Sweet Sorghum Crop Production and Management Practices

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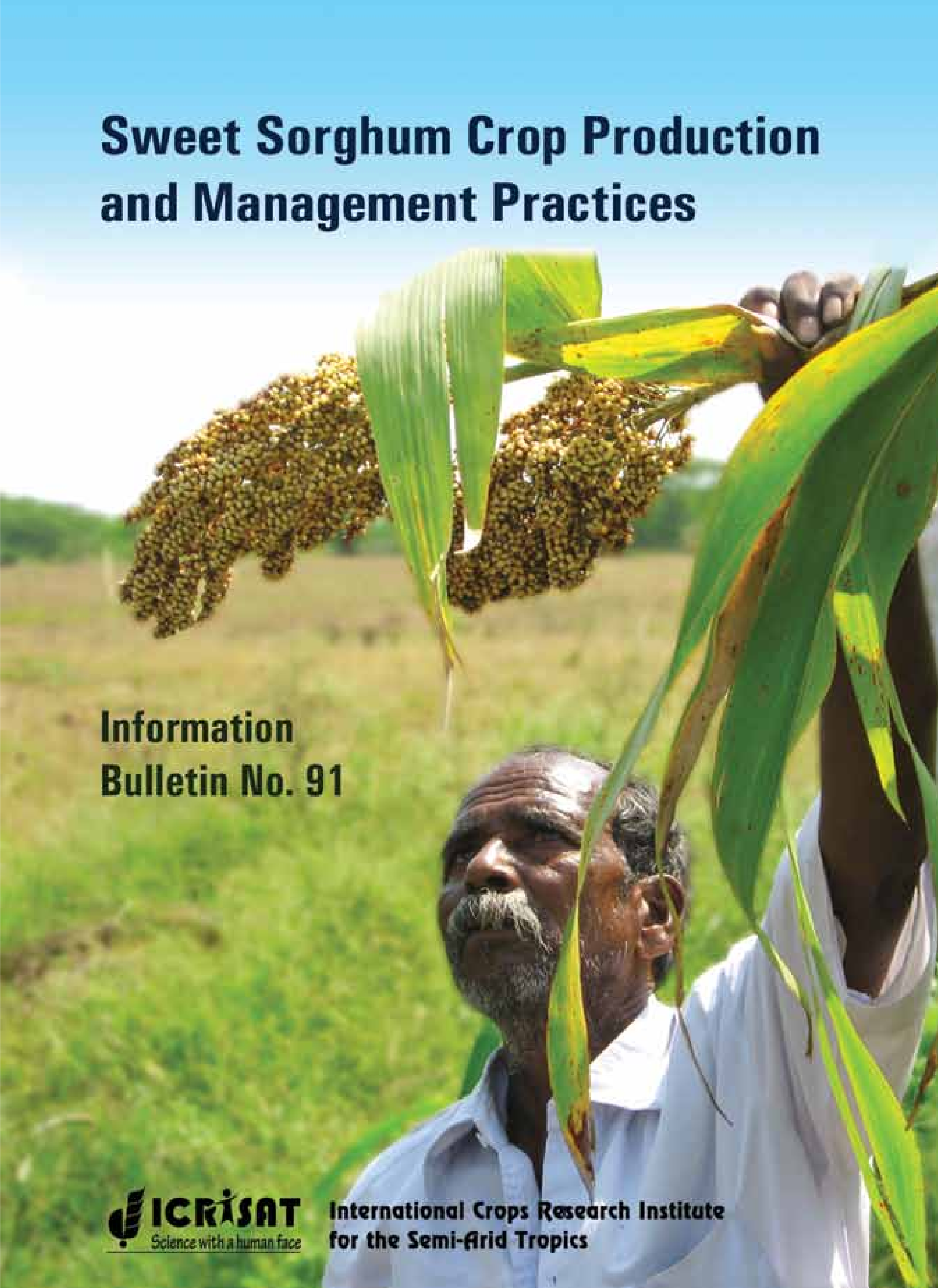

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Contents

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I. Sweet Sorghum Importance and Improved Cultivars

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is an important dryland cereal grown in India (7.8 m ha) and around the world (45.8 m ha) for food, feed, fodder, bioenergy and fiber. Sweet sorghums are similar to grain sorghum and are generally tall (3.0-4.0m), late maturing and relatively photoperiod sensitive. They produce a good grain yield with high stalk yields (70-75% of fresh biomass).

Sweet sorghum is a new generation bioenergy crop that has potential to accumulate sugars (10-15%) in its stalk similar to sugarcane, apart from producing grain. The bagasse (left over stalk after extraction of juice) can be used as animal feed or vermi-composting or can be used to generate power. The crop has the ability to adapt to various agroclimatic conditions and is reasonably tolerant to drought and saline-alkaline conditions. The crop is raised from seeds and is of short duration (115-120 days, ie, 4 months vs. 12-18 months of sugarcane) making it amenable for multiple cropping systems. Water use or seasonal evapotranspiration for sorghum is 508 mm while it is 1257 mm for sugarcane. Water requirement of this crop is one-third that of sugarcane on a comparable time scale. Also, sweet sorghum requires about 22% less water than maize. With these advantages, sweet sorghum is a good bioenergy crop and complements well the available feed stocks for biofuel production.

To use sweet sorghum as a biofuel feedstock, it is important to choose appropriate cultivars and follow improved crop management practices that will result in higher yields. The distillery/industry should develop a command area for regular and uninterrupted supply of feedstock to industry, as sweet sorghum commercial cultivation is yet to pickup speed in India and other countries. If a new cultivar is to be introduced or grown in large area in the command area of the distillery or industry, initial experiments must be conducted in different locations and estimated for both stalk and ethanol yields on a pilot scale basis. Adoption of good crop and soil management practices is important to get maximum production and make the system sustainable in the long run. This publication describes the cultivars and good cultural practices that need to be followed to raise a successful crop in farmer fields.

Fig 1. Sweet sorghum variety CSH 22SS grown on farmer's field in Medak distict of Andhra Pradesh, India.

Improved sweet sorghum cultivars developed in recent years

ICRISAT and Indian national agricultural research systems (NARS) are actively pursuing the improvement of sweet sorghum. Over the years cultivars SSV 84, CSH22SS and RSSV 9 have been released in India, and several new varieties and hybrids are ready for release. Some of the released cultivars and important lines ready for commercial cultivation are described below.

