate water stress conditions (Steduto et al., 1997) on marginal lands with little or no external inputs (Holmseth, 2008; Srinivasarao et al., 2009). It is drought tolerant when compared to sugar cane and sugar beet, and the growing cycle is shorter: four months compared to 10-12 months for sugar cane (Reddy et al., 2007b). It can be grown in the areas where sugarcane is being grown to supplement molasses for ethanol production and also to use the existing sugarcane machinery in the off season (Vinutha et al.2014). Sweet sorghum has such high levels of sugar in the stems, (fresh or dry stem) which can be fermented directly; referred to as solid state fermentation. Sweet sorghum biomass is considered as one of the best alternative renewable energy sources due to its wider adaptability which makes economy of the industries viable. The economic superiority is contributed by characters such as stalk yield, stalk sugar content, and stalk juice extractability, content of non-reducing and reducing sugars and grain yield. Some sweet sorghum lines attain juice yields of 78 % of total plant biomass, containing 15–23 % soluble fermentable sugar (Srinivasarao et al. 2009). The sugar is composed mainly of sucrose (70–80 %), fructose, and glucose. Most of the sugars are uniformly distributed in the stalk, with about 2 % in the leaves and inflorescences (Vietor and Miller 1990), making the crop particularly amenable to direct fermentable sugar extraction.

Yu et al. (2008) showed that this process yields 7.9 g of ethanol per 100 g of fresh stalks (100 L ethanol per tonne of stalks, where 0.46 g ethanol was generated per g sugar). Reddy et al., (2007) reported the ethanol yields as 760 litres /ha from the grain, 1,400 litres/ha from the stalk juice and 1000 litres/ha from the residues. Besides the juice extracted for bio-ethanol, additional benefits are the grain harvested for food, and bagasse left after extraction of juice from the stalk, which is an excellent feed for livestock In addition to the free fermentable sugars and starch, cellulose in the fibrous residues was efficiently degraded into glucose via low temperature alkali pretreatment and enzymatic hydrolysis (L. Wu et al. 2013). Like sugar cane bagasse, crushed stalks of sweet sorghum contain cellulose which makes it as a suitable raw material for lignocellulosic biofuel production. The food vs. fuel conflict does not arise with sweet sorghum as it meets food, fuel and fodder requirement. Research institutes in India and abroad have developed superior varieties and hybrids owing to its genetic variability in terms of stalk sugar traits such as total soluble sugars; green stalk yield, juice quantity and grain yield. For a tropical country like India Sweet sorghum is being widely considered to be suitable biofuel feedstock as sugarcane is grown primarily for sugar while corn is used in food and poultry industry (Zhang et al. 2010).

Comparative advantages in cost of production of feedstock

Sweet sorghum scores over sugarcane in terms of water use efficiency (4,000 m3 vs. 36,000 m3), fertilizer requirement (100-50–40 kg NPK/ha vs 250 to 400-150-150) and cost of cultivation (US$435 vs $1,079) by many fold compared to sugarcane (Table 1). While sugarcane yields more stalk/juice, the per day productivity of sorghum is much higher (416.67 kg vs 205.47 kg). These figures vary widely with respect to crop management, climate, soils, labor, etc (Srinivasa Rao et al 2009).

Table 1: Comparative advantages of sweet sorghum vs sugarcane/sugarcane molasses for ethanol production.

Crop	Cost of cultivation (USD ha^{-1})	Crop duration (months)	Fertilizer Require-ment (N-P-K kg ha^{-1})	Water require-ment (m^3)	Ethanol producti-vity (liters ha^{-1})	Av. stalk yield (t ha^{-1})	Per day producti vity (kg ha^{-1})	Cost of ethanol produc-tion (USD lit-1)
Sweet sorghum	435 over two crops	4	80 – 50 - 40	8000 over two crops	4000 $year^{-1}$ over two crops(a)	50	416.67	0.32(d)
Sugarcane	1079 $crop^{-1}$	12-16	250 to 400 –125 -125	36000 $crop^{-1}$	6500 $crop^{-1}$(b)	75	205.47	
Sugarcane molasses	-	-	-	-	850 $year^{-1}$(c)	-	-	0.37(e)

(a) 50 t ha^{-1} millable stalk per crop at 40 l t^{-1} ; (b) 85-90 t ha^{-1} millable cane per crop @ 75 l^{-1}; (c) 3.4 t ha^{-1} at 250 l t^{-1} ; (d) Sweet sorghum stalk at US$12.2 t^{-1}; (e) Sugarcane molasses at US$39 t^{-1}

(Source: Srinivasa Rao et al 2009).

The study undertaken by Dayakar Rao et al. (2004) at 2 locations in Andhra Pradesh (AP) and Maharashtra, India shows that the cost of production is Rs 17,820 in AP while it is Rs 13,375 in Maharashtra, whereas there is not much difference between the two states for sugarcane (Rs 49,250 vs Rs 48,750). Another study conducted in 2007, by Rajashekar (Table 2), to compare grain sorghum with sweet sorghum shows a clear advantage for sweet sorghum as the farmer gets an additional 133.33% increase (Rs 5700 for grain sorghum and Rs 13,300 for sweet sorghum) in net returns. This increased returns is due to the absence of any significant grain yield reduction in sweet sorghum. If the same analysis is extrapolated between sweet sorghum and corn or wheat, similar results can be expected as both corn and wheat require more irrigation and intercultural operations, besides requiring a high dose of fertilizer.

Table 2: Economics of sweet sorghum cultivation per ha in India (July 2007).

S. No.	Particulars	Grain sorghum		Sweet sorghum	
		Cost (Rs)	*Cost (US$)*	*Cost (Rs)*	*Cost (US$)*
I	**Inputs**				
1	Land preparation	600	14.63	600	14.63
2	Inputs (seed + fertilizers)	3400	82.93	3400	82.93
3	Crop management & harvesting	2800	68.3	3930	78.28
4	Transport & stripping	1000	24.39	2500	36.59
	A) Total cost of cultivation	7800	190.24	10430	254.5
II.	**Outputs**				
1	Grain yield (16 qtls/ha @ Rs 600/tl)	12000	292.68	9600	234.2

S. No.	Particulars	Grain sorghum		Sweet sorghum	
		Cost (Rs)	*Cost (US$)*	*Cost (Rs)*	*Cost (US$)*
2	Green stalks 20 tons @ Rs. 600/tonne	1500	36.59	12000	292.8
	B) Total gross returns	13500	329.27	21600	527.0
III.	**Net returns (B-A)**	5700	139.02	13300	324.5
IV.	**B:C ratio (B/A)**	1.73		2.07	

(Rajashekar 2007).

ICRISAT through its Agri-Business Incubator (ABI) collaborated with Rusni Distilleries, in Sangareddy, Andhra Pradesh, and along with other partners like IIMR, ANGRAU, CRIDA etc has promoted sweet sorghum as bio-fuel crop under NAIP-Sweet sorghum project funded by Govt of Inida utilising world bank funds between 2007-12. The results pertaining to the economics of the crop cultivation under the project are summarized below

Economics of biofuel production from sweet sorghum

Indian Instittue of Millets Research, (Formerly Directorate of Sorghum Research and formerly called NRCS) has conducted pilot studies on sweet sorghum-based ethanol production in collaboration with many distilleries and stakeholders such as M/S Renuka Sugars, Belgaum; Sagar Sugars, Chittoor, Andhra Pradesh; Praj Industries, Pune; National Sugar Institute, Kanpur; Somaiya Organo-chemicals, Sakarwadi; India Glycols Ltd, Khashipur; KCP Sugars, Laxmipuram, Andhra Pradesh; Nav Bharat Ventures, Samalkot, Andhra Pradesh between 2001-2006. The ethanol yields ranged from 25-40 lit/ton of sweet sorghum stalks crushed ((Dayakar Rao et al. 2004, Ratnavathi et al. 2005, Holigal et al. 2004) Reddy et al 2013). A big mill test with 356 tons of sweet sorghum stalk was conducted with a sugar factory in Karnataka and the extraction percentage realized was 50% with an ethanol yield of 38.89 l/ton stalk. (Hunsugi et al 2010). Techno-economic feasibility studies have shown that the cost of alcohol production from sweet sorghum was Rs 1.87 less than that from molasses (Dayakar Rao et al. 2004) (Table 3).

Table 3: Comparative per liter cost of ethanol production from sweet sorghum and sugarcane molasses.

Particulars	Sweet sorghum[1] (Rs liter^{-1})	Sugarcane molasses[2] (Rs liter^{-1})
Human power	0.50	0.25
Steam	1.00	1.00
Electricity	1.00	1.00
Yeast	0.10	0.10
Management/Administration	0.10	0.25
Pollution control	Nil	0.25
Raw material	10.41	12.13
Total	**13.11**	**14.98**

[1]Sweet sorghum stalk @ Rs 500 t ha^{-1}; [2]Sugarcane molasses @ Rs 2,000 t ha^{-1}.
(Source: Dayakar Rao et al., 2004).

The cost of sweet sorghum cultivation ranges in between Rs. 7000 to 8000 with inputs (fertilizers) accounting merely 20% and the remaining cost of cultivation accumulated by labour cost- which is one of the most advantage of sorghum over other crops. With the improvement in agriculture irrigation system in india, especially canals, the irrigation expenditure has reduced massively from 6.2 to 1.3 percent which roughly comes around 800 to 1000 rupees per hectare.

The net returns realized in cultivation of sweet sorghum excluding family labor was Rs 2999/ha (Table 4) for all the categories. There were no specific reasons for the increasing net revenues with the landholding size, except that the small and medium farmers seemed to have waited for the crop to fully mature prior to harvesting and thus harvested more grains compared to the marginal farmers.

Table 4: Economics of Sweet sorghum cost of cultivation according to Landholding, 2007.

Category	All Categories	Marginal	Small	Medium
Grain yield (Kg/ha)	346	255	449	299
Grain Value (Rs/ha)	2,214	1,617	2,865	1,912
Stalk (q/ha)	141	150	136	145
Stalk value (Rs/ha)	8,504	9,009	8,170	8,714
Gross income (Rs/ha)	10,718	10,626	11,036	10,626
Total Expenses excluding family labor (Rs/ha)	7,719	7,641	7,522	6,729
Net income excluding family labor (Rs/ha)	2,999	2,986	3,514	3,897
Source: Parthasarathy *et al* 2007-08 from Daultabad cluster in Medak district of AP Note: Large farmers included in all category				

There was considerable variation in the net revenues for sweet-sorghum based on the soil type it was grown (Table 5). Net revenue for farms with shallow red soil was Rs 3,624/ha, and for medium to shallow black soils was Rs 2,418/ha, and for medium black soil it was Rs 4,116/ha. The break even yield was 24.13 t/ha of stalk priced at Rs 600 t/ha.

Table 5: Economics of Sweet sorghum cost of cultivation according to Soil Type, 2007.

Category	All soil type	Shallow red soil	Deep red soil	Medium to shallow black soil	Medium black soil
Grain yield (Kg/ha)	346	366	141	272	389
Grain Value (Rs/ha)	2,214	2,447	988	1,840	2,398
Stalk (q/ha)	142	147	136	146	155
Stalk value (Rs/ha)	8,504	8,821	8,187	8,788	9,428
Gross income (Rs/ha)	10,718	11,268	9,174	10,628	11,826

Category	All soil type	Shallow red soil	Deep red soil	Medium to shallow black soil	Medium black soil
Total Expenses excluding family labor (Rs/ha)	7,716	7,643	7,086	8,211	7,710
Net income excluding family labor (Rs/ha)	3,002	3,624	2,089	2,418	4,116
Source: Parthasarathi et al 2007-08 from Daultabad cluster in Medak district of AP					

Conclusions:

For sweet sorghum to be a successful biofuel crop, largely it depends on the ethanol and feedstock pricing, besides the recovery rate of ethanol. Improvements in recovery and increase in feedstock prices and administered price of ethanol would certainly give a fillip to the promotion of sweet sorghum as a viable biofuel crop. The estimates on the demand side of ethanol blending show deficits from the current level of supply. The estimates show that the demand is going to outstrip supply. With the highest available alcohol from molasses at 2.3 billion l and further with the inability to increase area under sugarcane, the future supply of bioethanol has to be augmented through alternative feedstock like sweet sorghum.

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13.Sorghum cultivation in rice-fallows: A new opportunity

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Sorghum is emerging as a potential alternative feed, fodder and bio-energy besides, food crop under changing climate scenario. 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. The farmers were commercially motivated and selected to grow sorghum instead of maize on residual moisture of rice-harvested field without tillage condition after comparing economic benefits. They preferred to grow hybrids which had high grain yield potential and medium height (2.0 to 2.5 m) to avoid losses from lodging. With advancement in use of modern agricultural practices, the farmers were applying high inputs like, fertilizers, weedicides, pesticides, irrigations labourers, and its skillful management in order to the crop response to their soils. The practices of farmers' innovative knowledge were identified, validated and documented in this manuscript.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is emerging as a potential alternative feed, fodder and bio-energy crop apart from food grain. Moreover, its resilience to high temperature and moisture stress conditions makes it a climate-ready crop. There is a huge diversity in bio-physical and socio-economic environment in the sorghum cultivation of the country, and strong competition with cash crops in the present days. Therefore, the area under sorghum is decreasing rapidly from 18.6 m ha in 1970 to 7.06 m ha in 2010-11. However, sorghum cultivation in rice-fallows under zero-tillage condition is increasing in the Guntur district of Andhra Pradesh continuously since 2004 which is non-traditional area (Fig. 1). It is now grown in more than 24,000 ha area with an average productivity of 6.5 t/ha in 2010-11, which is the highest in the country (Fig. 2)[1]. Due to the latest adoption of the crop in this area, standard production practices for zero-till cultivation in rice-fallows are lacking. The farmers are adopting cultivation practices by using fertilizers and pesticides indiscriminately as per the crop response to their soils and their own wisdom[2]. Consequently, they are getting higher yield than any other sorghum situations in India. Practically, the sorghum growers in this area are inclined towards obtaining maximum monetary benefits from grain yields than other benefits.

Farmers' knowledge is the result of their own experience and response of the skillfully management of the available resources[3]. Though, the area is endow with rich natural resources in terms of fertile soils, moisture availability due to being coastal area, suitable temperature, sufficient sunlight, ecological conditions, possession of agricultural assets with the farmers and infrastructure facilities, most important is the farmers aggressiveness to adopt new ideas and tacit knowledge for efficient management. Obviously, their action is dependent on many factors like social, economical, physical, situational, cultural and market conditions, which regulates their decision making process to select new crop and its management on their own innovative ideas without scientific interventions[4]. Farmers-based innovative/indigenous knowledge has scientific rationale and great deal of relevance for agricultural productivity and sustainability. Such type of farmers' innovativeness and tacit knowledge to use high inputs to sorghum would be a path finder for the sorghum farmers to raise their profit margins in the different parts of the country. In contrast, knowledge, skill and strategy of farmers operating with their own ideas and tacit knowledge suitable to local situations have often been undermined in modern agriculture[5]. Therefore, the present investigation was carried out to identify and document farmers' innovative knowledge (FIK) used in sorghum farming in rice-fallows under zero-tillage conditions in achieving the highest productivity in the county. The study was conducted in seven villages namely, Athota, Kamathavaripalam, Dhanthuluru, Siripuram and Kunchavaram (Block-Kollipara), and Nandivelugu, and Ananthavaram (Block-Tenali) in the Guntur district of Andhra Pradesh which is coastal area (latitude $15^0$18'0" -16°50'0" N and 15°18'0" -16°50'0" E). The location was purposefully selected as the productivity of sorghum in the district was the highest (6.5 t/ha in 2011-12) in the country.

Motive behind selection of sorghum for cultivation in rice-fallows

Previously, rice-fallows-blackgram was the major cropping system in the coastal areas of A.P. where blackgram seeds were broadcasted in standing crop of rice (before rice harvest) to utilize the residual soil moisture. However, due to infestation of yellow mosaic virus (YMV) and parasitic weed, namely field dodder (*Cuscuta campestris)*, the productivity of blackgram declined considerably (Fig.3)[6] and the area has now been reduced drastically, which was the foremost reason to shift towards growing maize and sorghum in their area. Besides, due to the late receipt of monsoon and late release of water from the *Krishna* river now-a-days, transplanting of paddy crop is delayed and the crop is harvested in mid December. Sowing of blackgram in standing rice crop during late December leads to poor germination due to low temperature. In the changed scenario, the farmers were shifted to maize (in assured irrigation) and sorghum (in limited irrigations) in place of blackgram. Although, maize was a major competitor, nevertheless, sorghum was preferred in areas where irrigation is limited and requirements of inputs for maize are more which is not comparatively profitable. These were the second and third major factor behind sorghum cultivation. Taking advantage of residual moisture, saving in cost on land preparation, judicial use of seeds, limited irrigation water and weed management have shown positive change in attitude of farmers and farm functionaries[7]. The preliminary studies indicated that the farmers were interested in grain sorghum only because they found only marginal difference between price of sorghum (Rs. 1200/- per 100 kg) and maize (Rs. 1300/- per 100 kg). Fourth important motive was, a short duration crop like sorghum (110-120 days) is suitable to fit in the crop rotation and fifth motive was, less insect-pest problems were occurred on sorghum than other crops. From the last 6-8 years, the farmers are taking sorghum after harvest of rice on the residual soil moisture without tilling the field. It is observed that there is good scope for increasing yield and profits by using standard cultivation technologies. They were cautious to gain maximum economic benefits by cultivating sorghum hybrids mainly for grain purpose.[8&9] Area under sorghum in this area is expected to increase in future due to the scarcity of irrigation water.

Innovative practices followed by the farmers

Being new area of sorghum in rice-fallows, there was no specific standardized practices of sorghum cultivation. The farmers were following the practices based-on their wisdom and crop response to the given inputs. Some of the practices being followed by the farmers are mentioned hereunder.

Cultivars used

The farmers were commercially motivated and not at all using sorghum for their consumption. They wisely prefer to grow hybrids with high yield potential and medium height (2.0 to 2.5 m) to avoid losses from lodging. They were not aware about high yielding sorghum hybrids of public sector and were growing locally available private hybrids namely, Haritha, NH 27, Kaveri 6363 and Mahalaxmi 296. The Mahalaxmi 296 was ruling hybrid in the rice-fallows area[8]. If they find a hybrid which gives higher yield than the existing one, they are ready to adopt it in their fields.

Method of sowing, spacing and seed rate

Sowing of crops under zero-tillage has many economic and environmental benefits over conventional tillage, such as, lower labour and fuel needs, reduced soil erosion, reduced runoff, increased soil organic C contents, and increased soil biological activity[10]. The researchers recorded 25% higher grain yield in no tillage than reduced tillage and 98% greater than conventional tillage[11]. In this area, after the harvest of *kharif* transplanted rice, sorghum was sown in second fortnight of December under zero-tillage on the residual soil moisture. Sowing was done manually in rows (40 cm x 20 cm) at 4 - 6 cm depth by making a hole with wooden stick and putting 3-4 seeds in each hole with seed rate of 8-10 kg /ha. Making holes manually in line with the help of labourers without tilling the rice-harvested fields that is under zero-till conditions for sowing is however, time consuming and costly. Some farmers have designed manually operated small implement with wheel, which makes the holes in two rows at a time and is easy to operate in the field (Fig. 4). With taking advantage of high inputs and fertility of the soils, the farmers allow to grow 3-4 plant at each hill and plant density became higher (> 200000 per ha) than the normal cultivation as advocated for irrigated post-rainy (*rabi*) sorghum (180000 per ha). In view to high wages and shortage of labourers, mechanization like, use of zero-till seed-drill, combine harvester, etc., is essential to make sorghum production more cost-effective. A few active farmers are making efforts to fabricate a suitable tractor-driven holes making implement to overcome problem of labourers, out of their own interest (Fig. 5).

Nutrient management

As per recommended dose of fertilizers for traditional sorghum under irrigated condition requires 80-100 kg nitrogen, 40-50 kg phosphorus, and 40-50 potash /ha. Half quantity of the nitrogen and full amount of phosphorus and potash should be given at sowing and remaining nitrogen at 30-45 days after sowing. However, in rice-fallows, the farmers were applying higher dose of fertilizers (150-200 kg N, 75-80 kg P_2O_5 and 75 kg K_2O per ha). Being a zero-till manually sown crop, no nutrient was applied at the time of sowing. At 30 days after sowing (just before Ist irrigation), a mixture of 75-100 kg /ha N and 75-80 kg/ha P_2O_5 was side dressed to individual plant in rows with the help of labourers (Fig.6). At 60 days after sowing (just before 2nd irrigation) 75-100 kg N and 75 kg K_2O /ha were applied. Though, the farmers were obtaining high yields with higher dose of nutrients, the nutrient-use efficiency was overlooked as phosphorus and potassium fertilizers were applied as top-dressing. This point attracts attention of the researchers to understand the nutrient dynamics in rice-fallow sorghum cropping system as a whole, so that profit margin of the farmers could be enhanced.

Weed management

Weeds including grassy and broadleaf were the major problem in rice-fallows in zero-tillage. They emerged even before the crop sowing and compete with the crop for resources. Grassy weeds especially *Echinochloa* spp. were the major weeds infesting the crop. Some of the weeds already existed in rice-harvested field while sowing of sorghum and some were emerging after sowing. Therefore, two types of weedicides; pre-emergence and post-emergence were much useful under the situation. The farmers wisely used both, tank mixed application of paraquat + atrazine (1.0+0.5 kg/ha) one day after sowing for effective weed control. Paraquat controls already existed (emerged weeds) and atrazine acts as pre-emergence i. e. to control emerging weeds along with sorghum (Fig. 7). This practice is very important to maintain the crop healthy and overcoming the labour problem which was followed by the farmers timely and carefully.

Insect-pests management

Due to high humidity in coastal regions, heavy infestation of insect-pests and diseases was observed. Among major pests, shootfly, aphids and stem borer were dominant.

For effective control of shootfly, the farmers were spraying cypermethrin @ 2 ml/l of water at 1 week after germination and again giving need-based spray at two weeks interval. On the basis of improved practices of other crops, they were applying furodon 3G granules (@10-12 kg per ha) in leaf whorls of individual plant with the help of labourers after 30-35 days of sowing (Fig. 8).

Irrigation management

Scarcity of irrigation water due to very limited or no release of water from the *Krishna* river and late receipt of monsoon, were among the major reasons to increase in sorghum area in this region. Sorghum in rice-fallows was grown on residual moisture, which supports the crop growth for germination and early establishment. Lower initial soil moisture sometimes results in poor plant population. Two irrigations are sufficient to harvest good yield whereas, maize is required four irrigations and more inputs. The farmers were judiciously using available water by giving first irrigation at 30 days after sowing (DAS) and 2nd at 60 DAS. These two irrigations are sufficient to obtain good yield in that area. Irrigation frequency was also depends on the seasonal rains. They were receiving frequent rains with high wind velocity, which also supports to meet water requirements of the crop.

Harvesting and threshing

In the coastal areas, there is frequent occurrence of heavy rains and strong winds in March and April due to low pressure in sea resulting in severe damage of crop. Therefore, the farmers harvested the crop with the help of labourers at early maturity stage (105-110 days) to avoid losses from cyclonic rains and diseases. After harvest, the panicles were sundried for a week and thereafter the grains are separated by manual or mechanical threshing. On an average, the farmers obtaining grain yield of 6.5 t/ha, however, some farmers were getting up to 7.5 t/ha in this area. The higher grain yield than the normal sorghum productivity was may be due to more number of plants per unit area, timely use of high inputs and intelligent crop management done by the farmers (Fig. 9). Thus, they were able to earn gross returns of Rs. 78,000/- per ha (with an average market price @Rs.1200/- per 100 kg) excluding fodder price. All the farmers sold the produced grains in the local markets after harvest. The highest fodder yield was also recorded (12-15 t/ha). The high bio-mass was produced due to more plant populations and plant height. However, the farmers were burning fodder in their field itself due to lack of knowledge about its nutritional importance, and sufficient availability of grasses and paddy straw in this area [12]. Awareness regarding nutritional importance of sorghum fodder for animals over paddy straw marketing fodder in its deficit areas by building market linkage, would be additional source of their income. It indicated huge potential for increasing sorghum productivity in rice-fallows. The Directorate of Sorghum Research (DSR) has recently taken initiatives to standardize the crop production technologies for this area.

Summary

In rice-fallows of coastal Andhra Pradesh, sorghum cultivation was found to be high yield potential with labour and inputs intensive crop system. It is found that use of high inputs *viz.*, pesticides, weedicides, fertilizers, labourers, and skillful management of all the innovative practices including irrigations, were resulted into the high yield. It is implied that the farmers were highly profit oriented and obtained high returns from the sorghum cultivation. Continuously, rice followed by sorghum or maize cultivation in this area would deteriorate the soil health in long term. Another issues, proper utilization of stover as fodder and marketing of this bio-mass by making bio-fortified fodder blocks through value addition in deficit areas to prevent the present practice of fodder burning or incorporating in the soil, are needs to address through scientific interventions. Their profit margin could be further increased by mechanization and introducing standard package of practices. Keeping the yield benefits in view, the farmers innovative knowledge should be validated on their fields to develop standardize location-specific production technologies so that the productivity and soil health will sustain in long run. These innovative farmers would be able to educate and transfer the viable technologies more effectively among the other sorghum growers in rice-fallows as change agents.