1. **ICSV 93046:** A sweet stalk variety developed at ICRISAT-Patancheru that stood first in the All India Coordinated Sorghum Improvement Project (AICSIP) multilocation trials during 2005-07. It is derived by pedigree selection from a cross of ICSV 700 × ICSV 708. It is suitable for cultivation in both rainy and postrainy seasons. It has a tan plant color, thick and juicy stems with 13% sugar. It matures in 125 to 135 days and grows to a height of 3.0 to 3.2 m producing a millable cane yield of 40 to 50 t ha^{-1}, juice yield of 20-25 Kl ha^{-1} and has a Brix of 16-17%. It gives a grain yield of 2.5 to 3.0 t ha^{-1} and a fodder yield of 10.0 to 11.0 t ha^{-1}. The variety is tolerant to shoot fly, stem borer, and leaf diseases. It ratoons well and has a stay green trait (in stems and leaves even after physiological maturity).

2. **ICSV 25274:** A sweet sorghum variety developed at ICRISAT that stood first in the AICSIP multilocation trials during 2008-09. It is derived by pedigree selection from a cross between DSV 4 and SSV 84. This variety can be cultivated in both rainy and postrainy seasons. It flowers in 85 days, grows to a height of 3.0-3.5m and has a Brix of 18%. It gives a sugar yield of 3.5 t ha^{-1} apart from a grain yield of 3.0 t ha^{-1}. It is tolerant to downy mildew.

3. **RSSV 9:** A sweet sorghum variety developed at MPKV, Rahuri. This variety is recommended for cultivation in both rainy and postrainy seasons. The variety flowers in 82 days, grows to a height of 3.0 m and has a Brix of 18%. It gives a sugar yield of 3.5 t ha^{-1} apart from a grain yield of 3.0 t ha^{-1}.

4. **ICSV 700:** A sweet sorghum variety developed at ICRISAT that performed very well in the Philippines. The variety flowers in 80-85 days, grows to a height of 3.0-3.5m and has a Brix of 17-19%. It gives a sugar yield of 3.5-4.0 t ha^{-1} apart from a grain yield of 3.0 t ha^{-1}. It is tolerant to anthracnose and downy mildew.

5. **CSH 22SS:** A sweet stalked hybrid developed at Directorate of sweet sorghum Research (DSR), Rajendranagar, Andhra Pradesh, India, and released for commercial cultivation in India in 2005. It is derived from a cross between ICSA 38 and SSV 84. The male-sterile line was developed at ICRISAT-Patancheru, while the male parent is the first sweet sorghum variety released in India. This hybrid is recommended for cultivation in both rainy and postrainy seasons. It matures in 125 to 130 days and grows to a height of 3.0 to 3.2 m. It produces a grain yield of 2.5 to 3.0 t ha^{-1}, millable cane yield of 35 to 40 t ha^{-1} and juice yield of 15-20 Kl ha^{-1}. Jaggery prepared from CSH 22SS has confectionery taste.

6. **ICSSH 39:** A sweet stalked hybrid developed from a cross between ICSA 702 and SSV 74 at ICRISAT. This hybrid is recommended for rainy season cultivation. It has a tan plant color with thick and juicy stems. It flowers in 76 days and reaches a height of 3.5 m in the rainy season. It produces a millable cane yield of 45 t ha^{-1}, juice yield of 20.2 Kl ha^{-1}, Brix of 15% and a sugar yield of 3.1 t ha^{-1}

7. **ICSSH 58:** A sweet stalked hybrid developed from a cross between ICSA 731 and ICSV 93046. It has a tan plant color with thick and juicy stems. It flowers in 80 days and reaches a height of 3.2-3.4m in the rainy season. It produces a millable cane yield of 45-50 t ha-1, juice yield of 22-25 Kl ha-1, Brix of 16% and a sugar yield of 4.0 t ha-1.

In addition to the cultivars developed by public sector institutions, the cultivars developed by private seed companies like sugargrace, JK Recova, Urja are also under commercial cultivation in India.

II. Crop Production and Management

Adaptation and growing conditions: Sweet sorghum is a warm-season crop that matures earlier under high temperatures and short days. It tolerates drought and high-temperature stress better than many crops. Rainfall of 500 – 600 mm distributed ideally across the growing period is the best irrigation for the crop, unless the soil can hold much water. The crop does not respond well to high rainfall as high soil moisture or continuous heavy rain after flowering may hamper sugar content. Air temperatures suitable for its growth vary between 15 and 37^{0}C. Sorghum, being a C_4 tropical grass, is adapted to latitudes ranging from 40^{0}N to 40^{0}S of the equator.

Rationale for development of improved cultural practices:

The major constraints in sweet sorghum ethanol production include non-availability of sufficient feedstock to the industry during the crushing period. In order to meet the industry demand, raw materials (stalks) need to be available for a long period, so there is a need to develop and evaluate sweet sorghum cultivars that are insensitive to photoperiod and temperature with high stalk and sugar yields. Hence, evaluation of sweet sorghum under staggered planting in different seasons is urgently needed to meet the continuous supply of feedstock to the distillery.

a. Land preparation:

For a rainy season crop, with onset of rains in May-June, the field should be ploughed once or twice to obtain a good tilth. Harrowing of soil should invariably be followed after each ploughing to reduce the clod size. After the initial ploughing, the subsequent ploughings and harrowings are carried out when the moisture content of the clods are reduced. Field preparation depends on the system of sorghum sowing. The Tropicultor has provision for attachment of different implements to a tool bar for operations such as ploughing, cultivator and blade harrow operation. The required implement can be attached for the required operation.

Three systems of sorghum sowing are generally followed:

1. Sowing on a flat surface, or
2. Using ridge-and-furrow system, or
3. On a broad bed and furrow system

The broad bed and furrow (BBF) is highly suitable for Vertisols, whereas flat sowing followed by opening of furrows in every/alternate row by a ridger at inter-cultivation 20 days after sowing (DAS) is effective for Alfisol or lateritic soils under rainfed situations. Conservation furrows along with contour sowing is also suitable.

- If sowing is done on a flat surface, the land should be leveled after final ploughing using bullock-drawn or tractor-drawn levelers (Fig 2).
- Ridge and furrow (Fig 4) is effective under irrigated conditions. In the ridge and furrow system, ridges are made using either tractor drawn or animal drawn ridge ploughs at 60-75 cm spacing (Fig 3, 5 and 6).

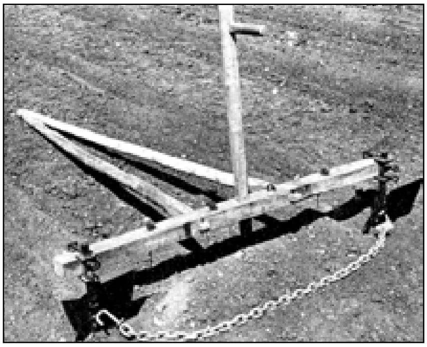


Fig 2. Chain attached to a wooden frame of a plough to level the land.

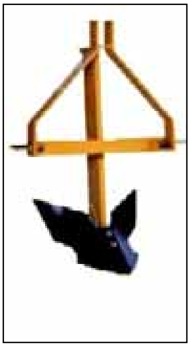


Fig 3. Tractor drawn Ridger.

Fig 4. Ridge and Furrows.

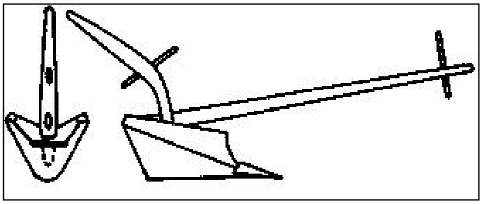


Fig 5. Animal drawn wooden ridge plough.

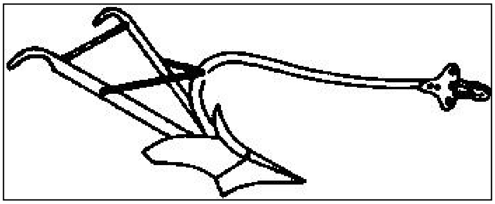


Fig 6. Animal drawn iron ridge plough.

Tropicultor – multi-tool carrier for rain fed systems:

A Tropicultor is a bullock drawn multi-tool carrier with multiple implement attachments. It has a provision for attachment of different implements to a tool bar with a simple flexible U-clamp system and a handle for lowering and raising the implements for all field operations with bullock or tractor power. Field operations such as ploughing and cultivator and blade harrow operation, are done by attaching the required implements. Broad beds and furrows are made with the help of a Tropicultor by attaching 2 ridgers 150 cm apart with a heavy chain attachment between and behind the ridgers that is dragged to form an approximately 100 cm wide bed and 50 cm furrow continuously after one key line with the required gradient. The furrows are exclusively for the traffic zone where bullocks and wheels of the Tropicultor will move, and from where all field operations like sowing, fertilizer application at required depth, and row spacing with optimum population and required fertilizer rate will take place. Inter-cultivation can be done with different sizes of duck-foot shoes (depending on crop row spacing) attached to the tool bar for inter-row tilling and ridgers without wings, to shape the furrow.

- The Tropicultor covers 2 ha/day whereas it ploughs 1 ha for BBF formation and tilling with left and right ploughs
- Reduces cost for planting, fertilizer application and seed covering by 50% and labor cost by 40% for weeding
- Sorghum or pearl millet (2 row) with pigeonpea (1 row) intercrop is possible with a Tropicultor.
- It facilitates placing of seed and fertilizer at the required depth in the moisture zone for good crop establishment

Fig 7. Implements set of Tropicultor.

Fig 8. Land preparation & BBF formation with Tropicultor.

- Provides for lower operational cost for sowing and inter-culture operations and higher income with increased crop yields compared to other machines. The operations are very efficient, economical and time-saving, and the operator can perform all field operations while sitting on the Tropicultor (Fig 9).

b. Planting time and method:

Sweet sorghum can be grown during the rainy season (*kharif*), postrainy season (*rabi*) and the summer season depending upon the availability of soil moisture / irrigation sources and with suitable temperature regimes.

Fig 9. Sweet Sorghum at various growth stages raised on Broad Bed & Furrow (BBF) system of farming.

Fig 10. Sorghum-pigeonpea crop planted with Tropicultor.

***Rainy season* crop (June–October):** Sowing should be done immediately after the onset of the monsoon, preferably from the first week of June to the first week of July, (depending on the onset of monsoon). Sow the seeds (two to three) in a furrow opened by the bullock-drawn plough or a locally available implement. In the ridges and furrow method, planting is done on the top or side of the ridge at a depth of 5 cm and at a distance of 10-15 cm by planter (as hand sowing is a laborious, time consuming and costly exercise). In this method, the rainwater is conserved in the furrow and avoids water logging. Make sure that the soil is fully charged with rainwater or irrigation at least in the top 15 cm (plough layer) to ensure good and uniform germination and seedling emergence.

***Rabi* crop (October–February):** Planting should be done from last week of September to the end of October. The night temperature should be above 15^{O}C at the time of sowing. Irrigate the crop if there is no rainfall at the time of sowing to ensure uniform germination and establishment. The ridges and furrow method of planting should be followed to conserve irrigation water similar to rainy season (*kharif)* crop.

Summer crop: Planting is done from mid-January to the end of February under supplemental irrigated conditions. The night temperatures should be above 15^{O}C at the time of sowing. Summer planting on ridges and furrow will help to realize excellent cane yield provided irrigation water is available.

Sowing

Fig 11. Bullock drawn Tropicultor – Fertilizer-cum-seed drill.