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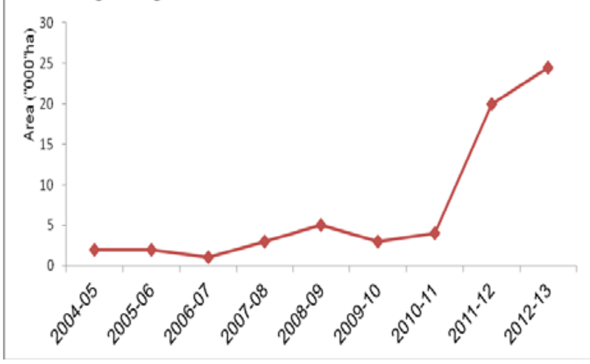

Fig.1. Sorghum area in Guntur district of Andhra Pradesh

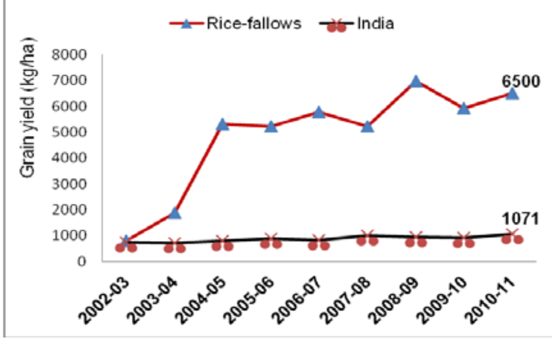

Fig. 2. Sorghum productivity of Guntur district of A. P. and India


Fig.3 Blackgram in rice-fallows is infested with YVM disease and weeds


Fig. 4. Sowing of sorghum in rice-fallows

Fig. 5. Tractor-drawn hole making implement for sowing

Fig. 6. Fertilizers application to sorghum at 30-35 days

Fig. 7. Sorghum infestated with grassy weeds (left) and treated with weedicides, atrazine + paraquat (0.50+1.0 kg/ha) (right)

Fig. 8. Furadon application in leaf whorl at 30-35 day after sowing

Fig. 9. A field view of sorghum in rice-fallows at maturity

14.Prospects for sorghum biofortification

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Micronutrient Malnutrition - a food-related health problem

Human malnutrition is not lack of adequate food, but lack of right kind of food. Globally malnutrition is responsible for more human deaths than any other cause, accounting for >20 million mortalities annually (Kennedy *et al*., 2003). Micronutrient malnutrition, also known as 'hidden hunger' primarily resulting from diets poor in bio-available vitamins and minerals, causes blindness and anaemia (even death); affects 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 who cannot afford a variety of food items in their diet suffer from deficiencies of calories and micronutrients. The main objective of crop improvement in staple food crops remained productivity enhancement and increased profitability to farmers and agricultural industries, 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 deficiency affects nearly 3.7 billion people (Welch, 2002). An estimated 49% of the human population is at risk for inadequate zinc in their diet (Brown *et al.*, 2001). 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, and hence cannot reach the poor population in the remote rural areas. Therefore, 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.

Iron is a redox-active constituent of the catalytic site of heme and non-heme iron proteins. About half of the anaemia cases are caused by iron deficiency. Iron deficiency adversely affects cognitive development, resistance to infection, work capacity, productivity, and pregnancy

Zinc is involved in RNA and DNA synthesis, and is a constituent of many zinc-containing enzymes critical to cellular growth and differentiation. 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.

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).

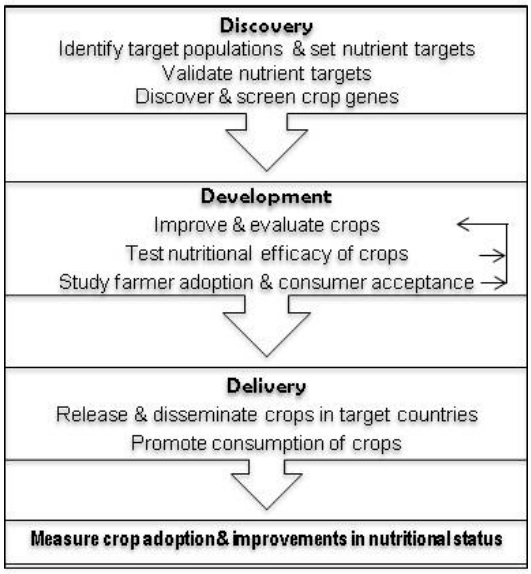

Figure 1. The Biofortification process

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.

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

Crop	Nutrient	Target country	Lead institutions	Release year
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*

In 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.

Sorghum - a crop of substance

Sorghum is the world's fifth major cereal in terms of production and area harvested, and dietary staple of more than 500 million poor and most food-insecure people living in about 30 countries in the sub-tropical and semi-arid regions of Africa and Asia.

Incidentally, these are the regions where most of the micronutrient malnourished people of developing world live. Sorghum is agronomically suited to hot and dry agroecologies where other food grains do not yield satisfactorily or even difficult to grow. In these agroecologies sorghum is a dual purpose crop, yielding both grain and stover. More than 80% of global sorghum area of 42.12 m ha (FAO, 2014) lies in developing countries, mainly in the African and Asian continents where sorghum grain is grown primarily for food by low-income farmers or small scale traditional farming households. The remaining area of 16-20% is predominantly in the developed world, especially cultivated by large-scale commercial farms, which produce sorghum mainly for animal feed. Because of the capability of sorghum to grow and produce under harsh environments of arid and semi-arid tropics it can be considered as climate-change compliant crop.

Sorghum - consumption level in India and nutritional status

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.

Variability for grain iron and zinc

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). ICRISAT has one of the largest global sorghum collections (~39000 accessions) in its genebank which represents 85% of the global sorghum diversity. As it is difficult to evaluate all these lines for grain Fe and Zn concentration, the core collection of sorghum germplasm accessions that represents nearly entire diversity in sorghum genebank was assessed for grain Fe and Zn concentration. 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). A good number of germplasm accessions with higher Fe concentration (> 60 mg/kg) were identified for use in the breeding programmes (Table 2). These donors formed the major sources for Fe and Zn in sorghum breeding programs at ICRISAT and IIMR.

Characterization of popular Indian cultivars, hybrid parents, elite breeding lines and some selected germplasm accessions collected from the major sorghum growing states by IIMR 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.

Table 2. Mean performance of selected sorghum landraces in 2010 and 2011 post-rainy seasons at ICRISAT

Accession	Iron (mg/kg)	Zinc (mg/kg)	Days to 50% flowering	Plant height (m)	Grain yield (t/ha)	Grain size (g/100)
IS 12750	76	39	76	2.5	1.9	2.43
IS 27054	73	29	75	2.4	3.6	2.53
IS 12858	73	32	68	2.2	1.8	2.13
IS 12785	70	27	77	2.4	1.7	2.28
IS 1563	70	38	73	1.8	1.3	2.29
IS 34	69	27	82	2.5	2.4	2.10
IS 13	64	33	74	2.1	2.9	2.52
IS 30	62	32	82	2.5	2.1	2.54
IS 20962	62	24	77	2.3	4.7	2.35
IS 9150	62	28	80	2.3	2.9	2.28
PVK 801 (C)	40	22	75	1.5	3.6	3.40
ICSB 52 (C)	30	16	71	1.3	2.9	3.68
Mean	43.62	26.57	74	1.89	2.38	2.71
CD (5%)	7.54	4.72	4.81	0.24	0.89	0.39

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).

Prospects for sorghum biofortification

In India, the popular post-rainy sorghum cultivars used as food *viz*., M 35-1, Solapur Dagadi, Parbhani Moti, Phule Vasudha, Phule Anuradha and Phule Chitra possess low Fe and Zn concentration (30 ppm Fe and 20 ppm Zn). Compared to post-rainy sorghums predominantly grown for food use in India, the rainy season grown commercial hybrids possessed better Fe and Zn contents (up to 44 ppm Fe and 33 ppm Zn), which is almost 50% higher. The mean grain Fe concentration among commercial cultivars ranged from 30 to 44 mg/kg and grain Zn concentration from 22 to 33 mg/kg. The hybrids GK 4035 and Mahabeej 703 showed higher mean Fe concentrations over two years indicating their stability for this trait. A significant positive association was observed between the grain Fe and Zn concentrations (r=0.85) (Ashok Kumar et al., 2013b).

There is a need to identify/develop cultivars with high grain Fe and Zn. To start with, promising rainy season adapted hybrids possessing >50% higher grain Fe and Zn than the post-rainy sorghum cultivars are to identified. These hybrids can be multiplied in post-rainy season and can be supplied to low income predominantly sorghum eating populations. Some of the available cultivars with high Fe and Zn are given in Table 3. A variety, Phule Rohini developed for papad purpose is found to have very high Fe (101.3 ppm) and Zn (51.4 ppm) content.

Table 3. Available cultivars with high iron and zinc

Cultivar	Iron (mg/kg)	Zinc (mg/kg)
CSV 15	75.7	20.4
CSV 18R	60.4	19.1
CSV 18R	60.4	19.1
CSV 20	53.6	19.6
PVK 801	46.5	21.8
Phule Revati	46.2	24.5
CSH 30	45.1	26.6
CSH 23	44.0	26.8
CSH 16	41.9	25.5

Further, a large number of sorghum hybrid parents have been developed with high grain Fe and Zn concentration at ICRISAT. An improved sorghum line ICSR 14001 showed significantly higher yield and higher grain Fe and Zn in multi-location on-station testing and on-farm testing in Maharashtra. It is currently under evaluation in All India Coordinated Sorghum Improvement Project. This is a first product ready for commercialization as biofortified sorghum variety in India. In addition, two hybrids ICSH 14001 and ICSH 14002 are under multi-location testing towards commercialization.

Development of food products with multi-grain/ready to cook suitable for mid-day meal with fortification using natural sources of Fe and Zn is in progress. These food products once standardized will serve as supplementary food to improve the nutritional status of the children. The products can also act as morning snacks or as side dish in the meal. Machinery retrofitting for processing and products development by incorporating Fe and Zn rich products in sorghum recipe combinations is being tried through different trials.

To conclude, it appears that biofortification in sorghum is 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.

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15.Sorghum genetic resources management (2000 – 2015)

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Summary

A total of 1318 acc. collected by NRCS/DSR/IIMR from 31 explorations during 2000-2015. Indigenous Collection number for 1194 accessions obtained from National Genebank, NBPGR – New Delhi. Out of 31 explorations, 4 are in collaboration with NBPGR (Regional Stations). A total of 1437 accessions collected from 12 states are available at IIMR. Which includes accessions assembled from NBPGR (Regional Station) collections. The maximum accessions are collected from Andhra Pradesh (259 acc.) followed by Maharashtra (200 acc.). A total of 36550 accessions received from various National and International centres. Which includes, sorghum (35925 acc.), Pearl millet (40), Finger millet (118), Foxtail millet (89), Proso millet (118), Kodo millet (86), Little millet (79), and Barnyard millet (93). A total of 10330 accessions characterized / evaluated at NRCS/DSR/IIMR, AICSIP centres and others. The accessions include germplasm, resistant source materials and segregation materials. Hyderabad has characterized / evaluated a maximum of 4007 accessions followed by Indore (1696) and Udaipur (1439). A total of 1249 crosses were made utilizing the germplasm accessions during 2004-2015. Maximum frequency of 225 crosses made during Rabi2007-08 followed by 207 crosses during Kharif2008. The maximum of 207 potential germplasm used for crosses followed by rabi landrace germplasm (149). The maximum crosses of utilizing germplasm accessions is for gran sorghum development with 207 crosses followed by high grain yielding with bold and lustrous grain (149). A total of 14 final products contributed from the germplasm section to the All-India Coordinated Sorghum Improvement trials during 2007-2010. Maximum of 6 sweet sorghum varieties contributed to the trials. A total of 53178 accessions distributed to the bonafied users in the country. A total of 488 MTAs signed for supplying the germplasm. The maximum of 24740 accessions distributed to the bonafied users internally during 2012-13 followed by 10067 in 2011-12. A total of 10141 accessions submitted to the National Genebank for long-term storage during 1991-2015. The maximum of 2083 accession submitted during 2015. A total of 57 sorghum genetic stocks registered with NBPGR during 2005-2015.

1. Sorghum germplasm collection

A total of 1318 acc. collected by NRCS/DSR/IIMR from 31 explorations during 2000-2015. Indigenous Collection number for 1194 accessions obtained from National Genebank, NBPGR – New Delhi. Out of 31 explorations, 4 are in collaboration with NBPGR (Regional Stations). The list of explorations conducted by NRCS/DSR/IIMR during 2000-2015 is presented in Table 1.

Table 1: List of explorations conducted by NRCS/DSR/IIMR during 2000-2015

SN	Mission Number	Season	State	Region	Collaboration	IC Numbers	No. of acc.
1	01/2000/01	Rabi	Karnataka	Dharwad	Individual	IC 308598 to IC 308688	92
2	02/2000/02	Kharif	Madhya Pradesh		AICSIP - Indore	IC 319847 to IC 319909	63
3	03/2001/01	Rabi	MS & KAR	Gulbarga	CRS - Solapur	IC 305882 to IC 305933	52
4	04/2001/02	Kharif	Rajasthan		AICSIP - Udaipur	IC 338968 to IC 339027	60
5	05/2001/03	Kharif	Madhya Pradesh	Western MP	AICSIP - Indore	IC 332460 to IC 332481	22
6	06/2001/04	Kharif	Uttar Pradesh	Ganga basin & Bundel khand	AICSIP - Mauranipur	IC 333346 to IC 333445	100
7	07/2002/01	Maghi	Andhra Pradesh	Andhra region	NBPGR (RS) – Hyderabad	IC 347567 to IC 347595	29
8	08/2002/02	Rabi	Andhra Pradesh	Rayalaseema	Individual	IC 345703 to IC 345736	34
9	09/2002/03	Rabi	Tamil Nadu	Dindigul & Madurai	Individual	IC 345243 to IC 345253	11
10	10/2002/04	Rabi	Maharashtra	Northern Maharashtra	CRS - Solapur	IC 345254 to IC 345297	44
11	11/2002/05	Rabi	Karnataka	Eastern Karnataka	CRS - Solapur	IC 345186 to IC 345209	24
12	12/2002/06	Maghi	Andhra Pradesh	Srisailam regions	Individual	IC 369119 to IC 369131	13
13	13/2002/07	Kharif	Rajasthan	Central parts	AICSIP - Udaipur	IC 369248 to IC 369276	29
14	14/2003/01	Rabi	MS + KAR + AP	Neighburing districts	CRS - Solapur	IC 392124 to IC 392159	36
15	15/2003/02	Kharif	Uttar Pradesh	Central parts	AICSIP - Muaranipur	IC 415792 to IC 415835	44
16	16/2004/01	Rabi	Maharashtra	North western	CRS - Solapur	IC 420936 to IC 420956	21
17	17/2005/01	Maghi	Tamil Nadu	Central districts	AICSIP - Coimbatore	IC 541308 to IC 541332	25
18	E2005-AP0013-03	Maghi	Andhra Pradesh	Khammam district	NBPGR (RS) – Hyderabad	IC 541847 to IC 541881	36
19	18/2006/01	Maghi	Tamil Nadu	Southern districts	AICSIP - Coimbatore	IC 541333 to IC 531466	34
20	19/2006/02	Kharif	Maharashtra	Melghat region	AICSIP - Akola	IC 568337 to IC 568361	24
21	20/2007/01	Kharif	Gujarat	Southern and Saurashtra districts	AICSIP - Surat	IC 568362 to IC 568401	38
22	21/2008/01	Late Kharif	Tamil Nadu	Northern districts	AICSIP - Coimbatore	IC 568402 to IC 568445	44
23	22/2008/02	Kharif	Madhya Pradesh	Bundelkhand	Individual	IC 568446 to IC 568515	70
24	23/2008/03	Kharif	Gujarat	North Gujarat	AICSIP - Deesa	IC 568516 to IC 568547	32
25	24/2009/01	Kharif	Madhya Pradesh & Uttar Pradesh	Bundelkhand	DOA, Bhopal	IC 0585135 to IC 0585170	36
26	25/2009/02	Kharif	Gujarat	Kutch	AICSIP - Deesa	IC 0585171 to IC 0585205	35
27	26/2010/01	Rabi	Tamil Nadu	South Tamil Nadu	AICSIP - Kovilpatti	IC 0585206 to IC 0585241	36

SN	Mission Number	Season	State	Region	Collaboration	IC Numbers	No. of acc.
28	27/2011/01	Kharif	Uttaranchal	Kumaon & Garhwal	AICSIP - Pantnagar	IC 597601 to IC 597629	30
29	28/2011/02	Kharif	Gujarat	Kutch	AICSIP - Deesa	IC 597630 to IC 597670	40
30	29/2012/01	Late Kharif	Andhra Pradesh	Khammam district	NBPGR (RS) - Hyderabad	IC 0596006 to IC 0596030	40
31	30/2015/01	Kharif	Maharashtra	Nandurbar and Dhule	NBPGR (RS) - Akola	To be assigned	124
						Total	**1318**

1.1: State-wise sorghum germplasm collection available at IIMR

A total of 1437 accessions collected from 12 states are available at IIMR. Which includes accessions assembled from NBPGR (Regional Station) collections. The maximum accessions are collected from Andhra Pradesh (259 acc.) followed by Maharashtra (200 acc.). The state-wise germplasm collected during 2000-2015 is presented In Table 2.

Table 2: State-wise germplasm assembled at IIMR during 2000-2015

State	No. of acc.
Andhra Pradesh	259
Bihar	12
Gujarat	146
Jharkhand	47
Karnataka	151
Madhya Pradesh	193
Maharashtra	200
Rajasthan	89
Tamil Nadu	150
Uttar Pradesh	149
Uttarakhand	29
West Bengal	1
(blank)	11
Grand Total	**1437**

1.2: Sorghum germplasm augmented from National and International research centres

A total of 36550 accessions received from various National and International centres. It includes, sorghum (35925 acc.), Pearl millet (40), Finger millet (118), Foxtail millet (89), Proso millet (118), Kodo millet (86), Little millet (79), and Barnyard millet (93).

2. Sorghum germplasm / segregating materials evaluated

A total of 10330 accessions characterized / evaluated at NRCS/DSR/IIMR, AICSIP centres and others. The accessions include germplasm, resistant source materials and segregation materials.

2.1: Centre-wise Sorghum germplasm / segregating materials evaluated

Hyderabad has characterized / evaluated a maximum of 4007 accessions followed by Indore (1696) and Udaipur (1439). The centre=wise list of germplasm and segregating materials characterized / evaluated during 2003-2015 is presented in Table 3.

Table 3: Centre-wise list of germplasm and segregating materials characterized / evaluated during 2003-2015

Location	No. of acc
Hyderabad	4007
Indore	1696
Udaipur	1439
Solapur	1371
Coimbatore	1356
Tandur	1196
Rahuri	1148
Deesa	1094
Akola	990
Mauranipur	711
Parbhani	648
Bijapur	575
AICSIP centres	465
Bhavanisagar	429
Port Blair	355
Hisar	317
Thrissur	287
Kovilpatti	254
Pantnagar	234
Surat	230
Trichy	156
Dharwad	95
NRCS	80
Coimbatore & Akola	67
Jhansi	66
Palampur	58
Coimbatore	39
Jammikunda KVK	8
Grand Total	**19371**

3. Sorghum germplasm utilization in the crossing programme

A total of 1249 crosses were made utilizing the germplasm accessions during 2004-2015. Maximum frequency of 225 crosses made during Rabi2007-08 followed by 207 crosses during Kharif2008. The year-wise crooses made is presented in Table 4. The maximum of 207 potential germplasm used for crosses followed by rabi landrace germplasm (149). The type of germplasm utilized in the crossing programme is presented in Table 5. The maximum crosses of utilizing germplasm accessions is for gran sorghum development with 207 crosses followed by high grain yielding with bold and lustrous grain (149).

Table 4: Year-wise crosses made utilizing germplasm during 2004-2015

Season/Year	No. of crosses
K2008	207
K2013	109
R2004-05	139
R2005-06	199
R2006-07	149
R2007-08	225
R2008-09	164
R2013-14	57
Total	**1249**

Table 5: Type of germplasm accessions utilized for crosses during 2004-2015

Type of germplasm	No. of crosses
Elite A line and sweet sorghum genetic stock	134
Elite A lines and potential germplasm lines	207
Forage, grain, dual-purpose and sweet sorghum germplasm	95
High biomass, wild and kharif landraces	109
Minicore and wild relatives	57
Rabi landraces	149
Scented sorghum and promising A lines	37
Scented sorghum and varieties	127
Shoot fly resistant landraces	91
Sweet and high biomass germplasm	139
Sweet sorghum F1s and high brix germplasm	104
Grand Total	**1249**

4. Sorghum Germplasm Crossing Programme Achievement - Product development (2007 – 2010)

A total of 14 final products contributed from the germplasm section to the All-India Coordinated Sorghum Improvement trials during 2007-2010. Maximum of 6 sweet sorghum varieties contributed to the trials. The list of final product contributed from germplasm section is presented in Table 6.

Table 6: List of final product contributed from germplasm section during 2007-2010

SN	Year	Varieties	Trial No	AICSIP Trial	Result	Follow up action
1	2007	IC 333426	SPV 1821	Dual-purpose sorghum variety to IVT	Identified as potential material for fodder yield in IVT	Application for registration with NBPGR submitted

SN	Year	Varieties	Trial No	AICSIP Trial	Result	Follow up action
2	2007	EC 515837	SPV 1742	Kharif grain sorghum variety to IVT	Identified as potential material for good roti, dough and protein quality, resistant to SF, tolerance to GM in IVT	Registered with NBPGR – INGR 09017
3	2008	SSS 1	SPSSV 31	Sweet sorghum variety contributed to IVT	Significant TSS (%), sucrose (%),	
4	2008	SSS 21	SPSSV 33	Sweet sorghum variety contributed to IVT	Anthracnose resistance	
5	2008	SSS 53	SPSSV 32	Sweet sorghum variety contributed to IVT	Taller	Submitted to IVT forage sorghum (Kharif 2009)
6	2008	SPV 1821	SPV 1856	Single-cut forage variety contributed to IVT.	Better dry fodder yield per day, early vigour, higher brix %	Application for registration with NBPGR submitted
7	2009	SSS 22	SPSSV 41	Sweet sorghum variety to IVT	**Grain yield, Juice brix (%), TSS (%), Sucrose (%), Bioethanol, stem borer resistant, ergot resistant, rust resistant**	Advanced to AVT (Kharif 2010)
8	2009	SSS 42	SPSSV 42	Sweet sorghum variety to IVT	**Grain yield, TSS (%), stem borer resistant, downy mildew resistant, ergot resistant, anthracnose resistant, zonate leaf spot resistant**	To be registered with NBPGR
9	2009	SSS 60	SPSSV 43	Sweet sorghum variety to IVT	**Grain yield, Juice brix (%), TSS (%), grain mold resistant, ergot resistant, rust resistant, leaf blight resistant, zonate leaf spot resistant**	To be registered with NBPGR
10	2009	27A x SSS 53	SPSSH 32	Sweet sorghum hybrid to IVT	Early maturing, taller than the CSH 22SS	
11	2009	SSS 62	SPV 2010	Single-cut forage variety to IVT	Leaf-stem ratio, digestibility dry matter, zonate leaf spot resistant	To be registered with NBPGR
12	2009	SSS 53	SPV 2009	Single-cut forage variety to IVT	Leaf parameters, brix (%), IVDMD (%), stem borer resistant	To be registered with NBPGR
13	2009-10	EP 87	SPV 2042	Rabi grain sorghum variety to IVT	*Shallow soil:* Yielded 10% more grain and fodder yield than the check Mouli. *Deep soil*: Higher grain size than the check CSV 22	Advanced to AVT Shallow soil (Rabi 2010-11) Advanced to AVT deep soil (Rabi 2010-11)
14	2009-10	EP 92	SPV 2043	Rabi grain sorghum variety to IVT	*Shallow soil:* Highest fodder yield (47.32% than the check) *Deep soil:* Highest fodder yield (28.33% more) as compared to the check CSV 22	Advanced to AVT deep soil (Rabi 2010-11)
	2010	SSS 22	SPSSV 41	One sweet sorghum variety for AVT	Brix content recorded significant superiority of 11 to 15% over the check, early to mature, recorded the highest TSS (14%)	To be registered with NBPGR

SN	Year	Varieties	Trial No	AICSIP Trial	Result	Follow up action
	2010-11	EP 87	SPSSV 42	Rabi grain sorghum variety to AVT	For both shallow and deep soil	To be registered with NBPGR
	2010-11	EP 92	SPSSV 43	Rabi grain sorghum variety to AVT	For deep soil	To be registered with NBPGR

5. Sorghum germplasm distributed to the bonafied users (2000 – 2015)

A total of 53178 accessions distributed to the bonafied users in the country. A total of 488 MTAs signed for supplying the germplasm. The maximum of 24740 accessions distributed to the bonafied users internally during 2012-13 followed by 10067 in 2011-12. The year-wise germplasm distributed from germplasm section is presented in Table 7.

Table 7: Year-wise list of sorghum germplam distributed to the bonafied users during 2000-2015

Year	No. of acc.
2001 - 02	167
2002 - 03	394
2003 - 04	409
2004 - 05	634
2005 - 06	534
2006 - 07	1037
2007 - 08	1253
2008 - 09	3385
2009 - 10	3564
2010 - 11	3152
2011 - 12	10067
2012 - 13	24740
2013 - 14	687
2014 - 15	1051
2015 - 16	2094
Total	**53168**

6. Sorghum germplasm submitted to National Genebank, NBPGR during 1991 – 2015

A total of 10141 accessions submitted to the National Genebank for long-term storage during 1991-2015. The maximum of 2083 accession submitted during 2015.

7. Sorghum genetic stock registered with NBPGR

A total of 57 sorghum genetic stocks registered with NBPGR during 2005-2015.

8. The multiple trait accessions identified during 2000 – 2014 at NRCS/DSR

The sorghum germplasm /genetic stocks identified as potential for agronomical traits and resistance/tolerance to biotic and abiotic stresses at the NRCS/DSR during 2000-2014 (Table 8).

Table 8: List of sorghum germplam/genetic stock identified for multiple traits duing 2000-2014 at NRCS/DSR

SN	Accession No	Multiple traits
1	104B	High degree of antixenosis for oviposition by shoot fly, High dry fodder yield and tolerance to cold stress, High grain yield, Resistance to shoot fly
2	463B	High grain yield, High test weight, Improved grain size, Resistance to grain mold, Resistance to shoot fly, Tolerance to mid-season drought stress
3	AKR 354	Bold and hard seed, Dual purpose and resistance to shoot fly, High dry fodder yield and tolerance to cold stress, High grain yield, Positive General Combining Ability (GCA) for days to 50% flowering, Positive General Combining Ability (GCA) for panicle length, Resistance to shoot bug, Resistance to shoot fly, Susceptible to low temperature
4	BJ 248	Better malt quality genotypes, High brix content, High sucrose content, High sugar yield, Late flowering, Low stem tunnelling by stem borer, *Chilo partellus*
5	C 43	High biomass, High grain yield, High grain yield under mid-season drought stress, Low endosperm utilization, Plant metabolism, biotic and abiotic stress, Resistance to aphid, Resistance to grain mold, Resistance to grain mold, Resistance to shoot bug and aphids, Susceptible to low temperature
6	CSH 22SS	High brix content, High enzyme activity, High juice extraction, High sucrose content, Superior extraction rate
7	E 36-1	High brix and sucrose content, High grain yield, High Stay Green (SG) rating, Low stalk rotting, Resistance to charcoal rot, Susceptible to low temperature
8	EC 15 (IC 345717)	Resistance to shoot fly, Resistance to stem borer and shoot bug, Resistance to stem borer, *Chilo partellus*
9	EC 16 (IC 345718)	More 100-seed weight, More shoot length (cm), Resistance to shoot fly, Seedling dry weight (mg), Seedling vigour index 5
10	EG 2 (IC 541309)	More root length (cm), Resistance to stem borer, *Chilo partellus*, Seedling vigour index
11	EG 25 (IC 541331)	High field emergence (%), More germination %, More root length (cm)
12	ELG 13 (IC 568349)	Long leaves, Resistance to stem borer, *Chilo partellus*
13	ELG 18 (568354)	High biomass, High dry matter, High grain yield, Long leaves, Thicker stem
14	ELG 20 (IC 568356)	Long leaves, tall, high biomass and dry matter yield, Resistance to stem borer, *Chilo partellus*
15	ELG 5 (IC 568341)	High biomass, High dry matter, Resistance to stem borer, *Chilo partellus*
16	EP 104 (IC 345193)	More 100-seed weight, More root length (cm), More shoot length (cm), Seedling dry weight (mg), Seedling vigour index
17	EP 57 (IC 343556)	High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, More 100-seed weight, More shoot length (cm), Post-flowering drought tolerance, Resistance to shoot fly, Seedling dry weight (mg)

SN	Accession No	Multiple traits
18	EP 78 (IC 343577)	Herbicide tolerant, High grain yield, More 100-seed weight, More shoot length (cm), Seedling dry weight (mg), Seedling vigour index
19	EP 81 (IC 343580)	High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High grain and total dry matter yield at Hyderabad High protein digestibility, Post-flowering drought tolerance
20	EP 82 (IC 343581)	Herbicide tolerant, High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High grain yield, High Leaf Area Index (LAI), High protein digestibility, Post-flowering drought tolerance
21	EP 87 (IC 343586)	High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High biomass under post flowering moisture stress condition, High grain and total dry matter yield at Hyderabad, High grain yield under post-flowering moisture stress condition, High Leaf Area Index (LAI), Larger Leaf Area Index (LAI) under stress conditions, Post-flowering drought tolerance
22	EP 93 (IC 343592)	Good seed set, High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High grain and total dry matter yield at Hyderabad, Post-flowering drought tolerance
23	ICSB 457	High degree of antixenosis for oviposition by shoot fly, Resistance to shoot bug, Resistance to shoot fly
24	ICSV 700	Dual purpose and resistance to shoot fly, High Cane Harvest Index (CHI), High Cane Harvest Index (CHI) and fresh cane weight, High degree of antixenosis for oviposition by shoot fly, Resistance to aphid, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
25	ICSV 705	High degree of antixenosis for oviposition by shoot fly, Moderately tolerant to shoot fly, Resistance to shoot fly
26	ICSV 745	Dual purpose and resistance to shoot fly, High amylose content, High degree of antixenosis for oviposition by shoot fly, Less damage of aphids, Resistance to aphid Resistance to shoot bug
27	ICSV 93046	Less damage of aphids, Resistance to aphid, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
28	IS 14332(South Africa)	Low electrical conductivity, Low grain mold incidence, Resistance to grain mold
29	IS 14384 (Zimbabwe)	Highest vigour index, Low electrical conductivity, Low floury endosperm percentage Resistance to grain mold
30	IS 18551 (Ethiopia)	Glossy and high degree of antixenosis for oviposition of shoot fly, High degree of antixenosis for oviposition by shoot fly, Oviposition behaviour of shoot fly Resistance to shoot fly
31	IS 2146 (Nigeria)	High degree of antixenosis for oviposition by corn plant hopper, High degree of antixenosis for oviposition by shoot fly, Resistance to shoot fly
32	IS 2205 (India)	High degree of antixenosis for oviposition by shoot fly, Resistance to shoot bug Resistance to shoot fly, Resistance to shoot pests, Resistance to stem borer, *Chilo partellus*, Restorer lines in shoot fly resistance breeding program
33	IS 2312 (Sudan)	Distinct superiority for chlorophyll and drought tolerant, High degree of antixenosis for oviposition by shoot fly, High leaf Nitrogen concentration, More leaves Oviposition behaviour of shoot fly, Resistance to charcoal rot, Resistance to shoot fly, Restorer lines in shoot fly resistance breeding program, Stay green, Superior in total chlorophyll and Chlorophyll Stability Index (CSI)

SN	Accession No	Multiple traits
34	IS 6962 (Sudan)	Good General Combining Ability (GCA) for stem girth, total biomass, fresh stalk yield and brix, High brix content, High sugar yield, High total soluble sugars, Forage and resistance to shoot fly, High biomass, High fodder yield, High grain yield, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
35	M 35-1	High degree of antixenosis for oviposition by shoot fly, High General Combining Ability (GCA) for grain yield, High grain yield, High stover yield and 100-seed weight, Positive General Combining Ability (GCA) for 100 seed weight, Positive General Combining Ability (GCA) for days to 50% flowering, Positive General Combining Ability (GCA) for panicle length, Resistance to shoot bug, Resistance to shoot fly, Resistance to shoot fly and charcoal rot with high grain yield, Stay green
36	NR 486	Dual purpose, High biomass, High grain yield, Resistance to grain mold
37	P 45	Dual purpose and resistance to shoot fly, Resistance to shoot fly, Resistance to shoot fly and stem borer, Resistance to stem borer, *Chilo partellus*
38	PEC 16 (IC 392139)	High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High grain and total dry matter yield at Hyderabad, High grain yield under post-flowering moisture stress condition, High Leaf Area Index (LAI), Post-flowering drought tolerance
39	PEC 23 (IC 392146)	High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High grain and total dry matter yield at Hyderabad, High grain and total dry matter yield at Solapur, High grain yield under post-flowering moisture stress condition, High Leaf Area Index (LAI), Post-flowering drought tolerance
40	PEC 32 (IC 392155)	High biomass, High biomass under post flowering moisture stress condition, High brix content, Larger Leaf Area Index (LAI) under stress conditions
41	PFGS 37	Dual purpose and resistance to shoot fly, Resistance to stem borer, *Chilo partellus*,
42	PGN 30	Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
43	PGN 39	Dual purpose and resistance to shoot fly, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*,
44	PGN 61	Dual purpose and resistance to shoot fly, Resistance to shoot fly, Resistance to shoot fly and stem borer, Resistance to stem borer, *Chilo partellus*
45	Phule chitra	High grain yield, High stover yield, Post-flowering drought tolerance, Resistance to cold stress
46	Phule Maulee	High 100-seed weight, High grain and biological yield, High grain yield, High production efficiency
47	PUGL 9	Dual purpose and resistance to shoot fly, Resistance to shoot fly, Resistance to shoot fly and stem borer, Resistance to stem borer, *Chilo partellus*
48	Ramkel	Forage and resistance to shoot fly, High biomass, High brix content, High fodder yield, Resistance to stem borer, *Chilo partellus*
49	Rampur local	Forage and resistance to shoot fly, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
50	RS 29	High amylose content, High electrical conductivity, High grain yield, High leaf Nitrogen concentration, Resistance to aphid, Resistance to grain mold and downy mildew, Resistance to shoot bug and aphids
51	RS 585	High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High dry fodder yield and tolerance to cold stress, High grain yield, Isolation of promoters, Positive General Combining Ability (GCA) for 100 seed weight, Positive General Combining Ability (GCA) for panicle length, Resistance to shoot fly

SN	Accession No	Multiple traits
52	RSE 03	Dual purpose and resistance to shoot fly, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
53	RSLG 262	Good combiner for earliness, Good General Combining Ability (GCA) for grain yield, High biomass under post flowering moisture stress condition, High grain yield, Resistance to shoot fly and charcoal rot with high grain yield
54	RSSV 9	Forage and resistance to shoot fly, High Cane Harvest Index (CHI), High Cane Harvest Index (CHI) and fresh cane weight, High grain yield, High total biomass, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
55	Satpani	Moderately tolerant to shoot fly, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
56	SLB 10	High grain and fodder yield, High grain yield, High grain yield than 104B, Improved B & R Lines
57	SLB 11	High grain yield, High grain yield than 104B, Improved B & R Lines, Resistance to stripe disease and charcoal rot
58	SLB 12	High grain and fodder yield, High grain yield, High grain yield than 104B, Improved B & R Lines
59	SLB 19	High grain and fodder yield, High grain yield, High grain yield than 104B, Improved B & R Lines, Less damage of aphids, Resistance to aphid
60	SLB 22	High grain and fodder yield, High grain yield, High grain yield than 104B, Improved B & R Lines
61	SLB 3	Best maintainer lines, High grain yield, Resistance to shoot fly
62	SLB 35	High grain yield, High grain yield than 104B, Improved B & R Lines
63	SLB 36	High grain yield, High grain yield than 104B, Improved B & R Lines
64	SLB 39	High grain yield, High grain yield than 104B, Improved B & R Lines
65	SLB 45	High grain and fodder yield, High grain yield, High grain yield than 104B, Improved B & R Lines
66	SLB 46	High grain and fodder yield, High grain yield, High grain yield than 104B, Improved B & R Lines, Resistance to shoot fly
67	SLB 48	High grain yield, High grain yield than 104B, Improved B & R Lines
68	SLB 49	High grain yield, High grain yield than 104B, Improved B & R Lines, Resistance to shoot bug
69	SLB 50	Less damage of aphids, Resistance to aphid, Resistance to shoot fly
70	SLB 54	High grain yield, High grain yield than 104B, Improved B & R Lines, Resistance to shoot fly
71	SLB 59	High grain and fodder yield, High grain yield, High grain yield than 104B, Improved B & R Lines, Resistance to shoot bug
72	SLB 60	High grain and fodder yield, High grain yield, High grain yield than 104B, Improved B & R Lines, Resistance to shoot fly, stem borer and shoot bug
73	SLB 80	High grain yield than 104B, Improved B & R Lines, Less damage of aphids, Resistance to aphid, Resistance to aphid and shoot bug, Resistance to shoot bug
74	SLB 83	High grain yield, Less damage of aphids, Resistance to aphid, Resistance to shoot bug
75	SLB 9	High grain and fodder yield, High grain and total dry matter yield at Solapur, High grain yield, High grain yield than 104B, Improved B & R Lines, Post-flowering drought tolerance
76	SLR 10	High grain yield, High grain yield than RS 585, Improved B & R Lines, Low plant damage by shoot bug, Resistance to aphid, Restorer line

SN	Accession No	Multiple traits
77	SLR 13	High grain yield, High grain yield than RS 585, Improved B & R Lines, Restorer line
78	SLR 17	High grain yield, High grain yield than RS 585, Improved B & R Lines, Resistance to charcoal rot and lodging, Restorer line
79	SLR 24	High grain yield, High grain yield than RS 585, Improved B & R Lines, Positive General Combining Ability (GCA) for 100 seed weight, Resistance to stripe disease, Restorer line
80	SLR 25	High grain and total dry matter yield at Solapur, High grain yield, Post-flowering drought tolerance, Resistance to charcoal rot and lodging
81	SLR 27	High grain yield, High grain yield than RS 585, Improved B & R Lines, Resistance to stripe disease
82	SLR 30	High fodder and grain yield, High grain yield, High grain yield than RS 585, Improved B & R Lines, Restorer line
	SLR 31	High grain yield, High grain yield than RS 585, Improved B & R Lines, Resistance to shoot bug, Restorer line
83	SLR 35	High grain yield, Low plant damage by shoot bug, Resistance to charcoal rot and lodging
84	SLR 39	High grain yield, High grain yield than RS 585, Improved B & R Lines, Resistance to aphid
85	SLR 47	High grain yield, Resistance to charcoal rot, Restorer line
86	SLR 57	High grain yield, High grain yield than RS 585, Improved B & R Lines, Restorer line
87	SLR 60	High grain yield, High grain yield than RS 585, Improved B & R Lines, Restorer line
88	SLR 67	High grain yield, High grain yield than RS 585, Improved B & R Lines, Restorer line
89	SLR 70	High grain yield, Resistance to shoot fly, Restorer line
90	SLR 71	High grain yield, High grain yield than RS 585, Improved B & R Lines, Resistance to shoot fly
91	SLR 72	High grain yield, High grain yield than RS 585, Improved B & R Lines, Restorer line
92	SLV 15	High grain and fodder yield with good grain quality and resistance to insect pests and diseases, High grain yield, High grain yield in deep soil, High grain yield in shallow soil, More grain yield in both shallow and deep soils, Resistance to charcoal rot and shoot fly
93	SLV 34	High grain and fodder yield with good grain quality and resistance to insect pests and diseases, High grain yield, High grain yield in deep soil, High grain yield in shallow soil, More grain yield in both shallow and deep soils
94	SLV 40	High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High grain and fodder yield with good grain quality and resistance to insect pests and diseases, High grain yield in deep soil, High grain yield in shallow soil, More grain yield in both shallow and deep soils
95	SLV 43	High biomass and grain yield, High biomass and grain yield under post-flowering moisture stress conditions, High grain and fodder yield with good grain quality and resistance to insect pests and diseases, High grain and total dry matter yield at Hyderabad, High grain yield in deep soil, High grain yield in shallow soil, More grain yield in both shallow and deep soils
96	SPSSV 11	High computed ethanol yield, High juice extraction, High stalk and juice, High stalk yield, High sugar yield, Superior extraction rate
97	SPSSV 20	High computed ethanol yield, High grain yield, High stalk yield, High sugar yield, Superior extraction rate

SN	Accession No	Multiple traits
99	SPSSV 30	Accumulated high brix, sucrose and Total Soluble Sugars (TSS), High computed ethanol yield, High juice extraction, High stalk yield, High stalk, juice and biomass, High sugar yield, More stalk yield
100	SPV 462	High degree of antixenosis for oviposition by corn plant hopper, High protein digestibility, High Relative leaf Water Content (RWC) and low leaf senescence, Promising in weed supressing, Resistance to shoot fly
101	SSRG 200	Good leaf parameters, High biomass, High biomass and fodder yield, High biomass and stalk yield, High biomass yield per plant, High fodder yield
102	SSRG 212	Good leaf parameters, High biomass and fodder yield, High brix content, High fodder yield, High Leaf Area Index (LAI)
103	SSRG 222	Good leaf parameters, High biomass, High biomass and fodder yield, High biomass and stalk yield, High fodder yield
104	SSV 74	Good plant vigour, High biomass, stalk yield, sugar content and bagasse yield, High brix content, High computed ethanol yield, High grain yield, High green fodder yield, High longevity and seed viability, High seed longevity and viability potential, High stalk yield, High stalk, biomass and brix yield, High sucrose content, High sugar yield, Salinity tolerance
105	SSV 84	Good General Combining Ability (GCA) for stem girth, total biomass, fresh stalk yield and brix, High biomass yield per plant, High biomass, stalk yield, sugar content and bagasse yield, High brix content, High green fodder yield, Plant metabolism, biotic and abiotic stress
106	SUENT 13	Dual purpose and resistance to shoot fly, Resistance to shoot fly, Resistance to stem borer, *Chilo partellus*
107	Urja	High brix and sugar content, High brix content, High enzyme activity, High sucrose content
108	VKG 34/12	More leaves, Resistance to stem borer, *Chilo partellus*
109	VKG 34/14	Resistance to stem borer, *Chilo partellus*, Wide ear head
110	VKG 34/15	Long leaves, Resistance to stem borer, *Chilo partellus*
111	VKG 34/37	High grain yield, Long leaves, Resistance to stem borer, *Chilo partellus*, Wide ear head
112	VKG 34/53	More leaves, longer and wider, tall plants and high biomass, Resistance to stem borer, *Chilo partellus*
113	VKG 34/54	High dry matter, High grain yield, Resistance to stem borer, *Chilo partellus*
114	VKG 34/55	High grain yield, More leaves, Resistance to stem borer, *Chilo partellus*, Wide ear head

16.Sorghum: An important forage crop

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The total area under cultivated fodders is 8.3 million hectares and of this, forage sorghum occupies the maximum area of 2.6 million hectares which is about 31% per cent of the total cultivated fodder cropped area. Forage sorghums are principally cultivated in Punjab, Haryana, Delhi, Uttarakhand, western and central Uttar Pradesh and adjoining areas of Madhya Pradesh. It is also popular in several regions of Central and Southern India. In these states, it is grown during kharif and summer seasons, either as single-cut (mostly in kharif, as rainfed) or as a multi-cut (summer and kharif) forage crop. Intensive cropping, short growing season, poor growth of perennial grasses during winter, nutritional quality and the need for continuous supply of green fodder created demand for forage sorghum in India.

Drought and salt tolerance combination makes sorghum an interesting feed resource for saline soils in arid and semi-arid regions. Single cut is preferred over multicut in kharif season as it fits well in sorghum–chickpea or sorghum-wheat crop sequence. Multi-cut has potential for intensive fodder production under irrigated condition.

Sorghum is an ideal forage crop

Sorghum is an ideal forage crop due to its quick growth, high yielding ability (350-400 q/ha and 700-750 q/ha of green fodder from single cut and multi-cut varieties/hybrids, respectively), high dry mater content (25-30%), better quality and its suitability for various forms of utilization like green chop, silage and hay. Its quick growth, high yielding ability, high dry matter content, leafiness, wider adaptability and drought resistance make sorghum an ideal forage crop. Extensive adventitious fibrous root system of forage sorghum which grow up to 140 cm depth can draw more moisture and nutrients at a much faster rate from the soil. Sorghum has the highest dry matter accumulation rate (upto 50 g dry matter/sq.m.) among the cultivated annuals, exceeded only by the Napier grass. Thus sorghum has the ability to provide good dry matter yield even in the rainfed low-fertility farming situations of the semi-arid tropics. Sorghum has all the essential attributes both as dry land and irrigated forage crop suited to warmer tropics where sunlight is abundant.

Forage sorghum is a good silage crop in highly mechanized agricultural systems whereas for the small holdings, cut-and-carry systems are more appropriate. The development of sorghum cultivars with good ratoonability is more useful for the cut-and carry production in semi-arid zones, *e.g.*, *Sorghum sudense* x *S. bicolor*) hybrids. As a silage crop, sorghum withstands more heat and drought than maize. Even the stalk of sorghum is sweet (brix value as high as 24% in some) and juicy. *Sorghum bicolor* readily crosses with sudan grass, providing for introgression of higher ratoonability and resistance to diseases.

Utilization of forage sorghum and its value addition

Green Chop is the most common way of utilizing forage sorghum in India. It is best cut at flowering stage or when is about 75 cm tall. Sorghum-sudan grass hybrid derivatives are best suited for this purpose. Sorghum possesses excellent qualities for conserving as silage. Silage is pickled, green, highly palatable and digestible preparation of forage sorghum. Ensiling enhances the keeping quality of the fodder. Ensilage ensures adequate supply of quality fodders during the lean periods (Nov-Dec; May-Jun).

As sorghum is thick stemmed, is not recommended for direct grazing. However, sorghum x sudan derivatives and sudan grass varieties that are thin stemmed can be used for grazing if requirements of livestock are not being met by native pasture. Sudan grasses are also best suited to make hay, i.e., drying of green forage without affecting the quality for storage.

Forage sorghum yield and quality as influenced by management factors

In India, there is a short supply of about 38 per cent green fodder, especially during the summer season. Sorghum provides green fodder to the animals for a considerable length of period i. e. from May to November. The quality of sorghum feed and fodder is acceptable for feeding all animals. The sowing time of the multi-cut sorghum affects the fodder supply to considerable extent and hence, proper sequencing of the sowing time should be done in order to achieve maximum fodder yield along with maintaining the regular supply of the green fodder. A study was carried out at Hisar during kharif by staggered sowing of the multi-cut sorghum every month starting from April to September revealed that sowing of the multi-cut sorghum during the month of first fortnight of May produced the maximum green fodder yield, followed by sowing during the second fortnight of April. The maximum fodder yield of multi-cut sorghum with sowing during this period may be due to less attack of insect-pests at the juvenile stage due to high temperature prevailing during summer months. Therefore, crop had opportunity to grow and develop up to maximum extent. Various management factors affect forage crop productivity and quality which are summarized here.

Effect of harvesting time: The quality of forage is dependent on the stage of harvesting of the crop. Forage sorghums are commonly used in the vegetative stage to fill summer forage production needs. Single cut crop is harvested at 50% flowering. In multi-cut forage, first cut (5-8 cm above ground level) taken at 55-60 days after sowing and subsequent cuts at 35-45 days interval. As the crop matures beyond flowering, there is a decrease in leaf/stem ratio and increase in lignifications of forage. Green fodder yield of single-cut varieties is about 400-450 q/ha. The multi-cut varieties/hybrids yield about 600-900 q/ha from 3-4 cuts, if sown by March-end to early May.

Intercropping: The forage protein content, which was highest with sorghum cv. BR-300, was increased by the presence of soyabeans as an intercrop (Oliveira *et al*., 1990).

Diseases: Increased milk and meat demand requires higher quality crop residues and feed. Disease-free feed will improve efficiency and quality of meat production. Plant diseases affect quality and quantity of crop residues fed to animals and reduces the income of farmers. Therefore, adoption of disease management practices will improve quality of crop residues and improve livelihood of farmers and dairy-owners.

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 urea + molasses or concentrates also increases dry matter digestibility.

Strategies to avoid HCN poisoning: All forage sorghum cultivars released after 2000 have been tested to be HCN-safe and can be grown and utilized as per recommended practices. Importantly, farmers should avoid grazing on sudan grasses or sorghum sudangrass hybrids until they reach 38 to 46 cm in height or forage sorghums until they reach 61 cm in height Also one should avoid grazing forage sorghum pastures that have been damaged by frost or drought. In summer season, crop should be irrigated 2-3 days before harvesting or else it is safer to harvest crop after flowering. Alternatively, leaving the green fodder for 24 hours in sun after harvest also helps to reduce HCN content.

Salient features of varieties of the forage crops in seed chain

(a) Single-cut varieties

S. No.	Crop / Varieties	Year of Notification	Breeding methods/ source	Breeding institution	Area of adoption	Specific features
1	Pusa Chari 9	1985	Selection from IS 4870	IARI, New Delhi	All forage sorghum growing areas of India.	223 cm tall with medium thick stem, non-sweet and pithy, green fodder yield of 425 q/ha, dry fodder yield of 135 q/ha
2	HC-171	1987	Selection from the cross SPV-8X × IS-4776	HAU, Hisar	All India	Resistant to foliar diseases

S. No.	Crop / Varieties	Year of Notification	Breeding methods/ source	Breeding institution	Area of adoption	Specific features
3	HC-308	1996	Selection from the cross SPV-8X × IS-4776	HAU, Hisar	All India	Resistant to foliar diseases, tolerant to drought Suitable for both early and late sown conditions
4	Pant Chari-5	1999	Selection from the cross CS3541 x IS 6953	GBPUA&T Pantnagar	All India	Highly resistant to anthracnose, zonate leaf spot and other foliar diseases
5	Gujrat Fodder Sorghum-5	2005	Derivative of cross (SPV-1087 x GSSv -148)	GAU, Banaskantha	Gujarat	Resistant to leaf spot and grain mold diseases
6	Pratap Chari 1080	2010	ICSR 17 X SPV 946	MPUAT, Udaipur	Rajasthan state forage sorghum growing regions with loam to light soils and moderate to low rainfall	Single cut forage sorghum variety, tan pigmentation, 240-260 cm tall with days to 50% flowering of 62-67 days; number of leaves - 12; colour of leaves - dark green; mid rib colour- dark green; panicle semi compact; seed colour-pearly white
7	CSV 30 F	2014	NSS 223 X NARI 111 (NARI 111 is selection from NST 9.)	MPKV, Rahuri	All forage sorghum growing areas of India.	Kharif forage sorghum, 267 cm pl.ht, non-tan, Drooping leaf, white midrib, well exerted semi-loose panicle, medium size seed pearly white in colour, l tolerant to shoot fly and stem borer and foliar diseases.

(b) Multi-cut varieties and hybrids

S. No.	Crop / Varieties	Year of Notification	Breeding methods/ source	Breeding institution	Area of adoption	Specific features
1	MP Chari	1978	Selection fromthe cross [K-49 (Sudan grass) x J-57 (Sorghum)]	JNKVV, Jabalpur	All India	Fast regeneration, multi-cut
2	HC-136	1982	Selection from the cross 3214 × PJ 7R	HAU, Hisar	All India	Dual purpose, tolerant to foliar diseases
3	Pusa Chari--23	1985	Selection from an exotic F1 hybrid Martin x 907010(Sudan group)	IARI, New Delhi	All India	Multi-cut, suitable for early as well as late planting, tolerant to drought and flood

4	Punjab Sudex Chari-1	1995	Selection from the cross 2077 A (Sorghum) × SGL-87 (Sudan grass)	PAU, Ludhiana	Punjab	Multi-cut, highly resistant to Anthracnose
5	CO (FS)-29	2001	Pedigree method of selection from the cross TNS 30 × *S. sudanense*	TNAU, Coimbatore	Tamil Nadu	Tolerant to shoot-fly/ stem borer, multi-cut, perennial, high crude protein and digestibility
6	Pusa Chari-615	2006	Selection from the cross Pusa chari 40 × Pusa Chari 67	IARI, New Delhi	NCR Delhi	Tolerant to major foliar diseases and insect-pests
7	Pant Chari-6	2006	Selection from Zimbabwe germplasm line EC-438401	GBPUA&T, Pantnagar	Uttarakhand	Resistant to major foliar diseases zonate leaf spot, downy mildew, grey leaf spot, anthracnose, sooty stripe
8	HJ-513	2007	Selection from the cross (PJ-7R × SPV-80) × HC-136	CCS HAU, Hisar	Haryana	Dual purpose, tolerant to major foliar diseases, grey leaf spot, zonate leaf spots, sooty stripe
9	CSH 20MF	2005	2219 A x UPMC 503	GBPUA&T Pantnagar	All forage sorghum growing areas of India.	Tan, dark green heavy foliage with green midrib. Medium thick juicy stem, resistant to foliar diseases.
10	CSH 24MF	2009	467 A x UPMC 503	GBPUA&T Pantnagar	All forage sorghum growing areas of India.	Tan plant colour, light green foliage with green midrib. Medium thick juicy stem with basal tillering. Medium long and broad semi-erect leaves with senescence only up to 3-4 lower leaves. Narrow cylindrical semi compact panicles borne on straight peduncle, fully exerted with semi drooping flag leaf. Resistant to major foliar diseases and insects

17.Go geen to reduce pollution and retard global warming which is the need of the hour

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Indiscriminate use of fossil fuel has resulted in increasing pollution to the extent of a point of no return. If this trend is not reversed soon we will have to carry a bottle of oxygen cylinder to breath. More over fossil fuel is a **onetime crop** its end can be seen.