- Deep black soil (Vertisol) or deep red loamy soil (Alfisol) with a soil depth of ^{3} 1.0 m is preferred.
- Seed rate 8-10 kg ha^{-1}
- Treat the seed with Carbendazim or Thiram @ 2g per kg of seeds and with Azospirillum @ 600 g per 10 kg of seeds
- Spacing: 45-60 cm distance between rows, and 12-15 cm distance between plants
- Two to three seeds are dibbled in each hill/planting hole and the seedlings are to be eventually thinned to one per hill.
- If a planter is used, then the existing seed rate will be reduced to 8 kg
- Pre-monsoon sowing or dry sowing of sweet sorghum is effective for improving rainfall use efficiency, as the crop takes advantage of the early monsoon without considerable effect on germination
- Sow in June for rainy season; sow in October for postrainy season. However, sowing should be avoided during cold months. For a summer irrigated crop, sowing during February is feasible
- Delayed sowing of sweet sorghum beyond 5 July makes the crop susceptible to shoot fly damage
- Crop rotation with legumes is necessary for sustainability of yields on long a term basis.
- Sweet sorghum/pigeonpea (2:1) intercropping is also viable inVertisols.
- Dry sowing cum fertilizer application with Tropicultor
- Planting on light shallow soils should be avoided.
- The ideal pH range is 5.0-8.5

Thinning:

1) First thinning is to be done at 12-15 days after planting (DAP) to retain two seedlings per hill at 15 cm apart.

2) Second (final) thinning should be done at 20-25 DAP to retain a single plant per hill. Thinning is very essential for uniform stand establishment and growth of plants. If this is not done, very thin stalks of uneven size are produced leading to crop lodging and low yields. Lack of crop uniformity will also pose a problem when deciding time to harvest.

De-tillering: Remove the basal tillers manually that occur from the base of the plant, if they occur within 20-25 days from planting. Tillers are produced mainly due to planting in late *rabi* (Oct-Dec) coupled with low temperature during the early vegetative stage, as well as due to shoot fly attack.

Plant population:

A good crop may have about 1,20,000 to 1,40,000 plants ha^{-1} (40000 to 48000 plants/acre). Maintain a minimum of about 10 plants per m^2. Cultivating sweet sorghum with a higher plant population than recommended will result in thin stalks that may lodge due to heavy winds, or rains, or both.

c. Nutrient management:

- It is necessary applying nutrients based on results of soil testing
- Application of 90 kg N is recommended for sweet sorghum along with 40 kg P_2O_5. In lateritic soil, application of K is also necessary at 40 kg K_2O
- ICRISAT realized widespread deficiency of S, Zn and B in the soils and application of 200 kg Gypsum (calcium carbonate), 50 kg Zinc sulfate and 1.25 kg of *Agribor* or 5 kg Borax (Boron) per hectare is recommended as a treatment once in three years to correct the deficiencies in the soil
- Half of total N, entire P and K should be applied as basal dressing and the remaining N should be applied at 30 DAS.
- Micronutrients and secondary nutrient should be applied as basal dressing.

Table 1: Comparison of mean grain and stalk yield of sweet sorghum under improved management (IP) and farmers practices (FP).				
Year	**Grain Yield (q ha^{-1})***		**Stalk Yield (t ha^{-1})**	
	IP	**FP**	**IP**	**FP**
ON-STATION TRIALS				
2008	11.8 (8.62-14.09)	9.6 (7.5-12.7)	26.4 (18.84-31.89)	19.62 (15.6-22.4)
2009	24.2 (17.41-27.83)		52.7 (40.5-61.3)	
2010	22.39 (15.94-28.96)		33.58 (23.9-43.4)	
ON-FARM TRIALS				
2009	11.8 (9.2-14.7)	8.7 (4.8-11.1)	28.4 (21.1-35.8)	19.62 (15.6-22.4)
2010	11.5 (5.9-16)		37.7 (29.8-47.1)	
2011	18.5 (10.8-23.5)		48.6 (39.7-57.6)	

*1 q (quintal) = 100kg

d. Weed management and Intercultivation:

- Weed management is critical in sweet sorghum cultivation
- Intercultivation with blade harrow or cultivator or Tropicultor (Fig 12) once or twice between 25 and 35 days after sowing, should be followed by hand weeding.

Fig 12. Intercultural operation with Tropicultor.

- The second interculture is to be followed by earthing-up of crop rows with bullock or tractor drawn implements to prevent lodging especially after flowering
- Selective pre-emergence herbicide Atrazine @ 0.2 kg a.i ha^{-1}or Atrataf R @ 1 kg ha^{-1} should be applied.

e. Irrigation / Rainwater Management:

Rainy season

Normally the crop raised under rainfed conditions in areas receiving rainfall of 550-800 mm does not require additional irrigation if the distribution of

rains, both in time and space, is adequate during the crop period. In case of late onset of the monsoon, plant the crop and irrigate immediately. Also, irrigate the crop if a dry spell continues for more than two weeks, especially at critical crop growth stages such as panicle initiation (35-40 DAS) and boot stages (55-65 DAS). Maintain soil moisture profile at or near field capacity. Always drain out the excess irrigation water or rainfall from the fields to avoid water-logging. By and large, 2-3 irrigations may be required for a *kharif* crop depending on the planting time, soil type and rainfall distribution at a particular location.

***Rabi* and summer**

Arrange first irrigation immediately after sowing, if no rainfall occurs. Subsequently, irrigate the crop at 15, 30, 55, and 75-80 DAS to realize good stalk yields. Thus, a total of 4-5 irrigations are required for *rabi* and summer crops. Apply irrigation water of about 50 mm each time. During the initial stages of crop growth, up to 30 DAS, sprinkler irrigation is preferable to flooding. This saves the precious water as the crop water demand is less at this time compared to later stages.

f. Harvesting:

Harvest the crop at about 35-40 days after flowering of the plants ie, at physiological maturity of grain (Fig 13) where black spots appear on lower end (hylar end) of the grain.

Alternately, the Brix of a standing crop can be measured using a hand Refractometer as is done with sugarcane. The methodology of pre-harvest crop quality survey and assessment is as followed for sugarcane (ie with a Refractometer). Harvest the crop if stalk Brix reaches to 16-18% at physiological maturity of the grain.

It is observed that the harvesting operation contributes 30 % of the cultivation cost of the sweet sorghum apart from high drudgery involved in the harvesting operations. Availability of labor at harvesting time is also important because wages paid for harvesting other commercial crops are higher than sweet sorghum. CRIDA has designed and developed a self-propelled harvester and tested in the field (Fig 12a). The initial trials showed promising results and the design is under final refinement before commercializing it. It is also planned to develop a tractor drawn harvester to make it suitable for 2-3 rows.