Every country has visualized this and investing on research and development of alternate source of green energy to meet ever increasing demand of energy. One form of energy cannot meet all demand of energy hence a mix of different type of sustainable green energies judicially to be used to meet the present energy demands.

To start with judicial use of fossil fuel and developing **ECO-FRIENDLY RENEWABLE GREEN ENERGY** and its use to be increased to the maximum extent possible for our survival.

Immediate options of Renewable energy available are –

- SOLAR ENERGY : This is a free fuel available for 5~6 hours a day
- WIND ENERGY : This is also free fuel available as per site specific
- HYDEL ENERGY : This is also free fuel available as per site specific
- GEO-THERMAL : This needs development and site specific
- DRY BIOMASS : This is scattered and availability is seasonal
- GREEN BIOMASS : This is sustainable fuel available 24/7 round the year
- BIO-DEGRADABLS : This needs to be segregated at source scaling up limitations. But it helps in keeping up the surrounding clean to reduce pollution.

Therefore depending up on site condition selecting suitable technology is at most important for better economics. It is a known fact that every projects needs a **feasibility study** to assess the Plant capacity/size, Sustainable fuel availability at an affordable price round the year, Marketing locations of end use product without piling up inventory etc. little money and time spent on this will help in a big way on the long run.

Many entrepreneurs skip this and cut corners to save money and get in to problems when the plant is commissioned. Cutting corners is a big mistake and expensive way of learning. **Hence it is recommended for a feasibility study to be economical & safe**.

Few lines on Hi-tech power gens present activity

HI-TECH POWER GENS is a green energy project consultant who is in to providing Green energy Solutions to Reduce energy input cost in Industries and promoting renewable green energy for sustainability and to reduce pollution.

I. Recently an alloy steel melting unit in Hyderabad has asked us to conduct a study to reduce electricity consumption in their plant as their power bill was going up to plus Rs.3.00 Cr per annum.

II. Induction furnace consumes 750 units of power per ton of melting. There are 20 induction furnace plants in and around Hyderabad.

   Our experts conducted a study and found that they are using Induction furnace to melt steel scrap from ambient temperature to 1500 degree Celsius through electricity alone.

   Hence we have suggested pre-heating the scrap up to 900 degree Celsius through bio-natural gas which can be produced in house. This has reduced electricity consumption from 750 units per ton to **300 units** of electricity per ton of melting. Net saving of 450 units of power per ton of melting. This has resulted in a big saving and now they are approaching bank for funding the project.

   Other induction furnace based Industries are awaiting to see this plant economics to follow as we have more followers than leaders

III. HTPG are in the process of implementing 5000, kg per day Bio-Cng project in Maharashtra to meet industry fuel switching demand as well as to meet Auto fuel to replace present LPG fuel.

   This is going to be An innovative 4F, Integrated Project which will produce **FOOD**. **FUEL**. **FODDER** & **ORGANIC- FERTILIZER.**

   1. FOOD – Growing Organic Fruit & Vegetable for good health
   2. FUEL - Bio-natural gas / bio-Cng for Power generation, Fuel switching and Automobile application
   3. FOODER – Fodder as cattle feed to provide nutritious feed
   4. ORGANIC FERTILISER - To reclaim de-graded soil by earlier use chemical fertilizer and convert it a fertailed soil

      This plant is going to take about 12 months to commission all are welcome to see and understand the latest technology involved in the project and take advantage.

IV. A one ton per day sorghum biomass waste based demo plant is going to come up in Indian Institute of Millet Research in Hyderabad soon.

V. IIMR has asked Hi-tech power gens to provide a solution to convert large quantity sorghum waste biomass available in Guntur district of Andhra Pradesh to useful energy. We have studied the input provided and our proposals are given below and request all participants to go through the same and suggest for valuable opinion as they are involved in this activity.

Sub: - Proposed Value addition to Sorghum Biomass Waste

As per the input provided by IIMR presently farmers are burning the waste biomass in the field itself and IIMR Hyderabad are looking for a green solution for a value addition to waste biomass generated. HTPG green energy experts have studied the input provided by IIMR and suggest the following proposal to add value to the waste product. Considering the inputs of grain sorghum the proposal is indicated below -

- Total area under Sorghum cultivation in Andhra Pradesh : 5, 65, 000. Acres
- Largest Sorghum cultivation District in Andhra Pradesh : **Guntur District**
- Growing and harvesting cycle : 4 months Kharif season
- Number of grain Sorghum plants per acre / season : 72 ~ 80,000.plants
- Water requirement per season : 365 lit / plant
- Cost of cultivation including Seed, Fertilser, Water, Labor : 14,938/- per acre
- Number of crops possible : 2. Crops /annum
- Moisture content after removing grain : 70%

- To increase productivity & reduce man power the following mechanization is required
- Seed Drill. Weeder. Harvester. Thrasher and Bagging machine to avoid grain leakage & facilitate proper grain storage and transportation.

GUNTUR DISTRICT IS CONSIDERED FOR A CASE STUDY

- Sorghum Cultivation in **Guntur-** Dist : **35,000. Hects**, x2.5 = [87,500. Acres
- Sorghum seed requirement : 3.2 kg/Acre
- Sorghum Grain generation per acre : 2. 00. Tons/season/acre
- Sorghum waste generation : 8. 40. Tons, per acre /season
- Sorghum waste generation : 735000. Tons/season
- Since waste is scattered in 40 villages : 70 % Collection is expected
- Total Sorghum waste biomass collection is : 514500. Tons/ season
- **Considering 330 days plant working : 1559. Tons/day** waste **is available**
- No of Villages in Guntur : 40. Villages

Proposal to convert Sorghum waste biomass to useful energy through Automated CSTR based Anaerobic digestion technology

CSTR Technology-

This automated continuously stirred and temperature controlled Reactor which will convert any bio-degradable matter to biogas. Biogas is further purified to 96% purity as a gaseous fuel for different application. By-product of anaerobic digestion is liquid and solid organic manure to reclaim de-graded soil.

One more by-product is available that is CO_2 which used to manufacturing Ice flakes **or** it can be liquefied for brewery application. Anaerobic digestion is a multi revenue system.

Since large quantity of sorghum biomass waste is available it is possible to convert it to Bio-Natural gas which is a clean combustible gas to generate POWER, FUEL SWITCHING OR for AUTOMOBILE application.

For long distance transportation gas will be compressed. Bottled and cascaded as Bio-Cng for any of the application indicated above.

How to implement the project

Step -1

- Framers individually cannot implement the projects as it is capital intensive project
- Hence it is suggested that all farmers to join hand and form a **Co-operative society** to work together to implement the project and share the benefit as per land holding
- We have to explain the advantage of joining hands so that the farmers will understand and agree for co-operative system as it is a long term advantage to them
- As a co-operative society they will be eligible to get loans from bank to implement the project and facilities from other institutions

Step -2

- Conduct a feasibility study of each village to establish locational advantage to store waste Sorghum at suitable site in each village as well as near town to implement the project
- Part of the sorghum waste biomass will be used to Generate Bio- Natural gas to replace LPG in all house hold of village to reduce cooking gas cost
- Balance Sorghum waste Biomass available will be used to generate Bio-Cng for sale
- It is suggested to collect Sorghum waste biomass and store it in **silage** farm as raw material which can be used round the year as raw material to generate Bio-Cng
- Apart from producing bio-Cng By-product of the proposed system is **liquid** and **solid organic manure** which have high NPK Value
- Liquid organic manure will be used to grow **Organic Vegetable & Fruits** which have a good market demand and will generate additional revenue to the project
- Solid organic fertilizer will be sold to generate more profit and viability to the project
- Presently most of **soil health** is affected by long time use of **chemical fertilizer**
- These **de-graded land** can be **re-claimed** by using liquid and solid organic manure

- This waste to energy green project is **Zero discharge** system and **eco-friendly** green project where Govt subsidies are available
- The project will also generate employment to the village youth and arrest migration
- In addition Bio-Cng use will reduce vehicular pollution in town
- Because the above advantages any bank will fund the project under renewable energy development waste to energy scheme

Project has plenty of scope in converting waste to energy hence looks to be very attractive.

IIMR is Requested to work seriously on the project to make it happen and show case a model of converting **Sorghum waste to green energy** to provide additional income to the farming community to improve their living condition.

HTPG are more than willing to work along with IIMR to make it happen

This project will also reduce **Vehicular pollution** in town and Retard global warming which is the need of the hour

18.Principles of quality seed production and maintenance in sorghum

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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 570 kg ha^{-1} in 1970 to 1000 kg ha^{-1} 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.

1. Sorghum seed multiplication chain

In India, the seed multiplication is in four stage generation system viz., a) 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	

2. Genetic purity maintenance

The genetically pure seed of a variety is expected to have all the unique economic and diagnostic characters. In cross pollinated species like sorghum inbred lines and varieties, the deterioration will be much faster due to contamination with undesirable pollen of other genotypes. The major factors causing deterioration of varieties or inbreeds leading to the production of seeds with low genetic purity are a) Residual genetic variation, b) Developmental variations, c) Cross-pollination due to undesirable pollen d) Mechanical mixtures, e) Damage due to pest and diseases. The other factors that may have influence on genetic purity are f) Plant breeder's techniques during selection programs and g) Mutations. The following important measures should be followed during sorghum seed production in order to maintain genetic purity.

1) Adequate attention must be given to land requirements, isolation, rouging, harvesting, drying, sorting of ears, threshing of ears etc., so as to maintain maximum possible genetic purity.
2) Proper class of seed should be the source for further multiplication.
3) The best cultural practices should be followed.
4) Inspection should be done at all critical stages of seed plots.
5) Mechanical mixtures should be avoided at sowing, harvesting, threshing, processing and storage.

Essential requirements of genetic purity maintenance:

a) Seed source: The seed for sowing should be collected from authentic source depending on the stage of seed multiplication.

b) Isolation of seed plot: Sorghum is generally a self pollinated crop but cross pollination up to 5–6% may also occur. It varies from 2–10% in different places and different varieties and normally higher in the top quarter of the panicle. Selection of a field with required isolation distance depending on class of seed, i.e., foundation or certified seed and the kind of objectionable crops viz, forage type or grain type. The pollen of forage sorghum types can pass and spread to a little more distance and hence require more isolation distance (Table 2).

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.

c) Rouging: Rouging of the seed field is very important for quality sorghum seed production. The rouging is done at three stages of crop growth i) Before flowering ii) At flowering and iii) Pre-harvest stage. The specific certification standards are given in Table 3.

i) Before flowering:

- *Start the rouging operation before off types, volunteers or shedders in the female rows start shedding pollen.*
- *All rouges and volunteer plants must be cut from ground level or pulled out to prevent re-growth and subsequent contamination of seed crop.*
- *Out crosses can be identified because of their greater height and should be removed as soon as these are noticeable.*

ii) At flowering:

- *Rouging should be done every day to remove pollen shedders in the seed rows. The sterile types have only the stigma, or a few abortive anthers exerted. These should not be mistaken for normal fertile plants. Normal fertile plants will have rich yellow anthers, which are full of pollen out to the tips of both lobes. On shedding, these lobes rupture on distal and discharge pollen. All plants out of place, ie., plants in between the rows, male plants in female rows and vice-versa have also to be removed. Special attention should be given at the ends where the border rows and seed rows meet, as male seed may fall in female rows (or female in male rows).*
- *In addition to remove off types and volunteers within the field, the other sorghum types and related plants such as Johnson grass, Sudan grass and forage plants should be eliminated within the isolation distance. These sources of undesirable pollen must also be eliminated before pollen is produced.*

iii) Pre-harvest rouging:

- *The field should also be rouged thoroughly before harvest and after the seed maturity to the stage when the true plant and seed characters are 'apparent'.*

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

*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.*

- *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.*

3. Seed crop management

a) Production environment: The area where the temperature during flowering ranges from 27–32°C is best suited for good seed production of sorghum. Night temperature should not fall below 11°C for longer period since it affects the seed development. Flowering and seed development stages should not coincide with the rains as the pollen loss and grain mold deteriorate seed quality. The fields where sorghum was not grown in the previous season should be selected. In addition there should be no Johnson grass in the seed field or with in isolation distance. The field should be well leveled and drained. The saline, alkaline or very lighter soils are not suitable. Uniform and level piece of land with good drainage should be selected. The pH should be around 5.5 to 8.5. Good irrigation facilities are essential for sorghum seed crop.

b) Season: Sorghum seed production is mostly undertaken during kharif in Maharashtra, Madhya Pradesh, Rajasthan and Gujarat. In the other sorghum growing areas it is taken in rabi or summer season. Seed produced in seasons other than kharif has good germination and vigor. During kharif, problems due to grain mold arise frequently. The sowings should be carried out before the end of June and September in kharif and rabi seasons respectively. Early sowing culminates shoot fly attack and seed crop passes through its life cycle at the most optimum environmental condition for crop growth and seed development. The seed of commercial hybrids is produced in rabi and summer seasons both by public and private seed agencies and marketed in summer season itself. However, seed for rabi has to be stored till the next rabi. Consequently, there is some difficulty in the availability of seed for rabi leading to stagnant production of rabi sorghum. The seed production in rabi is predominantly concentrated in Andhra Pradesh and adjacent part of Karnataka due to favorable ecological conditions.

c) Seed Treatment: Shoot fly can be effectively controlled by treating the seed with carbofuran before sowing. Seeds are treated with 50% soluble powder at 100 g for every kg of sorghum seed.

d) Sowing: Seed should be placed at 3– 4 cm depth. Maintenance of male sterile line (A-line) involves sowing of two parents i.e., A-line (male sterile) and B-line (male fertile, non-pollen restores). Similarly, certified seed production of hybrids includes male sterile A-line and fertility restorer R-line. The borders rows (4–6) should be sown with male line all round the seed production plot. To facilitate frequent rouging operation, a spacing of 60 cm (row to row) and 15–20 cm (plant to plant) is advisable. Precautions should be taken to avoid admixing two parental lines at the time of sowing. For A-line seed production the seed rate is 7.5 kg ha^{-1} of A-line and 5 kg ha^{-1} of B-line. The usual planting row ratio of A- and B-lines is 4:2 for breeder seed production. For certified hybrid seed production, the female and male lines in 4:2 can be sown. However, the proportion can be widened to 6:2. The general seed rate varies from 7–8 kg/hectare depending on spacing.

e) Fertilizer application: Recommended dose of fertilizers (80 kg N: 40 kg P_2O_5; 40 kg K_2O ha^{-1}) should be applied given for obtaining optimum yield and good quality seed. Higher fertilizer dose (100 kg N: 50 kg P_2O_5: 50 kg K_2O ha^{-1}) enables better expression of plant characters.

f) Irrigation: Risk should not be taken for growing seed crop in area without irrigation facility. Crops for all seed categories of seeds should be grown under assured source of irrigation. In sorghum flower primordial initiation, boot leaf, flowering and grain development are the most critical stages. Moisture stress at any of the stage will result in significant reduction in seed yield. Hence, irrigation is essential if there is drought at these stages during kharif season. In Rabi season irrigation should be given at all the critical stages.

g) Plant Protection: The successful disease and insect pest management is one of the most important factors in raising a healthy seed crop. Seed plots of all categories of seeds should be raised from seeds treated with proper fungicide/insecticide. Rouging of diseased plants should be done promptly. Spraying with insecticides and fungicides with proper dose is recommended through out the crop growing season.

i) Pest control:

Shoot fly: Seed treatment with Carbofuran before sowing controls shoot fly infestation. Seeds are treated with 50% soluble powder at 100 g kg^{-1} of sorghum seed. It can also be controlled by applying Furadan 3G or Phorate 10G in the seed furrows @ 20 kg ha^{-1} at the time of sowing.

Stem borer: Stem borer can be effectively controlled by application of Endosulfan 4G/4D, or Carbaryl 3G or Malathion 10D or Furadan 3G @8–12 kg ha^{-1} at 20 and 35 days after emergence.

Midge: High levels of midge infestation can be controlled by spraying any of these insecticides: Endosulfan 35 EC 1 litre, or lindane 20 EC 1.2 litres, or malathion 50 EC 1 litre per hectare in 500–600 litres of water followed by second application 4–6 days later.

Head bug: The population density (50nymphs/panicle) at pre bloom and 50% flowering stage requires dusting of Malathion 10D @ 20 kg ha^{-1}.

ii) Disease control:

Grain molds in kharif and charcoal rot in rabi are the key diseases. The seed should be treated with Thiram or Captan @ 3 g kg^{-1} of seed. Grain mold can be checked with Aureofungin solution @30g/10 lt of water + Captan (30g/10 lt of water) or Dithane M 45 + Captan @ 3%concentration). Charcoal rot can be reduced by proper soil management practices to conserve moisture, besides growing tolerant cultivars. Leaf spot such as rust can become serious in favorable climate during the kharif and rabi seasons, can be controlled by spraying Dithane M 45 @ 3% concentration. Sugary disease in hybrid sorghum seed production plots where female parent become infested, can be manage to certain extent by spraying Dithane M 45 or Dithane Z-78 @2g/lt of water or Bavistin @ 5g/10 lt of water at flowering stage. For chemical control of honey dew stage of ergot disease, spray Benlate (0.1%) at the stage of 50% flowering. For downy mildew control, spraying of Dithane M 45 (0.4%) four times at an interval of one week starting from seventh day after planting has proved to be the best.

h) Inter-culture: Hand weeding after 20 days of sowing is preferable. Inter-cultivation with guntaka (blade harrow or Danti cultivator) will help to control weeds and conserve moisture. Pre-emergence spraying of Atrazine (atrataf) at 0.5 kg active ingredient per hectare or propazine50 percent wettable powder @ 1 kg in 1000 lt of water can control weeds.

i) Harvesting and threshing: The seed crop must be fully ripe before harvesting. Harvesting should be done at physiological maturity stage when the black layer formation appears at the point of attachment of seed with the caryopsis. In general the seeds harvested 35–45 days after flowering have superior seed quality. The artificial drying is followed for seed production in kharif to avoid grain mold incidence. The harvested heads should be sorted out to remove diseased or otherwise undesirable heads, and dried on the threshing floor for a week or so in thin layer before threshing. Doubtful ear heads are rejected. The border rows of seed plots should be avoided to prevent the chances of natural contamination. The male rows should be harvested first and kept separately to avoid mechanical mixtures. After this, the female rows should be harvested. Threshing can be done by clean machine threshers at proper seed moisture content (13–14 %). Seed should be dried to 10-12%% moisture content before storage. Care should be taken to avoid mechanical mixtures while threshing.

4. Hybrid seed production

Sorghum hybrid seed production is a highly commercial venture. It is essential to maintain efficient level of crop management in order to maximize production at minimum cost. The basics for hybrid seed production are as follows.

a) Determining the hybrid seed quantity targets: The quantities of hybrid seed required should be roughly estimated on an annual basis in advance, depending upon the projected demand for the commercial hybrid under cultivation. It is desirable to maintain significant quantities of carry-over seed as an insurance against unforeseen seed crop losses.

b) Planting ratio: Male sterile (A) and restorer (R) lines are sown in alternate strips of rows, normally in a ratio of 4A:2R, depending on the local experience of success and the ability of the R-line to disperse the pollen. The borders on all four sides of the hybrid seed production field are sown with the restorer (R) lines to ensure an adequate supply of pollen and guard against incoming stray pollen. The ideal planting ratio between male and female lines is two male rows alternated by 4 to 6 female rows. Where the male lines have the smaller earheads and shorter span of flowering compared to the female ones, (as in case of CSH 14 and CSH 15R) it is desirable to allow only four female rows for each pair of male rows. The female rows for each pair of male rows can be increased to six as in case the male lines having larger panicle and longer span of flowering. A five row thick border all around the seed production plots must always be provided. Economizing on male lines both within the plots and borders may affect the seed set and is not a wise step which many seed growers are tend to do.

c) Isolation requirement for hybrid seed plot: Getting required isolations (300 to 400 meters for foundation and 200 to 400 meters for certified) is increasingly becoming difficult for sorghum seed production. Hence, it is necessary that the hybrid wise seed production is planned in few clusters of villages. Each cluster can have 2–3 contiguous villages with about 200 or more hectares. The number of clusters may depend on the total seed required based on demand and supply. Compact blocks are easy for supervision, maintenance of quality, minimizing the nicking and isolation problems to a major extent and will also serve as demonstration blocks.

d) Plant height: Most of the parental lines of sorghum hybrids have matching heights in the *rabi* season facilitating easy pollination process. The problem of disparity of heights can be avoided to some extent by planting the short parent on the raised ridges and the taller parent in the furrows below. Selective urea sprays also enable to increase the height to some extent by elongating the peduncle.

e) Nicking/ensuring synchronization: It is essential that the parental lines chosen for hybrid seed production flower at the same time i.e, the viable pollen is available when stigmas are receptive. Therefore, a prior knowledge on the flowering patterns of both the parents in hybrid seed production is necessary. The male and female parents of the various hybrids, with different degrees of photo and thermo-sensitivities may react variably under different day length and temperatures at various locations or seasons. Several methods are employed to ensure synchrony.

Measures for synchronization of flowering of male and female parents:

- The growth stages of male and female parents should be critically examined at 4 weeks stage or even later depending upon the length of their vegetative growth period.
- The flower primordia and the apex of male and female plants be sampled randomly and observed critically by stripping the leaves of stem. The difference in the time of initiation and size of the panicle bud would indicate the difference in their time to 50% flowering.
- The parent lagging behind can be hastened by selective measures like supplementation of nitrogen in the soil (additional dose of 50 kg N/ha) followed by foliar spray of urea spray (2%), soaking of seeds in water, GA spray at primordial initiation stage (Kannababu *et al*. 2002).
- Alternatively, selective irrigation of one parent and delayed irrigation of the other will also help in synchronizing the flowering date of the parents.
- Careful manipulation of nitrogenous fertilizers, foliar spray of GA and irrigation can synchronize the flowering of parents that differ by up to one week.
- If the male is advanced in the early stage due to adverse seasonal conditions, cut alternate plants to allow the tillers to come up and boost up such tillers with additional dose of nitrogen.
- In case of partial seed setting, sugary disease (ergot) may occur. Spray of Thiram/Captan to control the disease and avoid prolonged sowings in the same areas, since the disease may invade the late sown crop in epiphytotic proportion. However, making available pollen to achieve good seed set ensures better control of ergot disease.

f) Pollen production and dispersal: The pollen production is influenced by temperatures. During the winter months, especially in areas where the night temperatures are rather low, pollen production and dispersal is appreciably reduced. 2% borax spray (on both male and female lines), two times from ear-head emergence till the completion of anthesis would greatly solve the problem. In fact the staggered planting of the two male rows ensures adequate and prolonged availability of pollen. It is not safe to rely entirely on natural winds to aid in pollen dispersal. It is desirable to use artificial aids of pollen dispersal like tapping the male plant or blowing air through empty duster over the male heads. It is also advisable to spray 2% Borax to improve the pollen production and dispersal. If the pollen is not available in the same plot, collect the pollen in the morning from neighboring plots and instantly spray with water or dust on the earheads of the female parent. If there is dew fall hampering spread of pollen, blow empty power duster on the male rows to disperse pollen towards female heads or tap the male heads.

g) Stigma receptivity: Generally, the stigma retains good receptivity up to 4–5 days (MS 2219A, MS 296A and AKMS 14A) after flower opening, although in some lines it is extended beyond that period as in MS 2077A. However, during the hot summer months, the receptivity is lost faster owing to desiccation of stigmas.

h) *Rouging:* Regular rouging should follow the commencement of flowering. Apart from off-types, pollen shedders can also be a problem in A-lines. Shedders are plants that look similar to the A-line but exhibit fertile anthers and shed pollen. Such plants can only be identified at anthesis and should be uprooted immediately. Shedders can also arise from partial breakdown of sterility in the A-lines due to high temperatures (>38°C). Delay in identifying shedders will result in out crossing to male-steriles and subsequently contaminate the hybrid causing genetic deterioration. Therefore, it is recommended that rouging be carried out in the early morning hours before pollen shedding takes place. The R- line should also be rouged periodically.

i) Harvest of hybrid seed: All possible precautions against seed contamination should be taken during harvesting of hybrid seed production plots and threshing of panicles from the A- line rows. Usually, the R-line is harvested first and the harvest removed from the field. Later the A-line rows are carefully inspected for off-types and other chance admixtures and then harvested. Hybrid seed yield (on the A-line) depends upon the yield potential of the A-line, percent seed set, and environmental conditions.

5. Seed processing

Seed processing is an integral part of sorghum seed technology, which encompasses steps such as drying, cleaning, grading, treating, and bagging. Sorghum seed properly threshed can often be cleaned to the desired purity on the air screen cleaner alone. However, the gravity separator is commonly used, to remove light materials and improve germination.

a) Physical purity: The threshed seeds should be physically pure and should not contain weed seeds, disease and pest infested seed, other crop seed, other cultivar seed, undesirable seed, and damaged seeds. It is not desirable to sow the seed along with these contaminants as the yields and quality of resultant produce will be low. Seed processing includes several distinct steps that must be followed in a specific sequence. Sorghum seed of different classes should possess the following minimum seed purity standards.

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%
Other crop seeds (maximum)	5 /Kg	10/ Kg

Factor	Standards for each class	
	Foundation seed	*Certified seed*
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 vapor 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. The moisture content fluctuates during storage in cloth or hessian bags, but if the seed store is reasonably moisture vapor proof, the fluctuation in seed moisture content would be small. In sorghum, proper sun drying of earheads is essential to bring down the seed moisture to desirable level to avoid seed deterioration. In sun drying, seeds are normally dried by spreading them on floor under diffused sunlight or under shade. Frequent stirring of the seeds is required to facilitate rapid drying. If higher quantities are produced artificial drying can be considered. Maximum recommended air temperature for seed drying is 40° C, however in order to reduce the risk of damage, drying temperatures should be lower than the maximum. If seed moisture is more than 18%, maximum recommended drying temperature is 32°C and if lower than 18%, 40°C is the temperature for drying.

c) Seed Cleaning and grading: In order to maintain the physical purity to the required standards seed cleaning is the essential step in processing unit to separate the inert matter, weed seed, other crop seed, other variety seed, disease and pest infested seed and any other undesirable contaminants. Sorghum seed cleaning and upgrading is mainly based on physical differences in seed volume, test weight and density. 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 4.75 mm with round holes and the bottom screen at 9/64"or 3.5 mm 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 refers to the application of fungicides, insecticides, or a combination of both to disinfect the seed from seed borne pathogens and to protect from soil borne organisms. Some chemicals offer a systemic protection against diseases. The use of insecticide reduces the damage to seed by insects. It must be remembered that seed treatment with chemical disinfectants does not improve the germination percentage. Sorghum seed after seed treatment can b e protected from systemic pathogens like loose and head smut and non systemic like Helminthosporium blight, Fusarium and bacterial blights. Seed treatment also provides protection against storage pests (rice weevil) and shoot fly. The fungicides like Thiram or captan @ 3 g kg^{-1} 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 @ 3–4 kg bag^{1}, sewed with proper label of particular seed class and can be sealed with lead seal.