Additionally, the plants can also be sampled for small mill test (SMT) to find the juice Brix and other quality parameters, as is done for sugarcane. Cut the plants to the ground level using a sickle or knife and remove the leaves including sheaths. Remove the panicle with last internode and thresh the grains separately followed by drying. The fresh prepared canes can be made in to small bundles of 10-12 kg each, and must be transported to the mill for crushing within 24 hours of harvesting.

Fig 12a. Single row self-propelled harvester operating in a sweet sorghum field.

Fig 13. (A) Immature seeds not showing black spot, and (B) Physiologically matured seed showing black spot at hylar end.

g. Detrashing:

Follow manual leaf removal (detrashing) as is done for sugarcane (Fig 14). However, if suitable, harvesting machinery can be developed, and the cost of harvesting can be minimized. It is highly desirable to develop a commercial leaf stripper that can save the cost of detrashing sweet sorghum.

Fig 14. Stalk of CSH 22 SS, with leaves and without leaves (detrashed).

III. Pest management

1. Sorghum shoot fly (*Atherigona soccata)*

- Sorghum shoot fly females lay cigar shaped eggs singly on the lower surface of the leaves at the 1 to 7 leaf stage.
- The larva cuts the growing point, resulting in wilting and drying of the central leaf, which is known as "deadheart" (Fig 15).
- The damaged plants produce side tillers, which may also be attacked (Fig 16).
- During the rainy season, shoot fly damage is greater in crops planted 15-20 days later than the first monsoon rains or when the rainfall is erratic and farmers resort to staggered plantings.
- Shoot fly infestations are normally high in the postrainy season, on crops planted in September – October.

Fig 15. Egg laid and deadheart caused by shoot fly (magnified to make egg visible).

Fig 16. Tillers produced in response to damage caused by sorghum shoot fly. In stem borer damaged plants, side tillers are also produced.

Fig 17. Shot-holes caused by stem borer in sorghum leaves.

Fig 18. Deadheart caused by stem borer.

2. Stem borers (*Chilo partellus* and *Sesamia inferens)*

- The first indication of stem borer infestation is the appearance of small elongated windows or round holes (Fig 17) due to feeding by the young larvae. These damage symptoms on the leaves appear on a 15 to 25 day old crop.
- The third-instar larvae migrate to the base of the plant, bore into the shoot, and damage the growing point resulting in the production of deadheart in 25 to 45 day old crops (Fig 18). Normally, two leaves dry up as a result of stem borer damage, while only one leaf dries up due to shoot fly damage.
- Stem borer larvae also feed inside the stem and cause extensive tunneling (Fig 19 &19a), which is not apparent unless the stems are split open.
- Heavy damage in the stems and peduncle result in peduncle breakage or partial seed set.
- Extended periods of drought and poor plant growth result in greater damage by stem borers.

Fig 19 & 19a. Stem tunneling caused by stem borer, and holes on the stem in sorghum.

Fig 20. Pink stem borer, Sesamia inferens damage and Chilo partellus larvae (below) in sorghum.

- Spotted stem borer, *Chilo partellus,* is important in the rainy season crop, while the pink stem borer, *Sesamia inferens* (Fig 20) is predominant in postrainy season crops.

3. Oriental armyworm (*Mythimna separate)*

- The Oriental armyworm, *Mythimna separata* larvae (Fig 21) feed on the leaves, leaving only the midribs, and panicles (Fig 22).
- When the larvae are in a gregarious phase, they move in a band and feed on the foliage of most of the graminaceous plants they come across.

Fig 21. Oriental armyworm larvae.

Fig 22. Foliar damage in sorghum by Oriental armyworm.

- Feeding takes place mostly at night, and the larvae hide in the plant whorls or under the cover of vegetation during the day. Maximum larval density and damage occur during August.

4. Sugarcane aphid (*Melanaphis sacchari*)

- The sugarcane aphid, *Melanaphis sacchari* (Fig 23) prefers to feed on the under surface of older leaves. The damage proceeds from the lower to the upper leaves.
- The adults and nymphs are yellow colored, and suck sap from the lower surface of leaves resulting in yellowing of leaves and stunted plant growth (Fig 24).
- The damage is more severe in crops under drought stress, resulting in drying of leaves, and plant mortality. The aphids secrete honeydew, which falls on the ground, on which sooty molds grow.
- Their numbers increase rapidly at the end of the rainy season during dry spells.
- Sugarcane aphid is an important pest during the postrainy season.

5. Maize aphid (*Rhopalosiphum maidis*)

- Corn leaf aphid, *Rhopalosiphum maidis,* is bluish-green in color (Fig 25), and sucks the sap from the whorl leaves during the vegetative stage of the crop.

Fig 23. Sugarcane aphid, feeding on sorghum.

Fig 24. Symptoms of sugarcane aphid, damage in sorghum.

Fig 25. Corn leaf aphid, feeding on sorghum.

- It also feeds on the panicles, and produces honeydew on which molds grow.
- It also transmits maize dwarf mosaic virus. Damage may result in yellowing, tanning, and drying up of the leaves.

6. Shoot bug (*Peregrinus maidis)*

- Shoot bug, *Peregrinus maidis,* sucks sap from the leaf whorls (Fig 26). The damaged plants become stunted.
- In case of severe infestation, the top leaves start drying first, extending gradually to the lower leaves, and at times the entire plant also dies.
- The leaves curl and present a tanned appearance. Infestation at the later stages of plant growth may twist the top leaves, and inhibit panicle emergence (Fig 27).
- They also secrete honeydew on which the sooty molds grow.
- Shoot bug infestation is more severe under drought conditions, and it is a serious pest of sorghum in the postrainy season.

Fig 26. Shoot bug damage in sorghum.

Fig 27. Shoot bug infestation on sorghum leaf.

7. Spider mites (*Oligonychus indicus*)

- The spider mites, *Oligonychus indicus,* suck sap from the under surface of the leaves.
- The infested leaf becomes pale-yellow initially, reddish on the top later, and the entire leaf may turn brown (Fig 28).
- As mite numbers increase on the lower leaves, the infestation spreads upwards through the plant.