6. 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

b) Short term storage under ambient condition: Seeds of most of the sorghum species can be stored under ambient conditions for seed certification for at least 12–15 months, if seed moisture does not exceed 9–10%. Relative humidity of the atmosphere and storage temperature are the two important factors that influence seed viability during storage. The relative humidity of 70% and temperature of 20°C can be accepted as maximum permissible for safe storage. But in tropical countries like India, places registering mean temperature of 20°C throughout the year are few. The seed godowns must be rain proof, relatively moisture vapor proof and insect proof. There should be no cracks in wall or on floors. The bags should not be kept directly on the floor, but on wooden pallets and should be at least 50 cm away from the walls.

An exhaust fan may be fixed for ventilation when outside temperature is lower than the seeds stores, the relative humidity of the outside air should also be considered while planning to ventilate the seed stores. The careful ventilation can reduce both storage temperature and seed moisture. Seeds are invariably attacked by different insect pests during storage. To avoid the storage losses and to keep seeds free from insect pests during storage, one must adopt the following preventive and remedial measures.

c) Preventive measures before storing the seed:

1. The seed moisture content should be preferably below 9%. The moisture content fluctuates during storage in cloth and hessian bags, but if seed store is reasonably moisture vapor proof, the fluctuation in seed moisture content would be low.
2. New bags should be used to avoid both insect infestation and mechanical mixture.
3. The storage structure should be thoroughly cleaned and white washed.
4. The storage structure should be disinfected with residual sprays of insecticides such as Malathion 50EC (one part in 100 parts of water) @ 5litres per 100 sq. m.
5. Proper stacking should be followed for arranging seed bags in storage structures.
6. It should be ascertained that the seed is properly treated with disinfectants before keeping the seeds in storage.
7. Seeds of different types such as cereals, pulses, and vegetables should be stored separately to avoid the spread of insect infestation.

d) Maintenance of seed storage:

1. The processing units and storage structures should be clean.
2. All sweeps should be kept far away from the premises of seed godowns so that insects will not breed and reinfest seeds.
3. The inspection of seed lots in storage structures should be carried out every fortnightly. Seeds must be thoroughly fumigated at regular intervals.
4. Fumigation can be done with 1) Aluminium phosphide, 2–3 tablets (3 g each) per tonne of material with an exposure period of 5–7 days or 1 tablet per cu. m. space. 2) Ethylene dibromide (EDB) @ 32 g per cu.m. Space with an exposure period of 5–7 days. 3) Ethylene dichloride carbon tetrachloride (3:1) (EDCT) mixture @ 320–480 g per cu. m. space with an exposure period of 24–48 hrs.
5. Of all these fumigants, Aluminium posphide is safest. Its repeated application does not impair seed quality. Maximum of 3 fumigations may be given at an interval of 40–50 days.

6. During fumigation and surface sprays handle the chemicals carefully as they are highly toxic to human beings.
7. Seed structures should be aerated and thoroughly cleaned with brush or hard broomsticks to remove all dead and moribund insects.
8. To prevent reinfestation, surface treatment with Malathion 50EC or Finitrothion 50EC @ 4–5 litres per sq.m. area or Malathion dust 5% @ 3–4 kg per 100 sq.m. should be given.
9. Surface treatment of seed godowns and processing units should be carried out at an interval of 2–4 weeks depending upon the severity of pest check on re-infestation and prevents insect resistance to insecticides.

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19.Mechanization of sweet sorghum cultivation – An overview

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I. Introduction

Sweet sorghum is a unique multipurpose crop and of late widely promoted as biofuel crop. Its ability to produce grains for food/feed and stalks for fuel/ feed makes it one of the popular choices in the dryland regions. This crop is now widely grown in many of the countries as a feasible biofuel crop under different climatic conditions because of short its growing period and low water requirement (Soltani and Almodares 1994) as compared to sugarcane. When compared to other biofuel crops, sweet sorghum is best suited for ethanol production because of its higher total reducing sugar content (Huligolet al. 2004). Further, its suitability for mechanized crop production, seed propagation and higher ethanol production capacity of sweet sorghum have drawn the attention of researchers. The bagasse from sweet sorghum after the extraction of juice has a higher biological value in terms of micronutrients and minerals than the bagasse from sugarcane when used as animal feed (Seetharama et al. 2002). It can also be processed as a feed for ruminant animals. The crushed stalk contains similar levels of cellulose as sugarcane bagasse, and therefore is a good prospect as raw material for pulp and briquette making (for fuel purposes). Many attempts were made to use sweet sorghum for ethanol production in a centralized model of crushing the stalk for juice at the industry level. However, this model had some difficulties as the raw material availability was restricted for small period in a year apart from the problems of transportation of stalk from the farmer's fields to distillers. To address this, a decentralized model that involved the production attempt are continued in mechanizing the crop production from sowing to harvesting under on-farm conditions as mechanization of crop production appropriately handled may reduce the crop production cost by 30%.

2. Mechanization of sweet sorghum sowing operation

In sweet sorghum crop, the best sowing window is limited to 2 to 5 days after monsoon arrival, depending on the moisture availability. Success of sweet sorghum farming depends on the completion of sowing operation within this limited period. Otherwise the entire crop cycle becomes affected by the delayed sowing.

The recommended plant to plant spacing was 20 cm and row to row spacing was 60 cm. However in our interactions, most of the farmers were not convinced about this spacing as they had preconceived apprehensions about yield. So the seed drill setting was changed to 20 cm and 45 cm respectively. In conventional practice, sowing operation was done by a country plow to open the furrow, which was followed by two women laborers to place the seed and fertilizer. This used result in poor germination as there was no synchronization between the workers. To overcome this, improved seed drills implements suitable for the cluster were introduced to improve timeliness and precision so that sowing could be completed within the short sowing window. The implements included in the trials were: 4-row bullock drawn planters, 6-row and 9-row tractor drawn planters which were designed and developed by Central Research Institute for Dryland Agriculture (CRIDA) that were extensively popularized in dryland regions of India.

The performance of the 4-row bullock-drawn and 6-row tractordrawn planters was found to be satisfactory. The farmers could not use the 9-row tractor-drawn planter since their land holdings are very small. Some modifications with regards to the seed metering mechanism were made to achieve 20 cm plant to plant spacing. Though the row to row distance of 60 cm is recommended for sweet sorghum, the farmers would not adopt it because of strongly held preconceived ideas that the reduction in plant population would result in less yield. So a demonstration was conducted with 45 cm row to row spacing. As part of the training programme, farmers were also trained in repair and maintenance of planters which helped them understand the basic principles of the machinery. The poor response received for bullock-drawn planters was because it covers lesser area in the limited sowing window available.

It was observed that mechanized sowing helped save time by 65% when time was of the essence. The bullock-drawn planters were introduced, but it was found very difficult to popularize among the farming community owing to its poor per day coverage. Mechanized sowing improved the crop growth in terms of plant height and stem girth which influence the juice recovery of sweet sorghum. The stem diameter and height of the crop under mechanized sowing was higher compared to the performance under farmers' practices, which may be attributed to the proper placement of fertilizer and seed in with the planter when compared to the way the farmers tend to. The well spaced row sowing improved yields considerably apart from making the stem grow higher and therefore more suitable for crushing.

3. Mechanization of intercultural operations

In majority of dryland regions, weeds compete with crops for moisture, nutrition, light and space among several other factors required for plant growth. Moisture conservation is key for achieving high yields in drylands as crops are grown under limited moisture conditions. Intercultural tools remove weeds between crop rows but create soil mulch which helps in moisture conservation. Effective and timely weed control in sweet sorghum crop plays a very important role in improving crop productivity. Conventionally farmers use hand tool slike *khurpi* (hand shovel), wooden hoes, bullock drawn *guntaka* (blade) etc, which covers less area per day and is labor intensive. This leads to prolonged operations leaving weeds in the field for longer, depleting soil resources. Therefore, new power operated tools such as the power weeder and improved manual weeder were identified for weeding in sweet sorghum and introduced in the villages. The details of the mechanization process introduced are given below.

A) CRIDA manual weeder: The CRIDA manual weeder has a wheel mounted on a pipe frame, which has the weeding tool mounted on the frame and runs behind the wheel. Its efficiency is about 10 times faster than weeding with the khurpi (shovel). It is operated by the push-pull mode and is comfortably operated by women. It also improves the ergonomic efficiency of the operator.

B) Bullock-drawn weeders (guntaka): Bullock-drawn power weeders can be used comfortably between the rows and it has the added benefit of earthing up as well during weeding. They are available at the local markets with 30 cm and 45 cm blades which can be easily drawn by a pair of bullocks.

C) Mini power weeder: This is a self-propelled moving type intercultural implement. It has rotary tynes as the moving element which are mounted below the front end of the frame. The handle body with clutch and gear lever arrangement is attached to the rear side. A 1.5 hp engine provides power for forward movement and a rotary blade attached to the frame removes the weed and pulverizes the soil.
This machine has better maneuverability in the field during operation. Weed control was effective and created soil mulch which is desirable under dryland conditions.

D) Power weeder: It works with 1.5 hp petrol engine. Clutch can be used to engage and disengage the rotor during operation. Many farmers felt that the power weeders were very useful in the present conditions of labour and bullock power shortage, where it equally essential that weeding and intercultural operations be completed in time. They had observed that delay in weeding operation by 10 days affected crop yields significantly. The cost of power weeding worked out to around Rs 625 ha-1. The plant damage was also minimized with the power weeders when compared to the other methods.

4. Mechanization of harvesting operations

It was observed that the harvesting operation of sweet sorghum cost 30% of the whole cost of cultivation apart from high drudgery involved. Women, who are mostly involved in this operation, suffer a lot under the scorching heat. Since there were no small- to medium-scale harvesters available in the market, experiments were conducted with the modified self-propelled reapers which were normally used for paddy and other fodder crops.

Modification of front mounted reaper as sweet sorghum harvester: A front mounted reaper which can be attached to the tractor was modified to suit the harvesting operation of sweet sorghum crop. The reaper was a multi-crop harvester and is suitable to harvest soybean, paddy, wheat and other crops. It consists of a cutting bar and guiding wheels to bring the crop close to the cutting blade. The cut crop stalks are conveyed to the side to form a windrow via a belt.

Since the height of the sweet sorghum crop was more than 240 cm, the reaper was not suitable for harvesting it. Besides, the stalk thickness was more than the normal sorghum, and so the cutting blades were not suitable either. Modifications were carried out by increasing the height of the reaper to support the sweet sorghum stalk and conveying them to the top of the harvester. One more set of guiding wheels were fixed to the conveyer to bring the stem close to the vibratory cutting blade. Field testing of the modified tractor-drawn front mounted reaper revealed that it required some more modifications to cut and carry the stalks properly. Hence it was decided that modification work should be carried on a small scale harvester for effective cutting and conveying the sweet sorghum stalk.

Development of single row self-propelled harvester: As sweet sorghum was taller (around 320-350 cm) than the normal sorghum with higher stem girth (ranging from 16-30 mm), it was found very difficult to use the commercial self-propelled reapers which were available in the market. Apart from the problems of cutting, conveying the stalk to the side was found very difficult because of its size and weight..

This is mainly powered by 6.5 hp petrol engine which reduced normal vibrations. A 3-tier conveying system with chain mechanism was developed by anchoring the two sides with mild steel mesh panels. A horizontal 3- blade cutting disc was used to cut the stems as the machine moved forward. The RPM of the blade was adjusted to 850. The conveying speed was adjusted to synchronize with walking speed (3-3.5 km per hour). Initial trials showed promising results and the design is under final refinement before commercializing it. Research are in progress develop a tractor-drawn harvester to make it suitable for 2-3 rows.

Conclusion

Mechanization was partly successful in sweet sorghum crop production and our efforts helped identify the gaps in the presently available technologies. Much more refinement in harvesting machinery is needed to reduce the harvesting cost and drudgery in harvesting operation to make the crop a viable biofuel crop.

20.Millets: Current status in India, nutritional values and health benefits

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Background

In the 21st century, climate changes, water scarcity, increasing world population, rising food prices, and other socioeconomic impacts are expected to generate a great threat to agriculture and food security worldwide, especially for the poorest people who live in arid and sub arid regions. These impacts present a challenge to scientists and nutritionists to investigate the possibilities of producing, processing, and utilizing other potential food sources to end hunger and poverty. Agriculture is a primary activity in the world. It includes growing crops, fruits, vegetables, flowers and rearing of livestock. In the world, 50 per cent of persons are engaged in agricultural activity. Two-thirds of India's population is still dependent on agriculture. Favorable topography of soil and climate are vital for agricultural activity. The land on which the crops are grown is known as arable land. After almost 70 years of Independence, malnutrition continues to plague India. Even while vast segments of resource-poor people suffer from under nutrition, particularly micronutrient deficiencies (hidden hunger), there is a growing incidence of obesity and chronic diseases like diabetes, cardiovascular diseases, cancer etc.

The Global Nutrition Report 2016 demonstrates India's slow overall progress in addressing chronic malnutrition, manifest in stunting (low weight for age), wasting (low weight for height), micronutrient deficiencies and over-weight. Our track record in reducing the proportion of undernourished children over the past decade has been modest at best, and lags what other countries with comparable socio-economic indicators have achieved. In a ranking of countries from lowest to highest on stunting, India ranks 114 out of 132 countries, with the incidence of stunting at 38.7 per cent, compared with Germany and Chile at 1.3 per cent and 1.8 per cent, respectively. Even Bangladesh and Nepal rank marginally higher than India. On wasting, India ranks 120 out of 130 countries, at 15.1 per cent, compared with Australia and Chile at number 1 and 2, with 0 per cent and 0.3 per cent, and South Sudan at 130 with 22.7 per cent. On the prevalence of anemia in women of reproductive age, India ranks 170 out of 185 countries at 48.1 per cent, compared with Senegal which is the worst at 57.5 per cent and the U.S. which is the best at 11.9 per cent. These findings indicate that though India ranks number one in production of millets and rank number two in terms of green leafy vegetables production next to china, but the awareness about the consumption pattern and health benefits of millets is very poor in Indian context.

Millets are one of the cereals asides the major wheat, rice, and maize. Millets are major food sources for millions of people, especially those who live in hot, dry areas of the world. They are grown mostly in marginal areas under agricultural conditions in which major cereals fail to give substantial yields. Millets need very little water for their production. Compared to irrigated commodity crops currently promoted by policy measures, millets and require just around 25% of the rainfall regime demanded by crops such as sugarcane and banana. Thus, they do not burden the state with demands for irrigation or power. Millets are important foods in many underdeveloped countries because of their ability to grow under adverse weather conditions like limited rainfall. In contrast, millet is the major source of energy and protein for millions of people in Africa. It has been reported that millet has many nutritious and medical functions (Yang et al., 2012).

There are many varieties of millets. The four major types are Pearl millet (Pennisetum glaucum), which comprises 40% of the world production, Foxtail millet (Setaria italica), Proso millet or white millet (Panicum miliaceum), and Finger Millet (Eleusine coracana). Pearl millet produces the largest seeds and it is the variety most commonly used for human consumption. Minor millets include: Barnyard millet (Echinochloa spp.), Kodo millet (Paspalum scrobiculatum), Little millet (Panicum sumatrense), Guinea millet (Brachiaria deflexa = Urochloa deflexa), Browntop millet (Urochloa ramosa = Brachiaria ramosa = Panicum ramosum), Teff (Eragrostis tef) and fonio (Digitaria exilis) are also often called millets, as more rarely are sorghum (Sorghum spp.) and Job's tears (Coix lacrima-jobi) (ICRISAT, 2007; FAO, 2009; Adekunle, 2012).

In 2007, global millet production reached about 32 million tones with the top producing countries being: India (10,610,000), Nigeria (7,700,000), Niger (2,781,928), China (2,101,000), Burkina Faso (1,104,010), Mali (1,074,440), Sudan (792,000), Uganda (732,000), Chad (550,000) and Ethiopia (500,000) (FAO, 2009).

Position of millets in comparison to staple food grains in human food chain

There is a decline in consumption of millets and its products, where in it is originated and grown is due to the shift in consumer habits, rapid rate of urbanization, time and energy required to prepare millet based foods, inadequate domestic structure, poor marketing facilities, processing techniques, unstable supplies and relative unavailability of millets and its products, including flour, compared with other foodstuffs. Though mechanical pearling or polishing is well known for wheat, rice and maize, but for millet, this primary step in the commercial processing is essentially unknown. For instance, large imports of wheat and rice and policies to subsidize production of those crops in some countries had considerable negative impact on millets production. Millets could be in great demand in the future if the technologies for specific industrial end users are developed.

Though India is the largest producer of millets in the world, between 1961 and 2012, there has been drastic reduction in the area under cultivation of millets. Unfortunately the National food security mission launched in 2007, during the 11th five year plan, addresses the issue of cereals and pulses, but not millets. There is an emerging need to focus it on millet research and consumption interns of more health benefits compare with rice and other crops.

Table: 1 Fifty years of cultivation of millets vis-à-vis other crops in India *(Area in Million ha)

Crop / Year	1955-56	1965-66	1975-76	1985-86	1995-96	2005-06	2008-09	2011-12
Jower	17.36	17.68	16.09	16.10	11.33	8.68	7.53	6.25
Bajra	11.34	11.97	11.57	10.65	9.32	9.58	8.75	8.78
Ragi	2.30	2.70	2.63	2.41	1.77	1.53	1.38	1.18
Small.Millets	5.34	4.56	4.67	3.16	1.66	1.06	0.91	0.80
Total Millets	36.34	36.91	34.96	32.30	24.08	22.08	18.57	18.6
Rice	31.52	35.47	39.48	41.14	42.84	43.66	44.553	
Wheat	12.37	12.57	20.45	23.03	25.01	26.48	27.71	
Maize	37.00	48.00	60.30	58.00	59.80	75.88	81.74	
Total cereals	51.08	55.48	68.76	71.305	74.658	78.36	82.16	99.15
Share of millets (%)	42	40	34	31	24	21	18	14.6

Source: Directorate of Millets Development, DAC, Ministry of Agriculture, GoI, Jaipur, Agricultural statistics at a glance, Economics and Statistics, Ministry of Agriculture, GoI, New Delhi.

Reasons for Decline in Millets Area in India

Both demand and supply side factors have contributed to reduced interest in millets

Demand side factors: 1. Rapid urbanization, 2. Changing consumer tastes and preferences due to rising per capita incomes, 3. Government policies favoring other crops such as output price incentives and input subsidies, 4. Supply of PDS rice and wheat at cheaper price introduced in non-traditional areas of fine cereals:, 5. Low shelf-life of grain and flour.

Supply side factors: 1. increasing marginalized cultivation, 2, Low profitability-low remuneration for millets vis-à-vis competing crops, 3. more remunerative crop alternatives in kharif competing with millets 4. Lack of incentive for millets production, 6. Development of better irrigation infrastructure /options as in small millets.

Demand for millets can be increased by creating awareness regarding their nutritional and other health benefits making them available through PDS, value addition, inclusion under feeding programmes like the mid day meal, ICDS feeding, and adolescent girls nutrition scheme (now under consideration of ministry of women and child welfare). The future priorities for research on millets may be considered in order to sustain the production and productivity of millets.

Nutritive Value of Millet Grains

Nutritional quality of food is a key element in maintaining human overall physical well-being because nutritional well-being is a sustainable force for health and development and maximization of human genetic potential. Therefore, for solving the problem of deep-rooted food insecurity and malnutrition, dietary quality should be taken into consideration (Singh and Raghuvanshi 2012). In addition to their cultivating advantages, millets were found to have high nutritive value and comparable to that of major cereals such as wheat and rice. It has also been reported that millet proteins are good sources of essential amino acids except lysine and threonine but are relatively high in methionine. Millets are also rich sources of photochemical and micronutrients (Mal and others 2010; Singh and others 2012).

Table: 2 Nutritive Values of Millets

Grain/ nutrient	Bajra	Jowar	Ragi	Fox tail millet	Proso millet	Barnyard millet	Kodo millet	Rice-milled	Maize	Wheat-flour
Energy kcal	361	349	328	331	341	397	309	345	342	346
Protein g	11.6	10.4	7.3	12.3	7.7	6.2	8.3	6.8	11.1	12.1
Fat g	5	1.9	1.3	4.3	4.7	2.2	1.4	0.4	3.6	1.7
Calcium mg	42	25	344	31	17	20	27	10	10	48
Iron mg	8	4.1	3.9	2.8	9.3	5	0.5	3.2	2.3	4.9
Zinc mg	3.1	1.6	2.3	2.4	3.7	3	0.7	1.4	2.8	2.2
Thiamin mg	0.33	0.37	0.42	0.59	0.21`	0.33	0.33	0.06	0.42	0.49
Riboflavin mg	0.25	0.13	0.19	0.11	0.01	0.1	0.09	0.06	0.1	0.17
Folic acid mg	45.5	20	18.3	15	9	-	23.1	8	20	36.6
Fiber g	1.2	1.6	3.6	8	7.6	9.8	9	0.2	2.7	1.2

Processing Methods and their effect: Milling, roasting, soaking, malting, germination and fermentation have been found to reduce phytic acid and tannin contents of millets. The nutrient content of millet grain is relatively poor after milling but the bioavailability of certain nutrients, such as iron improves considerably.

Milling: Milling to separate the seed coat or decortications reduces protein, dietary fibre, vitamins and mineral contents of the grains to some extent but this is compensated by better consumer acceptability, improved bioavailability of the nutrients and enhanced product making qualities. The bran fraction from pearl millet and some of the small millets is very good source of dietary fibre and edible oil. Hence, it can serve as an extender to the rice bran for oil extraction.

Popping: Popping is one of the traditional and popular dry-heat (high temperature short time – HTST) processing methods followed to prepare ready-to-eat products. Popped grains serve as snacks after seasoning and can be used for preparation sweet meats such as laddu or sattu and chikki etc. Popped grains can be blended with toasted or puffed legumes, oilseeds and jaggery or sugar to prepare delicious and nutritionally balanced convenience supplementary foods.
Expanded grains: Expanded products which resemble rice poori or murmura are the new generation snacks from millets. Expanded grains are novel and high value products and can find application as ingredients for snacks and crispy in confectioneries as well as thickener in soup mixes.

Flaking: Cereal flakes are of three kinds in India and their methods of preparation include use of edge runner, roller flaker and extrusion cooker and flaker. The process of flaking gelatinizes the starch and also inactivates the lipase. Hence, the flakes are RTE products. They normally have better shelf-life. Malting and Brewing: Malting is one of the very early biotechnological processes adopted for cereal processing for food and brewing. Although, barley has the place of pride for malting, sorghum and finger millet malting is also practiced extensively. Finger millet malting is mostly followed in India for specialty food product formulations. Pearl millet has very limited scope for malting as the malt will have poor keeping quality; likewise, other minor millets are at disadvantage because of the low level hydrolytic enzymes in their malts. Malted finger millet being a good source of amylases and micro-nutrients is termed as "Amylase Rich Food" (ARF). Pasta/Vermicelli/Noodles: Pasta and vermicelli/noodles are generally prepared from wheat because of the beneficial properties of gluten. Hence, the flours or the fine semolina from millets need special pre-treatment to partially gelatinize the starch to extrude into strands. Very often some kinds of functional ingredients such as gums are also used to facilitate binding. However, efforts to prepare noodles from these grains have not been fruitful till date and the composite flour consisting of wheat and millets are used for the purpose.

Bakery products: Composite flours consisting of wheat blended with 20 - 30% millets could be used for preparation of such products without affecting the texture and taste. In fact, the products from the composite flour would be nutritionally superior to wheat- based products due to the phytochemical content of millets.

Extrusion Cooking: Extrusion -cooked products being of RTE nature will have greater scope for use as weaning and supplementary foods. With these technologies, it is possible to prepare multigrain snacks or supplementary foods or health bars. Extrusion cooking has very high potential for production of pet foods, the demand for which is expanding in the country.

Apart from the above said methods germination or malting, Fermentation and enzymatic hydrolyzation, popping or puffing, soaking and cooking are also plays an important role to extrapolate the nutrients from millets.

Health benefits of Millets

Millets contain more dietary fiber compared to rice and wheat. This enhances slow release of energy, thereby increasing physical efficiency. Millets also contain fat in a considerable quantity which is needed for body. They are a source of 'B' Vitamin and minerals. Compared to rice and wheat, mineral content in millets is higher. While finger millet contains 30 times more calcium than rice and wheat, other millets posses at least 2 time more calcium than rice and wheat. Little millet and foxtail millet have a higher degree of iron. Millets are also characterized by therapeutic qualities. Millets being non glutinous so used for people with gluten allergy. The fat content in minor millets not only provides energy but also aids in controlling the cholesterol synthesis in the body. Millet protein contains amino acids in balanced proportions and is rich in methionine, cysteine and lysine. These are especially beneficial to vegetarians who depend on plant food for their protein nourishment. The grain contains a high proportion of carbohydrates and dietary fiber which help in prevention of constipation, lowering cholesterol and slow release of glucose to the blood stream during digestion. Important vitamins namely thiamine, riboflavin and niacin are present in high quantities. It is reported that cardiovascular diseases, duodenal ulcers and hyperglycemia occur rarely in millet eaters. Awareness created on nutritional importance of small millets leads to the prevention of malnutrition.

Millet and Diabetes: Millets have been reported to have beneficial effect on diabetes mellitus. The diabetes preventing effect of millets is primarily attributed to high fiber content. The beneficial effect of soluble dietary fiber may be mediated through slower absorption and digestion of carbohydrates. This leads to reduced demand for insulin.

Millet and cardiovascular disease: Obesity, smoking, unhealthy diet, and physical inactivity increase the risk of heart attacks and strokes. Most of the world countries face high and increasing rates of cardiovascular disease. It has been demonstrated that rats fed with a diet of native and treated starch from barnyard millet had the lowest blood glucose, serum cholesterol, and triglycerides compared with rice and other minor millets. Also, the feeding of proso millet protein improved plasma levels of adiponectin, high-density lipoprotein (HDL) cholesterol in genetically obese type-2 diabetic mice under high-fat feeding conditions (Park and others 2008).

Millets and Other Degenerative Diseases: Diets high in fiber and antioxidants have been shown to have beneficial effect on serum lipid profile besides blood sugar. Some forms of cancer are also prevented by high fiber diets. Millets being high in fiber, antioxidants and complex carbohydrates are potential candidates for having beneficial effects on diseases like CVD, cancer and ageing in general. Few in vitro and animal studies support this view but well controlled studies in human are needed.

Millet against cancers and celiac disease: Millet grains based on literature values are known to be rich in phenolic acids, tannins, and phytate that act as "antinutrients". However, it has been established that these antinutrients reduce the risk for colon and breast cancer in animals. It has also been reported that populations consuming sorghum and millet have lower incidences of esophageal cancer than those consuming wheat or maize. Furthermore, a recent study has demonstrated that millet phenolics may be effective in the prevention of cancer initiation and progression in vitro (Chandrasekara and Shahidi 2011c).

Millet and aging: The chemical reaction between the aldehyde group of reducing sugars and the amino group of proteins, termed as nonenzymatic glycosylation, is a major factor responsible for the complications of diabetes and aging (Monnier 1990). Millet grains are rich in antioxidants and phenolics; however, it has been established that phytates, phenols, and tannins can contribute to antioxidant activity important in health, aging, and metabolic syndrome.

Antimicrobial activity: Millet grain fractions and extracts were found to have antimicrobial activity. In one study, seed protein extracts of pearl millet, sorghum, Japanese barnyard millet, foxtail millet, samai millet, and proso millet were evaluated in vitro for their ability to inhibit the growth of *Rhizoctonia solani*, *Macrophomina phaseolina*, and *Fusarium oxysporum.*

Conclusion: Based on the results of studies carried out, millet grains contain many health-promoting components such as dietry fiber, minerals, vitamins, and phytochemicals that include phenolic compounds, and they are comparable to those of major grains and they also have several potential health benefits. However, novel processing and preparation methods are needed to enhance the bioavailability of the micronutrients and to improve the quality of millet diets. Research is also needed to determine the bioavailability, metabolism, and health contribution of millet grains and their different fractions in humans. Making millet food products that deliver convenience, taste, texture, color, and shelf-stability at economical cost for poor people is needed. In addition, for promoting utilization of millet grains in urban areas to open new markets for farmers to improve their income, developing highly improved products from millet is needed. As the largest producer of millets, India can capture world market with appropriate, well-tested foods.

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21.Supply chain management of dryland agricultural commodities

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The rainfed ecosystem is the abode of 78% of the bovines, 64% of sheep and 75% of goat in the country. It contributes up to 40% in rice production, 85% in coarse cereals and about two-third of oilseeds and cotton besides three- fourth of pulses. However, the productivity of both the crops and livestock is poor. The major problems confronting the rainfed agriculture (RFA) or dryland agriculture are preponderance of resource poor and small/ marginal farmers, climate vagaries, and above all the marketing issues (Venkateswarlu and Kareemulla, 2016). It may be noted that millets contribute almost 19 mt of food grain production to the nation (Table.1) while pulses account for 16.5 mt and the oilseeds account for 33 mt. majority of this production comes from rainfed areas.

Table 1: Main millet crops cultivated in India

Millet crops	India's Production (lakh t)	Top 5 producing states
Pearl millet	89	Rajasthan , Uttar Pradesh Haryana Gujarat Maharashtra
Sorghum	72	Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh
Finger Millet	20	Karnataka, Uttarakhand, Tamil Nadu, Maharashtra, Andhra Pradesh
Other Millets (Barnyard, Little, Fox tail. Proso millets)	5	MP, Maharashtra, Karnataka, AP, Tamil Nadu etc.
Total	**186**	

Source: DHAN & WASSAN, 2012

A Supply chain is the connected network of individuals, organizations, resources, activities and technologies involved in the manufacture and sale of a product or service. A supply chain starts with the delivery of raw material from a supplier to a manufacturer, and ends with the delivery of the finished product or service to the end consumer. Supply chain management oversees each touch point of a company's product or service, from initial creation to final sale. With so many places along the supply chain that can add value through efficiencies or lose value through increased expenses, proper SCM can increase revenues, decrease costs and impact a company's/ firm/ farmers bottom line i.e. profits. In a nut shell, Supply chain management plays an essential role in keeping business costs at a minimum and profitability as high as possible.

Inadequate marketing infrastructure, presence of large number of intermediaries, lack of market information and intelligence and inadequate storage facilities results in huge post-harvest losses in the food supply chain. The paradox with rainfed agriculture commodities is that in most cases especially crops such as pulses and oilseeds the producers i.e the farmers do not get remunerative prices while the consumers are faced with situations of short supplies and high prices. The other major issue especially the consumers face quite often is the absence of quality in the commodities. These are some issues that need urgent attention of various stakeholders to make the supply chains responsive and vibrant. This paper makes an attempt to take stock of the situation and suggest some remedies for betterment.

The Context

As rainfed systems can not altogether bring in radical changes in their production patterns, what is desirable is the need for managing their produce to suit to the consumer demands. On the other hand, to the extent possible, in order to meet the demand profile changes led by economic growth and globalization, so the supply systems must adapt to accommodate this change (Pingale.2004).

Drylands are regions of agro-biodiversity as they host several crops and livestock species. In terms of crops the coarse cereals, rainfed rice, pulses and oilseeds are mostly produced in this region. Due to subsistence pattern of farming although the primary intention is to feed the grain to the family and to the livestock, sufficient surplus is generated across various commodities for the market. The actual quantity of such commodities sold in the market, often called as marketed surplus of some of the rainfed crops is indicated in tables 2 and 3.

Table.2 Major Producing States of Bajra in India during 2010-11

State	Area (mha)	% to all India	Production (m t)	% to all India	Yield (kg/ha)	Rainfed area (%)	% of marketed surplus
Rajasthan	5.49	57	5.57	44	832	96	53
UP	0.94	10	1.56	15	1660	93	82
Gujarat	0.87	9	1.09	11	1253	78	84
Haryana	0.66	7	1.19	11	1803	62	81
Maharashtra	1.04	11	1.12	11	1077	95	76
India	9.61	100	10.37	100	1079	91	67

Source: Tuteja, 2013

Table-3. Marketed surplus ratio for maize and red gram in India

Year	Maize	Red gram
1999-2000	67.30	63.50
2004-05	76.22	79.52
2010-11	86.00	73.82

Source: Kumar et al, 2013

Agricultural Marketing & Trade Status

The infrastructure for primary marketing (principal and sub yards) is highly skewed across the states. The average area served by regulated market yards range from 118 km^2/market in Punjab to 11215 km^2/market in Meghalaya. The Agricultural Produce Market Committee (APMC) Act enacted by States regulates the agricultural markets at present. The Levis and other market charges imposed by APMC states vary widely. In case of rice the charges vary from 14.5 percent in Andhra Pradesh to 10 percent in Odisha and Punjab. A major challenge in marketing is the post-harvest losses. As per estimates of ICAR, such losses were approximately to the tune of Rs 44000 crores in 2008-09. These were mainly due to the absence of a well-structured rural market, lacunae in APMC Act, and inadequate agriculture infrastructure. A part from APMC Act, the Essential Commodity Act, (ECA) should also be revisited for some provisions and the export of some commodities need to be allowed. The tariff on edible oil should also be revisited to encourage domestic production. Reforms in agricultural marketing were initiated to reduce the intermediaries in supply chain and enhance the private sector investment. However, many of the States are yet to adopt the model APMC Act suggested by the Central Government in 2003. Creaction of a Unified National Agricultural Market has been proposed in the Budget 2015-16 to benefit the farmers. The promotion of National Agricultural Market has already been initiated on a limited scale. The Department of Agriculture & Cooperation has allocated Rs. 200 Crore for 2015-16 and 2016-17 for the propose. It aims at implementation of agricultural marketing reforms by initiating appropriate e-market platforms in State with a view to move towards a National Market, Karnataka has already initiated the unified market in the State. In Karnataka, 51 of the 155 main market yards and 354 sub-yards have been integrated into a single licensing system. Rashtriya e-market Services Ltd. (ReMS) a joint venture created by the State Government and NCDEX Spot Exchange, offers automated auction and post auction facilities (weighting, invoicing, market fee collection, accounting), assaying facilities in the markets, facilitate warehouse based sale of produce, facilitate commodity funding, price dissemination by leveraging technology. The wider geographical scope afforded by breaking up fragmented markets has enable private sector investment in marketing infrastructure. Similar initiative needs to be taken by the States. Appropriate modification in APMC Act to promote re-trading would be a prerequisite.

Reardon and Minten (2011) indicate the following changes in the past two decades.

(1) A modern sector is emerging in the whole sale sector with the growth of modern logistics firms and specialized modern wholesalers.

(2) Tradition segment of the whole sale sector is also transforming. Based on earlier studies, this study presents the findings on transformation of traditional whole sale sector as follows.

(a) Rural traditional market transformation is much more advanced in certain regions For example, West and Central regions of Madhya Pradesh and West and Central Uttar Pradesh are different from Eastern regions of these states.
(b) The marginal farms (0-1 ha) look more like traditional rural India with low market surplus, chemical use, credit use, lower use of clod stores etc. On the other hand, small and medium farmers are more dynamic.
(c) The conventional view is that food supply chains are dominated by long chain of many hands. The recent findings show that supply chains can be short.

In those cases where small producers have been able to integrate into the supplying chains, supermarkets have offered enhanced security and considerably higher margins than the traditional clients, such as wholesales and groceries. However, there is scope for exploitation in contract farming and super markets if rules are not framed properly. Small farmers can benefit from the emerging super markets and value chains.(Dev, 2012).

National Initiatives for Supply Chain Strengthening

Some of the initiatives being taken up under public sector are indicated below:

i) *Initiative for Nutritional Security through Intensive Millets Promotion (INSIMP):* Government has announced an allocation of Rs. 300 crores in 2011-12 under Rashtriya Krishi Vikas Yojana (RKVY) for promotion of millets as Nutri-cereals. Scheme on Initiative for Nutrition Security through Intensive Millets Promotion has been formulated to operationalize the announcement. The scheme aims to demonstrate the improved production and post-harvest technologies in an integrated manner with visible impact to catalyze increased production of millets in the country. Besides increasing production of millets, the Scheme through processing and value addition techniques is expected to generate consumer demand for millet based food products.

As part of this Demonstration-cum-training centre were initiated. One processing unit along with the services of one Technical Assistant purely on contract basis would be set up in selected 100 KVKs to serve as demonstration cum training centres for furtherance of post-harvest technologies. To utilize the full capacity of these processing unit, KVKs may levy nominal charges. A single complete post harvest processing cluster/unit at a total cost up to Rs 4.00 lakh will comprise of both primary processing (3-in-one destoner cum grader cum cleaner + Pearling machine) costing up to Rs. 2.0 lakhs and secondary processing machines ((Rava / Flaking machine – Jowar; Popping roaster- Ragi; Parboiling unit- Pearl millet) costing up to Rs 2.0 lakhs.

Some other initiatives include Rainfed Area Development Programme (RADP) as part of Rashtriya Krishi Vikas Yojana" (RKVY), and Integrated Cereals Development Programmes in Coarse Cereals based Cropping Systems Areas (ICDP-CC) under Macro Management of Agriculture(MMA). Yet another important initiative is under National Mission on Sustainable Agriculture (NMSA).

National Mission on Sustainable Agriculture (NMSA) interventions for Supply Chain Strengthening in RFA

Some of the major initiatives that are to be taken up under this dimension include, reducing quantitative as well as qualitative losses across the supply chain; creating market aligned production systems; strengthening climate resilient post-harvest management, storage and marketing and distribution system; strengthening timely access to farmers to quality inputs; strong farmer institution-industry interface; and encouraging food processing industries and greater exports.

NMSA Mission Intervention #8 - Markets:

- To formulate market-aligned Research and Development programmes
- Improving Supply Chain Efficiency
- Creation of new market infrastructure
- Supporting community partnerships in developing food and forage banks
- Strengthening access to quality and timely inputs by farmers for mitigating risks

NMSA Mission Intervention #9- Access to Information*:*

- Minimizing Information Asymmetry through ICT-based systems
- Public Private Partnership to develop technology based solution for providing farmers with information on price discovery, commodity arrivals, mandi prices etc.
- Building an ICT enabled Knowledge Management network
- To Create, Manage and Develop National Resource Portal

Other and most vital Critical Interventions required (Arora, 2014) are:

- Link Agriculture to Markets (state level reforms, marketing infrastructure, cold chains)
- Greater private participation in extension and farm services
- Develop mutually rewarding models for Agri risk management
- Promote private sector investments in Agribusinesses and Agri infrastructure
- State Governments to speed up reforms
- Enable a globally aligned industry friendly food regulatory regime
- Capacity building in the food processing sector
- Promote promising Agri Value Chains

In order to rejuvenate the dryland crops especially the millets, DHAN and WASSAN had brought out a policy brief noting that :

- Inclusion of all millets into the PDS and menus of various food-based welfare schemes implemented at state level.
- Support for improvement and dissemination of post-harvest processing technology addressing needs at different magnitudes: i.e.
  - i. Support for small processing units within a radius of five km from the village
  - ii. Support for production cum processing cluster
  - iii. Support for ready-to-eat millet food entrepreneurs
- Government sponsored awareness raising programs focusing on three elements:
  - i. Consumption promotion campaigns through mass media coverage
  - ii. Iintegration of information on millets into education curricula
  - iii. Spreading information amongst farmers and other potential beneficiaries of the support offered through the strategy.

Success Stories

Pilot project introducing millets into the Public Distribution System

A pilot project was taken up under the APDAI project with the support of the Department of Civil Supply and District Administration of the Anantapur district with the objectives of: Promoting millets to ensure food and nutritional security for households through the Public Distribution System (PDS), Exploring the possibility of evolving a decentralized multigrain and need-based PDS suitable to local conditions, Bringing back millets in the production system and to make agriculture in the district more economical and sustainable, Developing rural entrepreneurship opportunities through millet processing and through creation of rural employment in the long run. The impact of this pilot was that the poorer section of the people felt that because of this, they are getting the millets close to their house at an affordable price and the regular use of millets in the daily food consumption has improved.

ITC e-Chaupal Sorghum Supply Chain

Under the e-Choupal system of supply chain, the ITC (ABD) Ltd facilitates buy-back procurement of the member farmers' produce. The practice is simple but most effective and profitable- effectiveness in building sustainable linkage between the buyers and sellers, and profitable to both farmers and processors. The processors could rely on the supplier since the supplier (ITC) has the desired quality and quantity of raw material (sorghum grain) and for which the processors are willing to pay higher price which automatically impact higher revenue towards the farmers since ITC main motive was to play the role facilitator for the benefit of the farmers (Dayakar and Reddy,

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22. Alternate uses of millets and scope for entrepreneurship

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Millets are major source of energy and proteins for a large section of people inhabiting the semi arid tropics of India. These people are especially under privileged and any improvement in the production and processing, use and nutritional improvement of millets would benefit the poorest. To improve the economic and nutritional status of millets farmer, it is not sufficient if agricultural production alone is increased. Simultaneously use of millets as food should be enhanced which will result in better market returns to the millets farmer.

The status of millets use has been low due to its colour, coarseness, high fibre content, long cooking time etc. Difficulty in traditional de-hulling process also limits its use. Primary and secondary processed products of millets are not readily available in the market which limits its use in general public.

Nutritious millets can also be promoted as health food. Millets possesses unique nutritional and functional properties which allows for the development of nutritious functional foods. They are gluten free, have unique phenolic compounds which have medicinal properties and compliments well with lysine rich vegetable and animal proteins to form nutritionally balanced foods of high biological value.

Value addition to millets can range from simple roti to the more prestigious pasta and noodles. With growing demand for ready-to-eat, ready-to-cook and ready –to-serve products due to changing demographics and life styles, there is an urgent need to convert millets into these forms so as to enable the food industry and entrepreneurs to include millet products in their product mix.

Difficulty in dehulling process and lack of technical knowhow about the use of dehulled flour and rava were the two limitations observed using millets in a variety of foods and increasing its market demand. Since the traditional hand pounding method for processing millets is a time consuming laborious and inefficient method, an agrohuller for millets processing is developed. Mechanical dehulling technology, not only reduces the drudgery of dehulling process and cooking time, but also enhances the quality of millets. Mechanical dehulling results in improved physical appearance and functional properties and also enhances both starch and protein digestibility by reducing tannin and fibre levels.

Culinary uses of whole millets were limited, but development of fine quality flour and semolina with dehulled millets has led to number of alternate uses of millets. The products thus developed can be grouped into two groups namely

- Products of Primary Processing
- Products of Secondary Processing

PRODUCTS OF PRIMARY PROCESSING

Dehulled millets: The quality of millets is improved by mechanical dehulling wherein good quality flour and semolina (rava) will be obtained. Partial or complete dehulling can be done by using specially fabricated abrasive dehulllers and pulverizers suitable for all millet grain sizes. These products can be marketed directly or can be further processed in to other value added products.

Steps in processing of dehulled millets: Millets-Cleaning –Drying-Weighing-Dehulling-Winnowing- Dehulled Millets

Flour and Semolina: Millet grains like Jowar, ragi, foxtail etc can be converted in to flour and semolina (fine and coarse) after partial or complete dehulling, by using specially fabricated abrasive dehullers and pulverizers suitable for al millet grain sizes. These products can be marketed directly or can be further processed in to other value added products

Composite Roti Mixes and Multigrain Flour: The beneficial effects of supplementation of cereals and pulses have long been established. Since millets are consumed in the form of roti by majority of millets consumers, nutritious roti blends of millets in combination with legumes were developed using bengalgram, redgram,greengram and blackgram. There is growing demand for multigrain flour. It can be prepared using various combinations of millets, pulses and other grains while balancing the important nutrients and sensory quality.

Products of Secondary Processing

With high quality dehulled millets flour it was possible to develop number of nutritious and novel recipes such as ready to cook mixes, dehydrated foods, breakfast foods, snack foods, baked products and millets based supplementary foods (infant foods) etc.

Ready to Cook Mixes: In view of the increasing demand for convenience foods, ready to use breakfast mixes (Idli and Dosa mixes) can be developed substituting millets in place of rice.

Dehydrated Foods: Production of dehydrated foods like papads is a home level enterprise which can be managed by women. Usually papads can also be prepared with dehulled millets flour. This is identified to be an enterprise with low technology inputs, minimum equipment and good market potential.

Breakfast Foods: Fermented batter products are popular breakfast items in India. Among these the breakfast items like dosa, idli and utappam are very popular in South India as ' Dokla' in North India. Since rice is the major ingredient used with pulse in breakfast foods, rice can be substituted with millets fully or partly. Preparations like Khichdi, Upma and Biryani can be standardized using millets rava.

Snack Foods: Deep fried foods are popular snacks in India in rural as well as in urban sector. They have good shelf life and women in our country are familiar with the preparation of deep fried foods unlike baked foods. A variety of traditional snack items like muruku, chekkalu, chekodi, pakodi etc., can be made with millets. These products are generally made by combining small amount of pulse flour also. The combination improve the nutritional quality and acceptability.

Puffed Millets: Puffing of cereals has been practiced since hundred of years for use as a snack food either after spicing or sweetening. The puffed Millets has a low bulk density and pleasing texture with a distinct appealing flavour. Popped millet flours hold promise as base for snack food products and have potential for use in development of breakfast and speciality food.

Millet Flakes: Flaked grains make excellent snack food. For getting a good quality flattened product, the millet grains are to be harvested slightly premature. Fully mature grains when soaked in water at ambient temperature for12-24 hours or lukewarm water for 4-6 hrs before roasting also yields a satisfactory product. The grains after partial roasting are flattened, dried, stored and usually deep fat fried before consumption as snack. The dried millet flakes can be powdered and used as a base for snack foods and weaning foods

Baked Foods

Biscuits, Cookies And Cakes: Products such as biscuits, cookies and cakes can be made by incorporating millet flours.

Bread and bun: Bread and buns are generally prepared from refined wheat flour. However, they can be successfully prepared from millet flours by blending with a small proportion of wheat flour.

Biscuits: Sweet and salt biscuits can be made as an alternate supplementary food in combination with millets and chickpea. The millet legume infant mixes and biscuits developed could easily meet the standards fixed for food supplements prescribed for infant feeding programmes i.e., to provide 300 K cal, 8-10gs of protein per child beneficiary. They are highly acceptable supplements to mothers as well as children. Supplementation also helps in preventing growth faltering and results in low morbidity.

Millets based Supplementary Foods

Infant mixes: Infant mixes can be prepared from a combination of dehulled millets and chickpea or greengram in the ratio of 4:1 by weight using malting process.

Therapeutic Foods: Apart from these alternate uses, millets can be beneficially utilized in the development of therapeutic foods which can be utilized for lowering blood glucose and lipid levels in diabetic and CVD subjects.

Malted Foods: Millets are malted in large scale in parts of Africa. The goal of malting is to produce high enzyme activity and a characteristic flavour with a minimum loss of dry weight. Malt has number of uses and can be used in brewing industry and baking industry and also in breakfast food industry as a flavouring agent. Ragi which is nutritious and has high keeping quality is used in the preparation of beer. However high oil content and poor keeping quality of other millet malts are the constraints for their utilization in brewing industry . Malted millets can also be used in the preparation of malted vinegar and medicinal preparations.

Starch Extraction

Technology for extraction of starch from Millets is available and the starch thus obtained from millets can be utilized as thickeners in soups and gravies and in development of ready mixes for soups.

Extruded Foods

Millets such as sorghum and pearl millet have been successfully used in the preparation of roller dried extruded products. Noodle like products have been prepared using formulae incorporating cowpea, pearl millet or sorghum flour with wheat flour which are acceptable. Vermicelli can also be prepared. These extruded products can be used as it is or it can be used in soups.

Cold Extruded Products: Pasta,Vermicelli and Noodles

The cold extruded products require cooking. There is growing market for theses products in India. By using appropriare food additives pasta products from millets in combination with wheat or alone can be successfully prepared.

Hot extruded products: Snacks

These are the puffed snacks and extruded at high temperature, additional spicing is required and can be consumed directly. As an alternative, spices can also be added before extrusion.

Millets Food Enterprises for Economic Development of Rural Women

Millets Food Enterprises if established in rural and semi urban areas will benefit women in enhancing their household income. This will indirectly improve the nutritional status of children also. For women in rural and semi urban sector different types of enterprises such as dehulling Unit – Primary processed Products, Snack selling Unit , Bakery Unit (Secondary processed products) etc are considered possible with Millets.

Millets enterprises can be run by single women with the help of family or it can be run as a group activity by few women. Organization of women into groups is an important initial step for running any income generating activity. Working as a group and the concept of group strength has to be understood by women. A successful experience of working together gives strength and confidence to the group to take on bigger issues in future.

Incubation Centre for Millet Processing

In order to promote and add value to millets through development of enterprises and establishment of market linkages this center was established at PJTSAU campus near Post Graduate & Research center, Hyderabad. The centre was equipped with many equipments for primary and secondary processed products of millets . Facilities for grain storage, grading, de-stoning, finished products packing etc. are also available. Facility for bulk production of millet processed products is available. Commercialization of the products with university name is being done. Any interested entrepreneur in millet processing without investing on purchase of equipment can easily use the facility and start their business

Millets enterprises can be successful ventures in the dryland region. This will not only create market demand for millets, it can also improve the nutritional status of dryland farm families indirectly by increasing the monetary benefits to the farm families. Development of alternate uses of millets alone will not solve the problem of millets farmers. Sustainable production of millets as well as wide consumer market for these products needs to be developed by the collaborative effort of Agricultural scientists and Food Technologists.

23.Farmers' Rights in the context of Plant Variety Protection

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Introduction

The Intellectual Property Rights (IPR) refers to the form of legal rights like patents, trademarks, copyrights or industrial designs, which can protect the creations of the human mind like inventions, literary and artistic works, and symbols, names and images used in trade or commerce that constitute the intellectual property of the creator. Intellectual property is divided into two categories: *Industrial Property* that includes patents for inventions, trademarks, industrial designs and geographical indications; *Copyright* that covers literary works (novels, poems, plays, etc.), films, music, artistic works and performances, and architectural design.

Plant Breeder's Rights (PBR), which is a form of IPR granted to the breeder of a new variety of plant as a recognition of his/her intellectual contribution, to the development of agriculture and to safeguard the interests of plant breeders. The PBR give the breeder exclusive control over the seed or propagating material of the variety for a specified number of years. With these rights, the breeder can choose to become the exclusive marketer of the variety, or to license the variety to others. The possibility to claim IPR on a variety, gives a breeder the exclusive rights to exploit it and to prevent others from doing so illegally. Protecting plant breeders' rights can stimulate investment for the development of new plant varieties.

The World Trade Organization (WTO), which came into being in 1995, requires all the member nations to provide protection for plant varieties or PBR either by patents or by an effective *sui generis* ('of its own kind') system, or a combination of both, in accordance with Article 27.3(b) of the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs). Many member countries are therefore developing and implementing a legal framework for the protection of plant varieties. India did not have any legislation on protection of plant varieties till 2001, and therefore the commercial varieties were freely available for research, seed production and cultivation. Being a member of WTO, India enacted the Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, 2001 by adopting a *sui generis* system to acknowledge the achievements of breeders of new plant varieties (PPV&FR Act, 2001).

Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA)

Upon enactment of PPV&FR Act, 2001, the PPV&FR Rules were notified in 2003 (PPV&FR Rules, 2003). The Indian legislation is not only in conformity with the UPOV Convention 1978 Act, but also have sufficient provisions to protect the interests of public/private sector breeding institutions and the farmers. To implement the provisions of the PPV&FR Act the Department of Agriculture and Cooperation, Ministry of Agriculture established the PPV&FR Authority on 11th November, 2005. The PPV&FR Regulations were notified in 2006 (PPV&FR Regulations, 2006).

The Indian Act recognizes the contributions of both commercial plant breeders and farmers in plant breeding. It mandates the PPV&FRA to grant IPR to breeders, farmers and researchers who have evolved or developed new and extant plant varieties. The Authority takes care of the ownership through registration of the varieties of all plant species except micro-organisms. The objectives of the PPV&FRA include: to establish an effective system for protection of plant varieties, the rights of farmers and plant breeders, and to encourage development of new varieties of plants; to recognize and protect the rights of farmers in respect of their contribution for development of new plant varieties; to accelerate agricultural development, protect plant breeders' rights, stimulate investment for R&D for the development of new varieties; and to facilitate the growth of seed industry to ensure production and availability of high quality seed and planting material to farmers. Other issues related to public interest include compulsory licensing rights and prevention of the propagation of varieties using Genetic Use Restriction Technologies (GURT), which are contrary to the interest of the farmers in general.