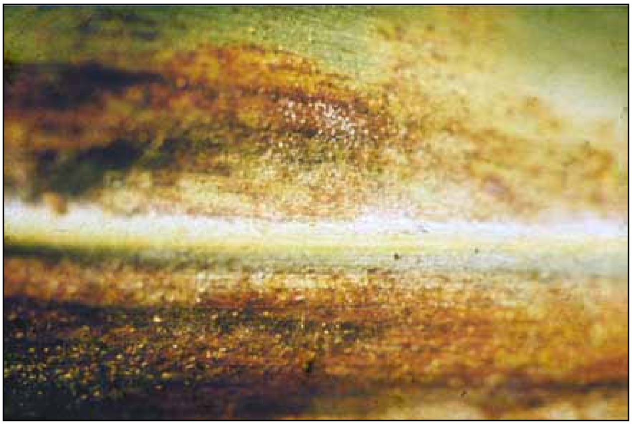


Fig 28. Spider mite damage in sorghum.

- The undersides of the infested leaves have a dense webbing. Under severe infestation, the mites may web the sorghum panicles as well.
- Infestation generally increases after panicle emergence.
- Infestations become severe under drought conditions, generally during the postrainy and summer seasons.

Fig 29. Midge damage in sorghum.

Fig 30. Sorghum midge female laying eggs.

8. Sorghum midge *(Stenodiplosis sorghicola)*

- Sorghum midge, *Stenodiplosis sorghicola* larvae feed on the developing ovary resulting in the production of chaffy spikelets (Fig 29).
- Females lay eggs in panicles at flowering during morning hours (Fig 30).
- Midge damaged spikelets have a pupal case attached to the glumes or have a small exit hole of the midge parasite on the upper glume.
- Maximum midge damage occurs in the late planted crops in October in the rainy season, and during March in the postrainy season.

9. Head bug (*Calocoris angustatus)*

- Head bug, *Calocoris angustatus* nymphs and adults suck sap from the developing grains (Fig 31). The damage starts as soon as the panicle emerges from the boot leaf.
- Bug damaged grain shows distinct red-brown feeding punctures. High levels of bug damage lead to tanning and shriveling of the grain (Fig 32).

Fig 31. Head bug on a sorghum panicle.

Fig 32. Head bug damage in sorghum.

- Head bug damage reduces grain yield, quality, and renders the food unfit for human consumption. Such grains also show poor seed germination.

10. Head caterpillars (*Helicoverpa armigera* and *Eublemma silicula)*

- Head caterpillars, *Helicoverpa armigera* (Fig 33) *and Eublemma silicula* (Fig 34) feed on the developing grain. They destroy the grain mostly inside the panicle.
- Some species produce webs of silken threads inside the panicle or make small holes in the grain.

Fig 33. Head caterpillar feeding on sorghum grain.

- In cultivars with compact panicles, the inside of the panicle may be completely damaged while the panicle may look healthy externally (Fig 35).
- Feeding on the developing grain causes maximum loss in grain yield.
- Head caterpillars cause heavy damage under humid conditions.

Fig 34. Head caterpillar damage in sorghum panicle.

Fig 35. Head caterpillar feeding on sorghum grains.

Integrated pest management practices

- Adopt synchronous and timely/early sowings of cultivars with similar maturity over large areas to reduce the damage by shoot fly, midge, and head bugs.
- Apply balanced fertilizers having adequate N and P to promote better plant growth, which results in reduced damage by shoot fly and stem borers.
- Use high seed rates, and delay thinning (to maintain optimum plant stand) to minimize shoot fly damage.
- Rotate sorghum with cotton, groundnut, or sunflower, to reduce the damage by shoot fly, midge, and head bugs.
- Intercropping sorghum with pigeonpea, cowpea, or lablab also reduces the damage by stem borers.
- Collecting and burning of stubble and chaffy earheads, and feeding the stalks to cattle before the onset of monsoon rains reduces the carryover of stem borers and midge.
- Plant sorghum varieties with less susceptibility to insect damage are relatively less damaged by shoot fly and stem borers.
- Treat seeds with carbofuran (5% a.i.), thiamethoxam (9.0 ml/kg seed), or imidacloprid (0.165 mg/kg seed) to improve plant stand, seedling vigor, and reduce the damage by shoot fly, and to some extent stem borer, and maize aphid.
- When the shoot fly damage reaches 5 to 10% of the plants with deadhearts (Plate 1), the crop may be sprayed with cypermethrin 10 EC (750 ml/ha) or endosulfan 35 EC (350 g a.i./ha). Alternatively, carbofuran granules (5 to 7 granules/plant) may be applied in the leaf whorls (Fig 36).
- For stem borers, dusts or granules can be applied in the whorl leaves of damaged plants or the entire field can be sprayed with endosulfan, fenvalerate, or cypermethrin.
- Neem seed kernel extract (5 kg/ha) or *Bacillus thuringiensis* (Bt) formulations can be sprayed for the control of stem borers, armyworms, and head caterpillars.
- For sorghum midge, the crop may be sprayed at the 50% flowering stage (1 midge/panicle) with endosulfan or cypermethrin. Early and uniform planting of the crop in a geographical area minimizes shoot fly, midge, and head bug damage.

Fig 36. Application of carbofuran granules in the leaf whorl to control shoot fly and stem borer damage in sorghum.

- For earhead bugs (1 to 2 bugs per panicle) and head caterpillars (2 – 3 larvae per panicle), the crop may be sprayed at the completion of flowering and at the milk stage with endosulfan or cypermethrin.
- Use of insect tolerant varieties such as ICSV 700 and ICSV 93046 minimizes losses due to shoot fly and stem borer.
- Use of intercrops such as pigeonpea and mung bean minimizes the risk of crop failure, and reduces insect damage.
- Use of carbofuran or imidachloprid seed treatment (@ 10 g / kg of seed) in case of delayed sowing or application of carbofuran granules in the soil (1.0 kg ai/ha) at the time of sowing controls shoot fly. After seedling emergence, 15 - 20 carbofuran granules are placed in the leaf whorls to control shoot fly, stem borer, aphids, and shoot bug, or imidachloprid or acephate is sprayed to control the aphids and shoot bug.
- Carbaryl (0.5 – 1.0 kg ai/ha) or fenvalerate (75 – 100 g ai/ha) or endosulfan (700 g ai/ha) is sprayed at 50% flowering to control sorghum midge (when we see > 1 midge fly per panicle) and at completion of flowering (1 bug per 2 panicles) for head bugs. At the milk stage, endosulfan or fenvalerate is sprayed if there are 5 to 10 nymphs per panicle.

IV. Disease Management

Introduction

Sorghum is the host of many diseases that are caused by fungi, bacteria, viruses, nematodes and parasitic plants. In most semi-arid tropical environments, economically important diseases of sorghum are grain mold, anthracnose, leaf blight, downy mildew, charcoal rot, rust, ergot, smuts and virus diseases - maize stripe and maize mosaic. These diseases, either alone or in combinations, cause substantial damage to crops resulting in heavy economic losses every year. In this bulletin, a brief account of disease symptoms and disease management practices including growing disease resistant cultivars, agronomic practices and chemical control by seed treatment with fungicides before sowing and protection of the standing crop with fungicide sprays are provided. Disease control by fungicide spray on a standing crop is not commonly practiced by farmers in sorghum as it is not economical. Seed treatment has proved to be most effective and economical for controlling some seed borne pathogens.

1. Grain molds (caused by a complex of several fungal species)

Symptoms

Initial symptoms of grain mold are discoloration of grains due to infection and colonization by mold fungi. Grain discoloration varies from light whitish, pinkish, grayish, to shiny black depending on infection and colonization by individual fungal species. Often grains are colonized by multiple fungi. In severe cases, grains turn completely black. In case of severe infection at anthesis, grain development is affected resulting in chaffy florets or small grains on the panicle. High humidity (>90% RH) due to frequent rains and a temperature range of 25-35˚c during the flowering to grain development period are quite favorable for infection and mold development.

Control measures

- Grow mold resistant cultivars, such as SPV 422, SSV 84, NTJ 2, ICSV 700 and CSH 22SS
- Avoid growing early-maturing mold-susceptible cultivars whose flowering coincides with the rainy season
- Harvest crop at physiological maturity and quickly dry grains after threshing Avoid delay in harvesting the matured crop
- Chemical control is not suggested for grain mold because it is impracticable and uneconomical, except in seed production plots on research stations depending on importance of genetic material.
- Some level of control can be obtained by three sprays on earheads with Aurofungin -200ppm and 0.2 % Captan starting from flowering to grain maturity with 10 day intervals under rain free conditions.

2. Anthracnose *(Colletotrichum graminicola* **(Ces.) Wilson)**

Symptoms

The foliar symptoms of anthracnose appear 30-40 days after emergence. Typical symptoms are small, circular, elliptical or elongated spots usually about 5mm in diameter. These spots develop gray to straw-colored centers with wide margins that may be tan, red, or blackish -purple depending on the cultivar and the pathogen population. Under conditions of high humidity, the spots increase in number and coalesce to cover a larger leaf area. The pathogen also infects midrib, leaf sheath and panicles including grains and rachis. Variation in foliage and grain symptoms may be due to host reaction, host physiological status, and the prevailing weather conditions.

Control measures

- Grow anthracnose resistant cultivars, such as SPV 386, SPV 422, NTJ 2 ICSV 247, CSH 25 and CSH 22SS
- Spraying Captafol 0.2%, benlate or carbendazim (0.5kg ha^{-1}), three sprays at 10-day intervals starting from 30 -day old crop, under rainfree conditions.

3. Leaf blight (*Exserohilum turcicum* (Pass.) KJ Leonard & EG Suggs)

Symptoms

Symptoms are visible from the seedling stage to the crop maturity stage. Small, reddish or tan spots develop on seedlings, the spots later enlarge and coalesce resulting in wilting of young leaves. On mature plants, long, elliptical, reddish purple or yellowish lesions develop, first on lower leaves and later progress to the upper leaves and stem as well. In humid weather, numerous grayish black spores are produced in the lesions in concentric zones.

Control measures

- Grow disease resistant cultivars, such as SPV 1411, ICSV 700, CSH 25 and CSH 22SS
- Spray Zinab or Mancozeb 0.2%, 3-4 sprays beginning at 40 days after emergence.

4. Downy mildew *(Peronosclerospora sorghi* [Weston and Uppal (Shaw)])

Symptoms

Both systemic and local infections occur. Systemic infection occurs when the young meristematic tissues of the growing seedlings are infected and the symptoms appear as chlorotic foliage and stunted, often resulting in death of seedlings. The first infected leaf shows chlorosis on the lower part of the lamina, which further grows to cover a larger part of the leaf. The other leaves on a plant that get infected subsequently show more chlorosis. Under cool and humid weather conditions, the abaxial (below) surface of chlorotic leaves produce abundant spores (conidia) that appear as white, downy growth. As the plant grows, new emerging leaves exhibit parallel stripes of green and white tissue; the white interveinal tissue dies and leaf shredding occurs. These shredded tissues usually contain numerous oospores.

The local lesions on foliage are the result of infection by conidia. These appear as stippled, necrotic lesions on leaf blades. The fungus produces white downy growth of conidiophores and conidia on these lesions. Conidia from these lesions get dispersed through wind currents to neighboring plants and cause disease. The local lesions become systemic when the conidia from these lesions infect meristematic tissues.

Control measures

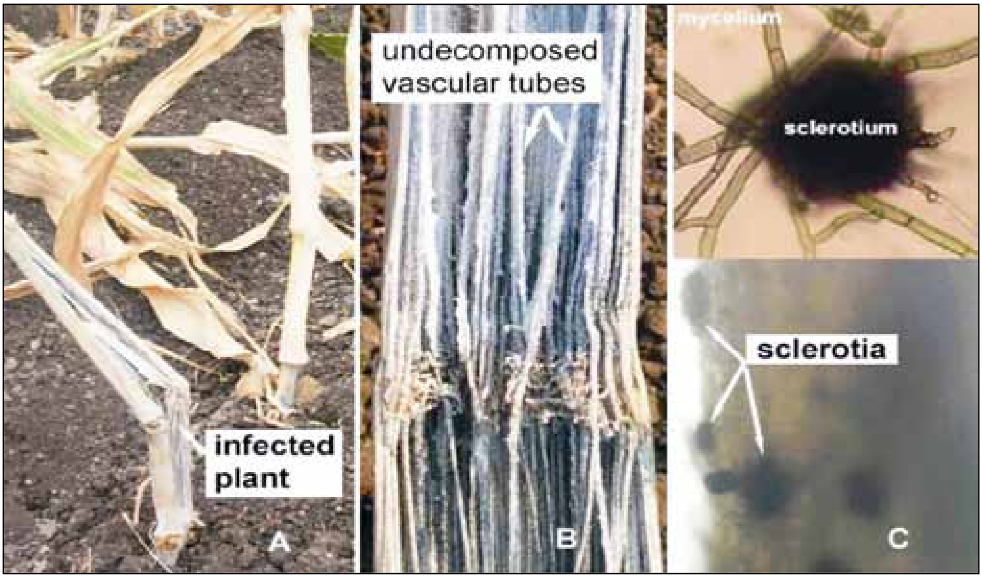
Downy mildew is not a serious and widespread disease in India, and thus most commercial cultivars are resistant to the disease as of now. However, in some cases where disease appears, the following measures can be taken.