The general functions of the Authority are: registration of new plant varieties, essentially derived varieties (EDV), extant varieties and farmers' varieties; developing Distinctiveness, Uniformity and Stability (DUS) test guidelines for new plant species; characterization and documentation of registered varieties; compulsory cataloguing facilities for all variety of plants; documentation, indexing and cataloguing of farmers' varieties; recognizing and rewarding farmers, community of farmers, particularly tribal and rural community engaged in conservation, improvement, preservation of plant genetic resources of economic plants and their wild relatives; maintenance of the National Register of Plant Varieties; and maintenance of National Genebank including field genebank.

Registration of a New Variety

The PPV&FR Act, 2001 grants plant variety protection or PBR by means of registration of a variety. A new variety shall be registered under this Act if it conforms to the criteria of novelty, distinctiveness, uniformity and stability. Novelty means commercial novelty, *i.e.*, the propagating or harvested material of the variety has not been sold or otherwise exploited earlier than one year in India or outside

India (not earlier than six years in the case of trees or vines, and four years in other crops), from the date of filing of application of registration. However, trial of a new variety which has not been sold or otherwise disposed off shall not affect the right to protection. A variety is distinct, if it is clearly distinguishable from any other variety whose existence is a matter of common knowledge at the time of the filing of the application or in simpler terms it is clearly distinguishable by at least one essential characteristic such as height, maturity, colour, etc. from any other variety. A variety is uniform if the plant characteristics are consistent from plant to plant within the variety. A variety is stable if its essential characteristics remain unchanged from generation to generation.

The breeder must also give the variety an acceptable 'denomination'. Apart from new variety, EDV, extant variety which is notified under section 5 of the Seeds Act, 1966 or farmers' variety or a variety under common knowledge can also be registered. Presently, 114 crop species have been notified by the Central Government for registration. The DUS guidelines for these crop species and list of DUS testing centres have been provided on the official website of the Authority (http://plantauthority.gov.in/crop-guidelines.htm). The Authority publishes Plant Variety Journal of India (http://plantauthority.gov.in/publications.htm), which has a status of Gazette of India. The journal contains a wealth of information relating to varieties which have been accepted for registration, details of registered varieties and DUS test guidelines for crop species notified for registration. This is a useful tool to monitor whether any person's variety is being misappropriated by some other person, and it will be useful to students and researchers involved in varietal research and also to entities involved in documentation of farmers' varieties. The latest application forms for registration of new and extant varieties (Form I), and EDVs (Form II) have been notified vide PPV&FR (Amendment) Regulations, 2013.

Rights Under the PPV&FR Act, 2001

Under the UPOV Convention 1978 Act, a new plant variety developed by a breeder could only be produced and marketed by him. The breeder had a monopoly via marketing rights for the sale of seed. But the system allowed two important exemptions: the breeder's exemption, which allowed other plant breeders to use the protected variety for breeding purposes, and the farmer's exemption. The farmers were allowed to use farm-saved seeds from their harvest to plant the next crop, even if the seed was protected by the PBR. In the UPOV Convention 1991 Act, the breeder's exemption was almost restricted by making way for authorization of the original breeder subject to certain conditions and limitations, royalty payments to the PBR holder from the breeders if their new variety bears some resemblance to the protected variety even if the new variety has been bred for different characters. Certain exceptions were provided for acts done privately and for non-commercial purposes. For example, the propagation of a protected variety by a farmer exclusively for the production of a food crop to be consumed entirely by that farmer and the dependents of the farmer living on that holding, may be considered to fall within the meaning of acts done privately and for non-commercial purposes. In other words, a farmer can use farm-saved seeds for his own purpose, but not for providing to others or selling the harvested produce which is considered as commercial purpose. Hence, farmers are required to pay compensation for the use of farm-saved seeds from protected varieties for commercial cultivation.

The Indian PPV&FR Act, 2001 is in harmony with the UPOV Convention 1978 Act, and provides for the following rights.

Breeders' Rights

Breeders will have exclusive rights to produce, sell, market, distribute, import or export the protected variety. The breeder can appoint agent/licensee and may exercise for civil remedy in case of infringement of rights. According to the Act "breeder" means a person or group of persons or a farmer or group of farmers or any institution which has bred, evolved or developed any variety.

Researchers' Rights

The researcher can use any of the registered varieties under the Act for conducting experiments or research. This includes the use of a variety as an initial source of variety for the purpose of developing another variety. But authorization or prior permission of the breeder of a registered variety is required where the repeated use of such variety as a parental line is necessary for commercial production of such other newly developed variety.

Farmers' Rights

Farmers' Rights section (Chapter VI) is a unique feature of the Indian Act, which gives the much needed importance to the farmers. India is the first country to consider it necessary to recognize and protect the rights of the farmers in respect of their contribution made at any time in conserving, improving and making available plant genetic resources for the development of the new plant varieties. The concept of farmers' rights, the meaning of a farmer and a farmers' variety according to the Act, and the process of registration of farmers' variety are dealt in detail here under.

Why Farmers' Rights?

The domestication of plants and settled cultivation or agriculture to meet various human needs started about 12,000 years ago. Since then, a wide range of plants have been collected from the wild and grown for varied purposes such as food, feed, fodder, fuel, fibre and medicine. Farmers around the world have been selecting and conserving varieties of different crop plants that they cultivated. This process has generated a rich wealth of varieties in each crop plant, seen to be most abundant in countries near the equator. Farmers in India grow a large number of crops. Generations of Indian farmers, with their continued selection and conservation, have created a rich wealth of varieties in many crops (Bala Ravi, 2004).

Each crop plant has originated in a specific region of the world depending on the needs of native people in that region. Crop plants from these regions spread to other parts of the world during different periods of our agricultural history. This spread happened as a result of farmer-to-farmer sharing and exchange and sale of planting material. Human migration, travel, trade and war also helped in the spread of crops to new regions far away from the place of origin. These new crop plants, introduced from a faraway land, were again selected by local farmers and adapted to local conditions and local needs (Bala Ravi, 2004).

Heritable changes in the varieties under cultivation occur in nature as a result of mutation as well as intercrossing with wild relatives. Farmers detected the useful changes in varieties and selectively propagated them leading to the development of new varieties. Thus, all new varieties arise from old varieties. As farmers understand that the emergence of a new variety does not reduce the importance of the old one, they conserved the new and old varieties. This wealth of varieties is the foundation and feedstock that the plant breeders use to breed new superior varieties. India is the place of origin of many crops including vegetables and fruit species. These plants were identified from the wild, selected and cultivated by Indian farmers over the years thus leading to a huge collection of varieties. Diversity of varieties is also available in crops that were introduced from other countries like wheat, sorghum, maize, bajra, ragi, groundnut, sugarcane, cotton, tea, rubber, etc. because of the wisdom of Indian farmers.

Farmers in India are habituated to cultivate more than one crop and variety if the holding is sufficiently big. By doing so, the farmers not only conserve many varieties, but also test their suitability to different farming situations and select among them. Therefore, each community of farmers conserves many varieties of crops included in the different cropping systems. Many times the wild species are also being preserved, often unknowingly, in waste lands surrounding the fields. Farmers gather a lot of knowledge on the behaviour of varieties such as maturity duration during different seasons, its resistance to different diseases, pests and other natural vagaries, its suitability to different soils, its characteristics and properties, quality of its produce, its suitability for different uses, etc. during the process of cultivation of different crops over the years, and many times such traditional knowledge is passed on from generation to generation. This knowledge base of each variety available with farmers is as highly valuable to modern crop improvement as the genetic diversity of crop plants. In the selection of every variety, there is an intellectual contribution from farmers and this has been responsible for the evolution of most of the traditional or farmers' variety. Thus, cultivation in many parts of India goes hand in hand with selection and conservation (Bala Ravi, 2004). That is why the need to recognize the farmers' contribution in the process of varietal development and conservation has arisen, and grant rights to farmers to own their varieties similar to the rights given to breeders to own new varieties created by them through organized breeding programmes.

Who is a Farmer?

As per the Act, 'farmer' [Section 2(k)] means any person who:

(i) Cultivates crops by cultivating the land himself; or

(ii) Cultivates crops by directly supervising the cultivation or land through any other person; or

(iii) Conserves and preserves, severally or jointly, with any other person any wild species or traditional varieties or adds value to such wild species or traditional varieties through the selection and identification of their useful properties

In other words, the Act recognizes the farmer as a cultivator, conserver and breeder. This definition embraces in all farmers, landed or landless, male and female.

What are the Rights of Farmers?

Under the Act, a farmer is entitled to the following rights:

1. **Right to register traditional varieties**: A farmer who has evolved or developed a new variety is entitled to registration and other protection in like manner as a breeder of a variety. Farmers' variety can also be registered as an extant variety [Section 39(1)(i)].
2. **Right for reward and recognition**: A farmer who is engaged in the conservation of genetic resources of landraces and wild relatives of economic plants and their improvement through selection and preservation shall be entitled in the prescribed manner for recognition and reward from the Gene Fund, provided that material so selected and preserved has been used as donors of genes in varieties registerable under this Act [Section 39(1)(iii)].
3. **Right on seeds**: A farmer can save, use, sow, resow, exchange, share or sell his farm produce including seed of a variety protected under the Act in the same manner as he was entitled before the coming into force of this Act provided farmer shall not be entitled to sell branded seed of a variety protected under the Act [Section 39(1)(iv)].
4. **Right to get compensation for the loss suffered from the registered variety**: There is also a provision for compensation to the farmers for non-performance of variety. The Act requires that the breeder of a registered variety shall disclose to

the farmer or the group of farmers or the organization of farmers to whom the propagating material has been sold, the expected performance under given conditions. If such propagating material fails to provide such performance under such given conditions, the farmer or the group of farmers or the organization of farmers, as the case may be, may claim compensation in the prescribed manner before the Authority and the Authority, after giving notice to the breeder of the variety and after providing him an opportunity to file opposition in the prescribed manner and after hearing the parties, may direct the breeder of the variety to pay such compensation as it deems fit, to the farmer or the group of farmers or the organization of farmers, as the case may be [Section 39(2)].

5. **Right for benefit sharing**: A breeder might have used farmers' varieties developed by one or more farming or tribal communities or their derivatives as parents for breeding new plant varieties. When such new variety is registered the breeder holds the exclusive rights for commercial exploitation, and in the event of that variety getting popular the breeder alone stands to gain huge profits from seed sale. The Act provides for equitable sharing of the benefit earned from the new variety with farming or tribal communities that had contributed varieties used as parents [Section 26(5)].
6. **Right to receive compensation for undisclosed use of traditional varieties**: A breeder or other person making application for registration of any variety under the Act shall disclose in the application the information regarding the use of genetic material conserved by any tribal or rural families in the breeding or development of such variety [Section 40(1)]. The lapse on the part of the breeder may be either from an honest ignorance on the identity and origin of the parental varieties or a dishonest suppression of parental variety identity. If the applicant fails to disclose any such information, the Registrar may, after being satisfied that the breeder or such person has willfully and knowingly concealed such information, reject the application for registration of a new variety [Section 40(2)]. On the event of grant of registration for such a variety, and if the communities concerned are not capable to detect such use of their varieties or traditional knowledge in the breeding of a new variety and set to loose the opportunity for benefit share, any third party who has a reasonable knowledge on the possible identity of the traditional varieties or knowledge used in the breeding of the new variety is eligible to claim compensation on behalf of the concerned local or tribal community [Rights of Communities, Section 41].
7. **Right for protection against innocent infringement**: The right established under this Act shall not be deemed to be infringed by a farmer who at the time of such infringement was not aware of the existence of such right; and no cognizance of any offence under this Act shall be taken, for such infringement by any court against a farmer who proves, before such court, that at the time of the

infringement he was not aware of the existence of the right so infringed (Section 42)

8. **Right for receiving free services**: Farmer shall not be liable to pay any fee in any proceeding before the Authority or Registrar or the Tribunal or the High Court under the Act (Section 44).
9. **Right for the seeds of registered varieties**: One of the objectives of the Act is to promote the availability of high quality seed and planting material to farmers for accelerated agricultural development. The Act tries to achieve this by ensuring adequate availability of seeds of registered varieties to farmers at reasonable cost, which is important for reaping the benefits of scientific crop improvement. While granting exclusive right to the breeder for commercial exploitation, the Act expects the breeder to meet farmers' demand for seeds at reasonable prices. According to the Act, when the registered breeder does not satisfy this requirement three years after registration of the variety, farmers have the right to complain about non-availability, poor supply, or high price of seed to the PPV&FRA. On receiving such complaints and on its verification, the Authority can take remedial actions. One of these actions may be enforcement of compulsory licensing [Chapter VII, Section 47-53]. Compulsory licensing revokes the exclusive right on commercial production and marketing of seed granted to the registered breeder and transfer this right to third parties determined by the Authority. This revoke of exclusive right is done for a period decided by the Authority. The Authority shall make available to the licensee of such compulsory license, the reproductive material of the registered variety stored in the National Genebank or any other centre. The third parties, who are given the right to produce and market the seed, are required to meet the demands and supply seed at reasonable prices.

What is a Farmers' Variety?

As per the Act, 'farmers' variety' [Section 2(l)] means a variety which

(i) Has been traditionally cultivated and evolved by the farmers in their fields; or

(ii) Is a wild relative or landrace or a variety about which the farmers possess the common knowledge.

The farmers' variety is a cultivar that has been evolved by farmers or farming communities over several years and has proven special features compared to other materials. As these cultivars have been traditionally cultivated for number of years, because of repeated propagation, progeny assessment and advancement, the farmers' variety tends to be more homogenous and stable with distinct character(s). Such varieties have been provided with unique identity with a vernacular name often describing their unique features. The farmers' variety gets distributed over local areas because of the farmer-to-farmer exchange and consumer acceptance for the produce that may have some specialty, even when the variety may not be high yielding. This only proves that market driven selection was done by farmers in the selection of farmers' variety, and thus is an improvement over the wild relatives and/or landraces. The farmers' variety can be elaborated as a variety that is almost uniform, homogenous, has distinct trait(s) and enjoys consumer acceptance (Nagarajan, 2007).

Registration of Farmers' Variety

The procedure for registration of farmers' variety is similar to that of a new variety. The applicant has to fill up the variety registration application form and deposit the specified quantity of seed material. Any farmer or group of farmers or community of farmers claiming to be the breeder of the variety can apply for registration of the variety as specified under clause (d) of section 16 of the Act. It is important that the applicant farmers should have reasonable ground to claim ownership on the variety either by its breeding or longer conservation. A community conserving a farmers' variety gains eligibility for its registration only when the farmer or community of farmers who had originally evolved that variety remains unknown. When a community registers a variety, each legitimate member of that community will enjoy equal ownership.

The Ministry of Agriculture notified the PPV&FR (Criteria for Distinctiveness, Uniformity and Stability for Registration) Regulations, 2009 for criteria of DUS testing for registration of variety about which there is common knowledge (VCK) and farmers' variety (PPV&FR Regulations, 2009). According to these, any person who applies for registration under clause (c) of Section 14 of the Act shall submit half the quantity of seeds as divided into five equal numbers of packets for the purpose of field test and also for storing in the National Genebank and the seed supply procedures shall be such as may be specified in the Plant Variety Journal by the Authority. Wherever the distinctiveness of the variety is required to be verified, field test will be conducted for DUS in the test Centres. The farmers' variety along with example variety and any other similar variety shall be evaluated in the paired-row test. The length of the row and plant population shall be such as may be specified by the Authority. It shall be a replicated trial and will be conducted for one season at two locations for the limited purpose of confirming the distinctiveness, following the descriptors for the crop species. The uniformity levels for farmers' variety for the respective species shall not exceed double the number of off-types. If the variety meets the uniformity criteria, it shall be deemed to have met the stability criteria. The test criteria for registration of VCK (applied under clause (b) of Section 14) is similar, with a field test for one season at two locations for the purpose of confirming the DUS following the descriptors and plot size as specified by the Authority.

Application for farmers' variety by farmers or community of farmers or group of farmers shall be submitted as specified in the Sixth Schedule of PPV&FR Rules added as per Gazette notification No. 104 dated 21st February 2013 [PPV&FR (Amendment) Rules, 2013] (see Appendix I) with an endorsement in Annexure 1 either by the concerned Panchayat Biodiversity Management Committee, or District Agricultural Officer, or Director of Research of concerned State Agricultural University or District Tribal Development Officer. In case the variety is evolved and conserved by 'group or community of farmers', it shall be endorsed so in Annexure I. The commercialization or otherwise exploitation of the variety also has to be declared. All the information on the variety, known to the farmer(s) and as required under the form, has to be accurately provided, and in case certain information required in the form is not available, it should be stated so.

If the applicant is an individual farmer he is required to declare that he has been a permanent cultivator since last many years in the particular geographical location and that he and his family are the initial and exclusive developers and conservers of the candidate variety with the specified denomination. If a group/community of farmers apply, then also it has to be declared that they have been the permanent cultivators since last many years in the particular geographical location and that they are the initial and exclusive developers and continuous conservers of the candidate variety with the specified denomination. Further, they have to authorize a member on behalf of group/community to do the needful and be the signatory on their behalf for the limited purpose of securing registration of the candidate variety in their favour under the PPV&FR Act. The endorsing official has to certify that the said farmers' variety has been developed and continuously conserved and cultivated only by the applicant farmer or group of farmers or community of farmers and he/she is fully conversant that the candidate variety is due to their efforts.

Once the farmers' variety is granted registration, the farmer or the community of farmers are required to meet the demand for the seed or the propagating material of their variety. They can organize quality seed production by themselves or by licensing the variety to any commercial seed producer. When they fail to meet this demand and if other farmers complain to the Authority, the variety may attract compulsory licensing. Licensing of farmers' variety may be done on the commercial strength of the variety for negotiated considerations and other mutually agreed terms. As long as the farmers are holding the PVP, they alone are responsible to prevent the unauthorized exploitation of their variety by other parties (Bala Ravi, 2004). The annual fee for farmers' varieties shall be Rs. 10/- (http://plantauthority.gov.in/pdf/fee_farmer_gazette.pdf), while there is no renewal fee for farmers' varieties (http://plantauthority.gov.in/pdf/GN-427.PDF).

Farmers' Varieties in Sorghum

Many farmers' varieties are available in sorghum in different states (Table 1), especially where sorghum is grown traditionally for household consumption as well as a forage in dry seasons for the cattle. These cultivars are mostly confined to local pockets and many times the village names preceed the otherwise popular cultivar name. Maldandi is one such very popular cultivar in Maharashtra and Karnataka, which was released in the 1930s, is known by different names depending on the name of region and over the years some variants of original cultivar have been selected by the farmers and started getting known by different names that have vernacular connection with Maldandi. Some of the examples are Magalweda Maldandi, Ankoli Maldandi, Gurang Maldandi, Vadgaon Maldadi, Tongraligaon Maldandi, Chungi Maldandi, Hasapur Maldandi, Jamgaon Maldandi, Yedshi Maldandi, etc. M 35–1 is a selection from the original Maldandi landrace released in the year 1969 (from Agricultural Research Station, Mohol, currently under MPKV, Rahuri), which is still ruling among the post-rainy sorghum farmers because of its wider adaptability and good grain quality. Some of the landraces used for special purposes like hurda preparation in Karnataka are Dudhmogra, Gulbhendi, Sakri-Mukri Jola, Raosaheb, etc. A lot of farmers' varieties or landraces are available in forage sorghum also.

Table 1. Farmers' varieties in sorghum in India

S.No.	Local Name	State
1	Konda Jonna, Pachcha Jonna, Tandur Local	Telangana
2	Mudda Jonna	Andhra Pradesh
3	Annegiri, Hurda Jola, Bidarkundi Chandiki, Nagayi Maldandi, Kuta Aurad Local or Gund Teni, Kadabina Jola, Muddihali Jola, Hattarkihal Local, Dodda Maldandi, Gidda Maldandi, Talikoti Local, Chitapur Local, Yaranal Local, Bhirwadagi Local, Yannigar, Kadakol Local, Dood Mogra, Harini Dagadi, Khatizapur Local, Biligundu, Gundu Jola, Afzalpur Local, Bidar Local	Karnataka
4	Hatikunta, Basmati Jowar	Madhya Pradesh
5	Shalu, Dadar, Barshi Joot, Joot, Lakadi, Solapur Dagadi, Jalna Dagadi Aispuri Local, Hurda, Karad Local, Wani Jowar	Maharashtra
6	Hegari, Rampura Local	Rajasthan
7	Irungu Cholam, Matthappu Cholam, Sevappu Cholam Vella Cholam, Periya Manjal Cholam, China Manjal Cholam, Sencholam, Talaivirichan Cholam, Vellai Cholam, Makkattai	Tamil Nadu
8	Dudhanya	Uttar Pradesh
9	Malwan, Solapuri	Gujarat

Rights of Communities (Section 41)

Any person or group of persons (whether actively engaged in farming or not) or any governmental or nongovernmental organization may, on behalf of any village or local community in India, can file in any centre notified by the Authority, any claim attributable to the contribution of the people of that village or local community, as the case may be, in the evolution of any variety for the purpose of staking a claim on behalf of such village or local community. When any claim is made, the centre may verify the claim in such manner as it deems fit, and if it is satisfied that such village or local community has contributed significantly to the evolution of the variety which has been registered under this Act, it shall report its findings to the Authority. When the authority is satisfied after such inquiry, it may issue notice in the prescribed manner to the breeder of that variety and after providing opportunity to such breeder to file objection in the prescribed manner and of being heard, it may order compensation to be paid to the claimant who has made the claim. The compensation granted shall be deposited by the breeder of the variety in the Gene Fund.

Authorization of Farmers' Variety (Section 43)

Although the rights of the breeder of essentially derived variety (EDV) are same as rights of the breeder of a variety (sub-section (6) of section 23 and section 28), where an EDV is derived from a farmers' variety, the authorization to any person to produce, sell, market or otherwise deal with the variety registered (sub-section (2) of section 28) shall not be given by the breeder of such variety except with the consent of the farmers or group of farmers or community of farmers who have made contribution in the preservation or development of such variety.

National Gene Fund (Section 45)

The Central Government has constituted the National Gene Fund to support the conservation and sustainable use of genetic resources across the country, and also to promote, recognize and reward those farmers who are engaged in the conservation of genetic resources of landraces and wild relatives of economic plants and their improvement through selection and preservation in the agro-biodiversity hotspots. Many a times material so selected and preserved have been used as donor of genes in varieties registered under the Act. The Gene Fund established by the Authority receives the contributions from (a) the benefit sharing received in the prescribed manner from the breeder of a variety or an essentially derived variety registered under the Act, or the propagating material of such variety or essentially derived variety, as the case may be [sub-section (6) of section 26; clause (a) sub-section (1) of section 45]; (b) the annual fee payable to the Authority by way of royalty [sub-section (1) of section 35]; (c) the compensation deposited by the breeder [sub-section (4) of section 41]; (d) the contribution from any national and international organizations and other sources.

The Gene Fund shall be utilized for (section 45) any amount to be paid by way of benefit sharing, the compensation payable to the farmer/community of farmers for use of genetic material towards evolution of new and essentially derived variety, supporting the conservation and sustainable use of genetic resources including *in* *situ* and *ex situ* collections and for strengthening the capability of the Panchayat in carrying out such conservation and sustainable use, and for framing of schemes related to benefit sharing. The Gene Fund shall also be applied to support and reward farmers, community of farmers, particularly the tribal and rural communities engaged in conservation, improvement and preservation of genetic resources of economic plants and their wild relatives, particularly in areas identified as agro-biodiversity hotspots.

Awards and Recognitions to Farmers/Communities

The PPV&FRA has instituted Genome Savior Community Awards and Recognitions to recognize and reward the farmers for their contribution in plant genetic resources conservation and improvement, and making available these for modern crop improvement. These awards are mainly given to communities/farmers engaged in the conservation of genetic resources of landraces and wild relatives of economic plants and their improvement through selection and preservation and the material so selected and preserved has been used as donors of gene in varieties registerable under the PPV&FR Act, 2001. These awards and recognitions are specially aimed at farming community including tribals and farm women residing in the agro-biodiversity hotspot for their contribution to agricultural growth and development related to plant varieties. Other objectives include to stimulate plant variety development by encouraging the conservation and usage of agro-biodiversity, to facilitate the revival and awareness to conserve the agro-biodiversity to have effective plant breeding and development of new varieties in perpetuity, to conserve production or cropping technology that promotes agro-biodiversity like Backyard garden, shift cultivation, coastal marine system, etc., and to promote all kinds of plant based agro-biodiversity conservation activity, related to plant variety development.

Applications for the recognition awards (Appendix II & III) will be invited every year through advertisement in newspapers and mass media all over the country. It is essential for the applicants to forward their application through Chairperson or Secretary of the Concerned Panchayat Biodiversity Management Committee or Concerned District Agricultural Officer or Director of Research of concerned State Agriculture University or concerned District Tribal Development Officer. Applications may be filled either in Hindi or English. There is no application fee and only complete form with supporting document(s) is to be submitted. The proposals should be duly verified by designated authorities as mentioned in the application format. If required, site verification may also be undertaken by the Authority and the decision of the Authority shall be final.

Farmers whose applications are shortlisted for Reward and Recognition shall be required to deposit specified quantity of seeds or propagating material.

The PPV&FRA organizes a public function to honour the recipients every year, and the contributions of the recipients will be published in Plant Variety Journal of India and brought to public attention that would be a valuable recognition and would also discourage the piracy of the farmers' plant material, and making wrong claims of ownership.

Plant Genome Saviour Community Award

The Authority in consultation with Govt. of India instituted the 'Plant Genome Saviour Community Award' starting from the year 2009-10 to recognize the contribution of large number of individual farmers and farming communities who are engaged in agriculture for generations in conserving the agro-biodiversity which many times has even contributed in the development of many improved varieties. The award is open to the farming community/farmers, particularly the tribal and rural farmers engaged in conservation, improvement and preservation of genetic resources of economic plants and their wild relatives particularly in the areas identified as agro-biodiversity hotspots (22 Agro-biodiversity hotspots distributed over 7 agro-geographical zones – Appendix IV). The applicants are required to submit evidences in support of the conservation work done by them, provide seeds/planting material of the conserved varieties, brief proposal for the utilization of the award money in community welfare and also to inform if the material has been utilized by any breeder in developing any other improved varieties, etc. The award, which is given annually, consists of Rs. 10 lakhs in cash, a citation and a memento, with a maximum of five awards per year. The selection of awardee(s) is done by a national level committee.

Plant Genome Savior Recognitions

Before the formal initiation of Plant Genome Savior Community Awards, the Authority as a mark of recognition for the selfless conservation of genetic resources by farmers/farming communities, has awarded 'Plant Genome Savior Community Recognition' certificates to nine farmers/communities during 2007-08 and 2008-09. The Government of India notified the PPV&FR (Recognition and Reward from the Gene Fund) Rules, 2012, whereby a farmer who is engaged in the conservation of genetic resources of landraces and wild relatives of economic plants and their improvement through selection and preservation, and the material so selected and preserved has been used as donors of genes in varieties registerable under the Act, shall be entitled to 'Plant Genome Savior Farmer Reward' and 'Plant Genome Savior Farmer Recognition'. There shall be a maximum of 10 rewards (comprising of citation, memento and cash of Rs. One lakh and fifty thousand) and 20 recognitions (consisting of a citation, memento and cash of Rs. One lakh) in a year.

How to Mobilize Farmers?

The PPV&FRA and the DUS testing centres located across the country are actively engaged in conducting awareness-cum-training programmes among the breeders, farmers and other stakeholders to create awareness on the PPV&FR Act, 2001, Plant Variety Registration, Agrobiodiversity Hotspots, Farmers' Rights and other issues related to the Act. Apart from this, to reach out the farmers and communities in the target areas organizing of farmers' camps, farmers' rallies, constitution of registered farmers' organizations, speading the awareness on benefits of registration, motivation of self-help groups, taking along the NGOs involved in tribal development, etc. are required. Some of the State Agricultural Universities, local community centres and other agencies are already putting the efforts to take advantage of the available legislation. But more needs to be done as early as possible to save the valuable agro-biological wealth available in the country at least in its present form.

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Appendix I

APPLICATION FOR REGISTRATION OF FARMERS' VARIETY UNDER PROTECTION OF PLANT VARIETY AND FARMERS' RIGHTS ACT, 2001.

[See Proviso to sub-section (1) of section 18]

(Instruction to applicant: Wherever a box item appears against queries, please tick the relevant box and provide legibly written/typed response in other queries.)

1. Identity of the Applicant(s):

FARMER ☐

COMMUNITY OF FARMERS ☐

GROUP OF FARMERS ☐

Note: Application for farmers' variety by farmers or community of farmers or group of farmers as contained in the Protection of Plant Varieties and Farmers' Rights Act, 2001 shall be submitted only with an endorsement in Annexure 1 either by the concerned Panchayat Biodiversity Management Committee, or District Agricultural Officer, or Director of Research of concerned State Agricultural University or District Tribal Development Officer.

2. Name(s) of Applicant(s)

[Insert additional rows, if required]

a. Serial Number.

b. Name

c. Complete Address

d. Nationality

3. Name and Address of the Person to whom Correspondence related to this application is to be sent: (Attach authorisation in Form-PV-1, if required)

Name ____

Address ____

____

Pin ____

Telephone: ____

Fax: ____

E-mail: ____

4. General Information of the Variety:

a. Common name of the Crop: ____

b. Botanical name: ____

c. Family: ____

d. Denomination (in block letters): ____

Note: Botanical names mean the scientific name approved by the International Code for Nomenclature of Cultivated Plants, 2004.

5.(a.) Classification of the Candidate Variety:
TYPICAL VARIETY
OTHER (SPECIFY)

Note: Typical variety means a variety, which is not a hybrid or an essentially derived variety and normally propagated by using propagules saved from previous crop production cycles (Example: pure lines including parental lines/composite varieties or vegetative propagated varieties).

6. Names and Addresses of farmer(s) who has/have bred the Candidate Variety:

Name: ____
Address: ____
____
Telephone: ____
Fax: ____
E-mail: ____
Nationality: ____

Note: In case of more than one breeder, mention all names as (ii), (iii) and so on in the above format. If required insert extra page. In the case the variety is evolved and conserved `by group or community of farmers', it shall be endorsed in Annexure I.

7. Has the candidate variety been commercialised or otherwise exploited?
☐Yes No
If yes, please indicate the following:
Date of the first sale of the variety: ___________________________________
Country (ies) where Protection is made (if applicable) ___________________________________
Variation in important trait with Respect to first filing: (attach sheet)
Denomination used ___________________________________
Trademark used, if any: ___________________________________

I/we__________ hereby declare that the genetic material or parental material acquired for breeding, evolving or developing the variety has been lawfully acquired.

(Signature of the Applicant)

Following are the attachments (duly signed/seal) submitted along with of the application (note that wherever signature is affixed in the application or attachments, all such signatures shall be in the original):
(a) complete application ;
(b) endorsement in Annexure 1 in the case of farmers' variety (vide column 1, if applicable);
(c) document of authorisation in Form PV-1 (if applicable) ;

ANNEXURE 1

Endorsement of application for registration of farmers' variety under Protection of Plant Varieties and Farmers' Rights Act, 2001

1. Name(s) of applicant farmer/ Group of farmers/Community of farmers

Serial Number	Name with surname/Name of Group/ Name of Community	Permanent Address

2. Denomination of the variety: ___________________________________

3a. (Applicable to individual farmer applicant)

I hereby declare that I have been a permanent cultivator since last many years in the …………………….village falling under the …………………… local body/Panchayat in the …………………….. District of ………………………… State and that I and my family are the initial and exclusive developers and conservers of the candidate variety denominated as. …………………………, under the kind………………………………. (Common name of crop) to the botanical species ……………………………………

3b. (Applicable to group/community of farmers applicant)

We hereby declare that we have been the permanent cultivators since last many years in the……………………. village(s) falling under the ………………… local body/ Panchayat(s) in the ……………………District(s) of. ……………………………State(s) and that we are the initial and exclusive developers and continuous conservers of the candidate variety denominated as …………………...under the kind ……………………… (Common name of crop) belonging to the botanical species……………………………………… We on behalf of our group/community hereby authorise……………………… s/o………………… (Name), who is a member of our group/community and permanent resident of ……………………………………. (Complete postal address) to do the needful and be the signatory on our behalf for the limited purpose of securing registration of the candidate variety in our favour under Protection of Plant Varieties & Farmers' Rights Act, 2001.

Dated…………………

Place…………………

Signature and Name of the Farmer or

Authorised person of Group/Community

(To be signed before the endorsing official)

It is hereby certified that the above said candidate variety is bred / developed and continuously conserved and cultivated only by the applicant farmer / group of farmers / community of farmers who is / are permanent residents of above said village(s) and I am fully conversant with the applicant farmer / group or community of farmers and that the candidate variety is due to their efforts (strike out unwanted words given as options).

Signature
Name
Date…………
Place………..

(Chairperson / Secretary of the Concerned
Panchayat, Biodiversity Management
Committee OR Concerned District
Agricultural Officer OR Director of
Research concerned State Agricultural
Universities OR Concerned District Tribal
Development Office.
(With Official Rubber Stamp)"

[F.No.]

Appendix II

Protection of Plant Varieties & Farmers' Rights Authority
NASC Complex, DPS Marg, Opp. Todapur Village
New Delhi 110 012

Annexure-I

APPLICATION FORM FOR THE 'PLANT GENOME SAVIOR COMMUNITY AWARD'FOR FARMING COMMUNITIES ENGAGED IN CONSERVATION OF GENETIC RESOURCES OF ECONOMIC PLANTS AND WILD RELATIVES OF ECONOMIC PLANTS AND THEIR IMPROVEMENT THROUGH SELECTION AND PRESERVATION PARTICULARLY IN AREAS IDENTIFIED AS AGRO-BIODIVERSITY HOTSPOTS (AS PER SECTION 45 OF THE PPV&FR Act, 2001 AND SECTION 70(2)(a) OF THE PPV&FR RULES, 2003)

Year ____________

1.	Name of the Applicant/ Community (ALL CAPITALS)	
2.	Postal address (for correspondence) Block Village P.O. District State Pin Tel. (if any)	
3.	Status of applicant (Community/Farming Community Based Organization)	
4.	Agro-biodiversity hotspot area to which the community/applicant belongs? (please refer the list)	
5.	Location(s) of the conservation site(s)	
6.	Plants/Crop(s) in which conservation efforts had been made.	
7.	How many varieties (including farmers' varieties, economic plants, wild relatives and other genetic resources) had been conserved? (give details plant/crop wise)	
8.	How much area is being planted/ cultivated by the applicant with the	

	conserved varieties? (give details)	
9.	Whether any innovative methods of conservation like cultural practices, storage techniques etc developed/ adopted? (give details)	
10.	Give information (if available) about the varieties that were shared with others.	
11.	What is the distinct trait identified in the conserved variety/ varieties? (Give details on variety basis)	
12.	Name of the organization, if any, that identified any useful trait in the conserved varieties.	
13.	Has the variety(ies) been entered in the Peoples' Biodiversity Register maintained by Biodiversity Management Committee	YES/NO
14.	Whether the farming community rewarded or recognized for the conservation efforts by any other organization? (give details)	
15.	Name the agencies (governmental or NGO's) conversant with the claims made	i. Governmental: ii. NGO :
16.	Give a brief outline of the proposed work plan for utilization of the Award Money*. (in 15-20 lines)	

Note:

1. Please sign each page of the Application Form.
2. There is no application fee for the farming community.
3. For details/information in any column, extra pages can be attached as Annexure.
4. Any clarifications can be sought from the officials of PPV&FRA.

Annexure-II

PROTECTION OF PLANT VARIETIES & FARMERS' RIGHTS AUTHORITY
MINISTRY OF AGRICULTURE, GOVT. OF INDIA
S-2, 'A' BLOCK, NASC COMPLEX, DPS MARG, OPP. TODAPUR
NEW DELHI-110012
Tel: 011-25848127, 011-25842846, Fax: 011-25840478, E-mail: ppvfra-agri@nic.in

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(DECLARATION)

(To be attach as an informal consent from the community /organization/ registered society who represents the society that conserved, improved, preserved and shared the resource.)

Name and address/telephone no. /e-mail of the person with whom the Registrar, PPV&FRA can correspond with:

Name (Block Letter) ____
Agro biodiversity hotspot number (as per list) ________________________________
Postal address (Block Letter) ____
Block ____
Village ____
P.O. ____
District ____
State ____
Pin ____
Tel. (if any) ____
E-Mail ____
Telephone_______________________________

It is certified that the above said genetic resource(s) was/were/is being conserved, improved, preserved and cultivated by the applicants/community of farmers who are permanent residents of above said village(s) and I am/we are fully conversant with the applicant farmers/group or community of farmer and the candidate variety/varieties. The information give in the application is true to the best of my knowledge, Information and belief. (strike out the non-applicable words givesn as option.)

Signature

(Representative(s) of the Farming Community)

Verified by a Gazetted official/Panchayat/Registered Organization
(Chairperson/Secretary of the Concerned Panchayat Biodiversity Management Committee or Concerned District Agricultural Officer of Director of Research of concerned SAU or Concerned district Tribal Development Officer)

(Seal, Sign with date)

Appendix III

APPLICATION FORM FOR THE 'PLANT GENOME SAVIOR FARMER REWARD/ RECOGNITION'

Annexure-I

Protection of Plant Varieties & Farmers' Rights Authority
NASC Complex, DPS Marg, Opp. Todapur Village
New Delhi 110 012

APPLICATION FORM FOR PLANT GENOME SAVIOUR FARMER REWARD/ RECOGNITION FOR A FARMER WHO IS ENGAGED IN CONSERVATION OF GENETIC RESOURCES OF LAND RACES AND WILD RELATIVES OF ECONOMIC PLANTS AND THEIR IMPROVEMENT THROUGH SELECTION AND PRESERVATION AND THAT THE MATERIAL SO SELECTED AND PRESERVED HAS BEEN USED AS DONORS OF GENES IN VARIETIES REGISTRABLE UNDER PPV&FR ACT, 2001 (SECTION 39(1)(III) OF THE PROTECTION OF PLANT VARIETIES AND FARMERS' RIGHT ACT, 2001)

Year ___________

1.	Name of the Applicant (ALL CAPITALS)	
2.	Postal address (for correspondence) Block Village P.O. District State Pin Tel. (if any) E-mail Fax Mob.	
3.	Location(s) of the conservation site(s)	
4.	Plants and varieties in which conservation efforts had been made.	
5.	Whether the material so selected and preserved has been used as donors of genes in varieties registrable under Protection of Plant Varieties & Farmers' Rights Authority Act, 2001. (Certificate from the concerned institution to be attached)	
6.	How many varieties (including farmers' varieties, land	

	races, wild relatives and other genetic resources) had been conserved? (give details plant/crop wise)	
7.	How much area is being planted/ cultivated by the applicant with the conserved varieties? (give details)	
8.	Whether any innovative methods of conservation like cultural practices, storage techniques etc developed/ adopted? (give details)	
9.	Give information about the varieties that were developed with conserved variety.	
10.	What is the distinct trait identified in the conserved variety/varieties.	
11.	Name of the organization, if any that identified any useful trait in the conserved varieties.	
12.	Whether the Farmer rewarded or recognized for the conservation efforts by any other organization? (give details)	
13.	Name the agencies (governmental or Non Government Organizations) conversant with the claims made	i. Governmental: ii. Non Government Organizations)
14.	Whether the material finds it place in People's Biodiversity Register	

Note:

1. Please sign each page of the Application Form.
2. There is no application fee.
3. For details/information in any column, extra pages can be attached as Annexure.
4. Any clarification can be sought from the officials of PPV&FRA.
5. Declaration to be attached.

Annexure-II

PROTECTION OF PLANT VARIETIES & FARMERS' RIGHTS AUTHORITY
MINISTRY OF AGRICULTURE, GOVT. OF INDIA
S-2, 'A' BLOCK, NASC COMPLEX, DPS MARG, OPP. TODAPUR
NEW DELHI-110012
Tel: 011-25848127, 011-25842846, Fax: 011-25840478, E-mail: *ppvfra-agri@nic.in*

(DECLARATION)

Name and address / telephone no. / e-mail of the person with whom the Registrar, PPV&FRA can correspond with:

Name (Block Letters) ____
Postal Address (for correspondence) ________________________________
Block __________________________
Village ___________________________
P.O. _______________________________
District ______________________________
State ______________________________
Pin _____________________________
Tel. (if any) ____________________

The information given in the application is true to the best of my knowledge, information and belief.

Signature of the Applicant

It is hereby certified that the farmer named in this application has conserved and improved the material mentioned in this application form and the said material has been used as donor of genes in varieties registrable under PPV&FR Act, 2001.

(To be certified by Chairperson/Secretary of the Concerned Panchayat Biodiversity Management Committee or Concerned District Agricultural Officer or Director of Research of concerned SAU or concerned District Tribal Development Officer)

Appendix IV
Annexure-3

Agro-biodiversity Hotspots of India

S.No.	Hotspot Region	Areas Covered
1.	Cold Desert	Western Himalyas covering Ladakh and Kargil. Upper reaches of Lahual-Spiti districts of Himachal Pradesh.
2.	Western Himalayan	Districts of Srinagar, Anantnag, Udhamput, Riasi, Kathna in Jammu & Kashmir, all the districts of Himachal Pradesh except the cold arid region and all the districts of Uttarakhand.
3.	Eastern Himalayan	All the districts of Arunachal Pradesh, Sikkim and Darjeeling district of West Bengal.
4.	Brahmaputra Valley	Dhubri, Kokrajhar, Bongaigaon, Barpeta, Nalbari, Goalpara, Kamrup, Golaghat, Darrang, Morigaon, Nagaon, Sonitpur, Jorhat, Lakhimpur, Sibsagar, Dibrugarh, Dhemaji and Tinsukia.
5.	Khasia-Jaintia-Garo Hills	All the seven districts of Meghalaya, i.e. East Garo Hills, West Garo Hills, South Garo Hills, East Khasi Hills, West Khasi Hills, Jaintia Hills and Ri-Bhoi.
6.	North-Eastern Hills	All the districts of Manipur, Mizoram, Nagaland, Tripura and the adjoining Cachar and North Cachar districts of Asom.
7.	Arid Western	Sikar, Nagaur,Pali, Hanumangarh, Ganganagar, Jalore, Sirohi, Jodhpur, parts of Jaisalmer and Bikaner, Udaipur, Dungarpur, Churu, and Jhunjhunun districts of Rajastahan.
8.	Malwa Plateau and Central Highlands	Malwa plateau, Central highlands, the Mewar plateau and semi- arid south-eastern Rajasthan. Shadol, Raisen, Bhopal, Sehore, Shajapur, Indore, Ujjain, Mandasaur, Rajgarh Hoshangabad, Narsinghpur, Jabalpur, Mandla, Umaria districts.
9.	Kathiawar	Ahemadabad, Surendranagar, Jamnagar, Rajkot, Porbandar, Junagadh, Amreli, Bhavnagar, Bharuch, Surat, Navsari, Valsad, Banaskantha and Anand districts of Gujarat.
10.	Bundelkhand	Districtsof Jhansi, Banda, Chitrakoot, Hamirpur, Jalaun and Lalitpur in Uttar Pradesh and Damoha,Datia, Panna, Sagar, Tikamagarh and Chattarpur in Madhya Pradesh.
11.	Upper Gangetic Plains	Districts of Hardoi, Sitapur, Barabanki, Lucknow, Unnao, Rae Bareilly, Kanpur, Kannuj of Central Uttar Pradesh and the districts of Maharajganj, Sidharatnagar, Kushinagar, Deoria, Sant Kabir Nagar, Gorakhpur, Bast of North-eastern Uttar Pradesh.
12.	Lower Gangetic Plains	Districts of Paschim Champaran, Purbi Champaran, Gopalganj, Siwan, Sitamarhi, Muzaffarpur, Saran, Buxar, Bhojpur, Patna, Rohatas, Jahanabad, Vaishali, Samastipur, Darbangha, Madhubani, Sheohar in North Bihar.
13.	Gangetic Delta	Broadly includes the deltaic 24-Parganas districts, and the districts of Hoogly, Howrah, Nadia, Bardhaman, Birbhum and Murshidabad.
14.	Chotanagpur	Districts of Singhbhum, Gumla, Ranchi, Lohardaga, Palamau and Hazaribagh and Santhal Pargana in Jharkhand and Mayurbianj district in Orissa.

S.No.	Hotspot Region	Areas Covered
15.	**Bastar**	Districts of Bastar, Bilaspur, Durg, Jashpur, Kabirdham, Kanker, Kirba, Koria, Mahasamund, Kondaigaon, and Rajnangoan of Chattisgarh.
16.	**Koraput**	Districts of Malkangiri, Sonabeda, Jeypore, Koraput, Nabrangpur, Kalahandi, Bolangir, Rayagada of Orissa and districts of north eastern Andhra Pradesh i.e.Srikakulam, Vijanagaram and Vizagapatnam.
17.	**Southern Eastern Ghats**	Districts of Chittoor, Ananthapur, Cuddapah and Kurnool in Andhra Pradesh and districts of Bellary, Raichur and Kolar in Karnataka.
18.	**Kaveri**	Districts of Chengalput, South Arcot, North Arcot, Thiruvannamalai, Tiruchirapalli, Pudukottai, Thiruarur, Vellore, Kanchipuram, Dharmapuri, Salem, Namakkal, Karur and Dindigal.
19.	**Deccan**	Districts of Jalna, Hingoli, Parbhani, Beed, Nanded, Latur, Osmanabad, Solapur, Sangli, Gondia, Gadchiroli in Maharash-sa, districts of Adilabad, Karimnagar, Warangal and Khamman in Andhra Pradesh and districts of Bidar and Gulbarga in Karnataka.
20.	**Konkan**	Coastal districts of Thane, Raigad, Ratnagiri, Sindhudurg and part of Sahyadri districts of Pune, Satara and Kolhapur of Maharashtra, all the districts of Goa and Uttar Kannda district of Karnataka.
21.	**Malabar**	Districts of Kasargod, Kannur, Wayanad, Kozikode, Malappuram, Palakkad, Thrissur, ldukki, Ernakulam, Alappuza, Kollam, Kottayam, Pathanamthitta & Thiruvananthpuram in Kerala, Udhagamandalam (Nilgiri) and Kanyakumari districts of Tamil Nadu and districts of Dakshin Kannada, Kodagu and Udipi in Karnataka.
22.	**Islands**	Andaman and Nicobar Islands and Lakshadweep

24.Sorghum production technology transfer and its impact

Rajendra R Chapke
Principal Scientist, Indian Institute of Millets Research, Hyderabad

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)

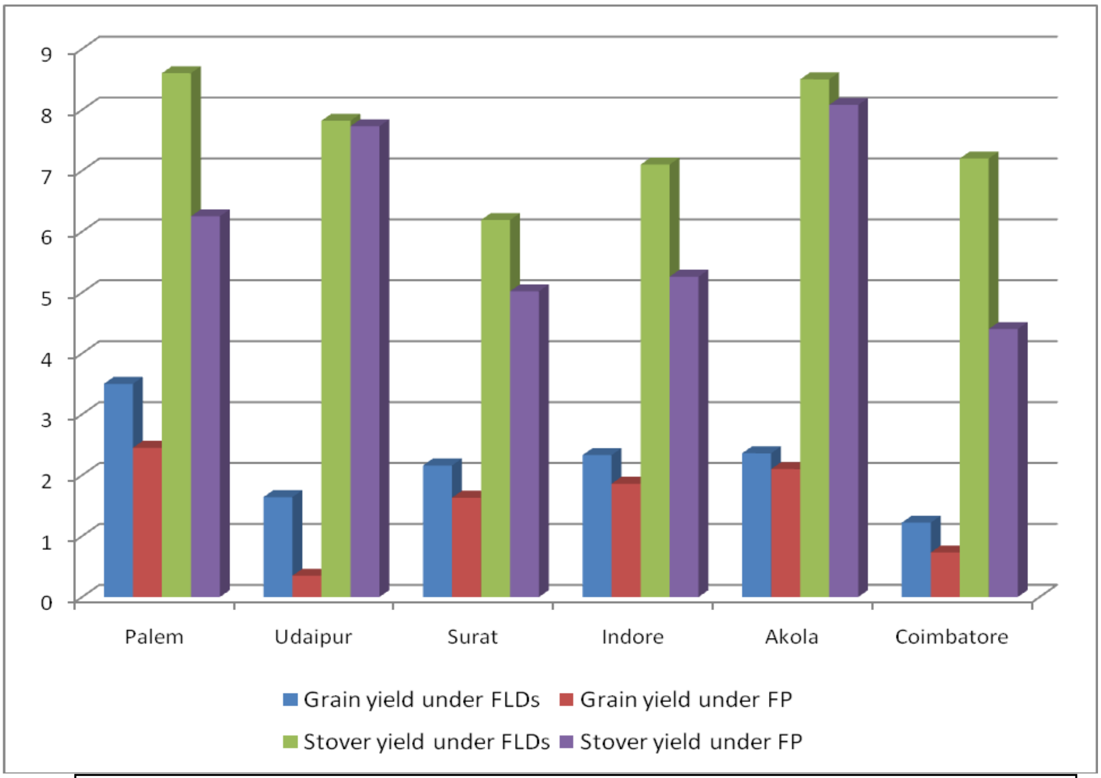

Fig. 1 Performance of kharif FLD cultivars over local check (t /ha)

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

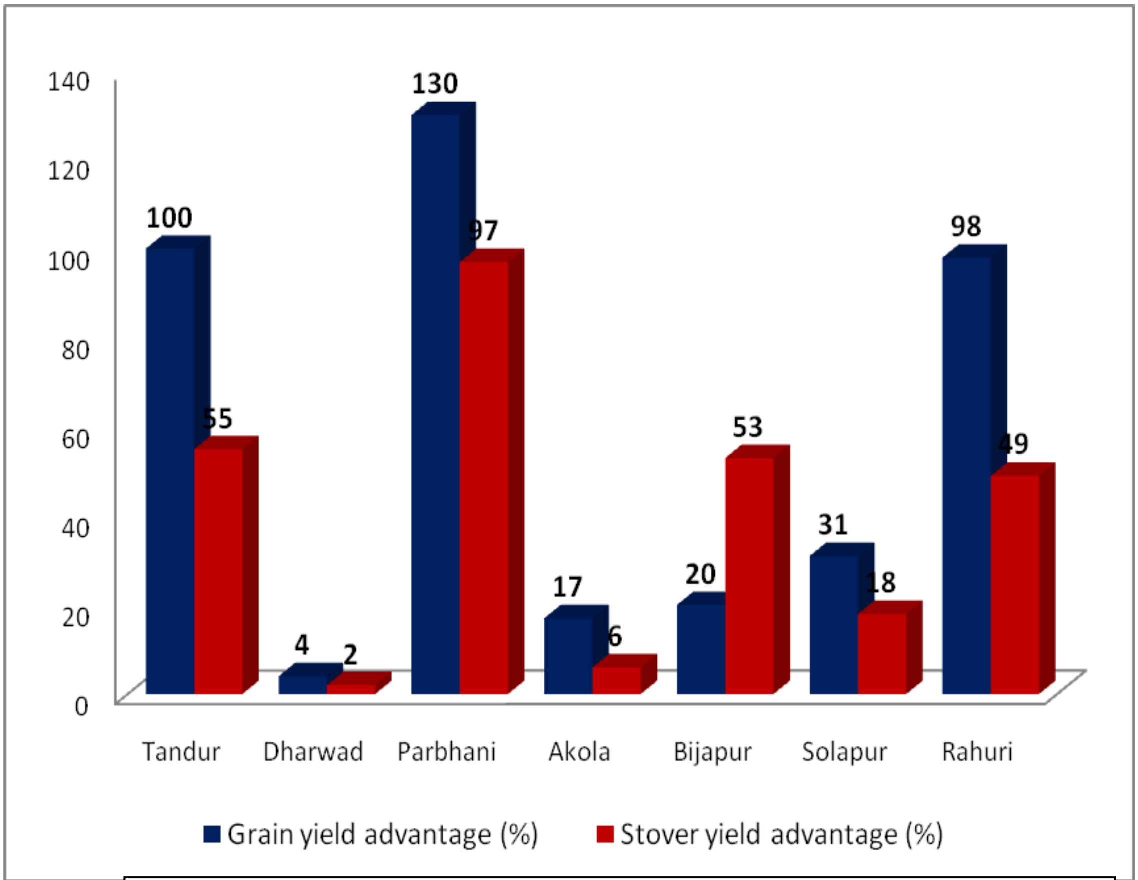

Fig. 2 Yield advantage of rabi FLD varieties over local check (%)

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.