- Uproot and destroy the diseased seedlings to prevent disease spread
- Treat seed with Apron SD 35/Ridomil (metalaxyl) @ 2 g a.i kg^{-1} seed, followed by one spray with metalaxyl @1g a.i l^{-1} (750L ha^{-1}) at 40 days after planting.

5. Charcoal rot/stalk rot (*Macrophomina phaseolina* (Tassi) Goid)

Symptoms

Infected roots and lower stem of the infected plant show water-soaked lesions that slowly turn brown or black. Affected stalks become soft at the base and often lodge due even to moderate wind or by bending the plants. Thus premature lodging is the most apparent symptom of charcoal rot. When an infected stalk is split open, the pith is found disintegrated across



several nodes. The cortical tissues are disintegrated and vascular bundles get separated from one another. Numerous minute, dark, charcoal-colored sclerotia of the pathogen are formed on these vascular tubes. Normally the disease appears during the post-flowering stage, but in some cases seedlings can also get infected.

Control measures

- Charcoal rot is not a widespread disease. The disease appears only under terminal drought conditions, mostly in *rabi* sorghum. If the crop is irrigated to alleviate moisture stress during flowering to grain filling stage, the disease can be prevented.
- The effect of disease on yield loss can be reduced by growing charcoal rot tolerant cultivars. Most sorghum cultivars with the stay-green trait have some level of tolerance to charcoal rot.

6. Ergot/sugary disease (*Sphacelia sorghi* McRae)

Symptoms

The first symptom is exudation of honeydew droplets from the infected florets on sorghum panicles. Depending on weather conditions and host genotype, the honeydew color could be dirty white to brown, and viscous. Under favorable conditions, honeydew exudation is profuse and the droplets drip down on foliage and on the ground appearing as whitish patches. These honeydew droplets contain numerous conidia. The honeydew exudates impart a typical fermented smell that can be realized from a few meters away from the infected panicles.

The infected florets do not set seed and develop sclerotia in some florets. These are elongated structures, larger than grain, protruding from the glumes.

Control measures

- Growing resistant cultivars, if available
- Some grasses that serve as collateral hosts on the bunds of sorghum fields should be uprooted and burnt to destroy the inoculum
- Use clean seed free from sclerotia -removal of sclerotia from seed by hand picking, by machine or by soaking seed in 10% common solt solution
- Spraying of Captafol 0.2% three time at 5-day intervals starting from earhead emergence in seed production plots only.

7. Rust (*Puccinia purpurea* Cook)

Symptoms

The typical symptoms of rust appear as scattered purple or red flecks on both surfaces of the leaves. The color of flecks varies depending upon plant pigmentation. In resistant plants, these remain restricted while in susceptible ones, these enlarge and appear like blisters that are brown to dark red pustules. As the leaf matures, the dried epidermis over the pustules ruptures, releasing the aggregates of reddish brown urediniospores. Gradually, most uredinia are converted into telia and the color of pustules changes from reddish brown to dark or blackish brown.

Control measures

- Grow rust resistant cultivars, such as SSV 84, NTJ 2. CSH 25 and CSH 22SS
- Spray Calixin 75EC/WP, Dithane M-45 @ 0.2%, or Mancozeb @ 0.2% three times at 10-day intervals starting from 30 days after emergence.

8. Smuts

There are four different kinds of smuts affecting sorghum. These are, head smut, long smut, loose kernel smut and covered kernel smut. Of these, head smut is more widespread and damaging, while the other three smuts occur in relatively low frequency but are potentially important in several sorghum growing regions of the world. Because of their potential economic importance, these are being described here (Table 2).


Loose kernel smut.


Head smut.


Covered kernel smut.


Long smut.

Virus diseases

Two economically important sorghum viruses prevailing in India and other semi-arid tropical parts of the world belong to isolates of maize stripe virus (MStV) and maize mosaic virus (MMV). The earliest symptoms of viral diseases under field conditions often resemble those associated with herbicide, insecticide, or fungicide damage, or with genetic abnormalities.

Symptoms

Maize Stripe Virus (MStV-S). The characteristic symptoms include the appearance of chlorotic stripes/bands between the veins on infected leaves, stunted plants with small internodes, partial exsertion of the panicle with fewer seed setting or no panicle emergence, depending on the crop stage at infection.


Maize stripe virus.

Maize Mosaic Virus (MMV-S). The symptoms include the appearance of fine continuous chlorotic or broken streaks between the veins on leaves that may become necrotic as the disease progresses, severe stunting of plants with shortened internodes and fewer seed setting on panicles.

Table 2. Sorghum Smuts

Head smut *Sporisorium reilianum* (Kühn) Clinton	Long smut *Sporisorium ehrenbergii* Vánky	Covered kernel smut *Sporisorium sorghi*	Loose kernel smut *Sporisorium cruentum* (Kühn) Vánky
Head smut typically affects the inflorescence and rarely the foliage. The whole head turns into smut sorus, a white peridium initially covers the sorus; large ruptured sori reveal distinct vascular strands. Parts of inflorescence that do not form a gall usually show a blasting or proliferation of individual florets. Smut galls may also develop occasionally on the leaves and stems in some cultivars of sweet sorghum and Sudangrass Control measures Avoid seed from endemic fields for planting Grow resistant cultivars.	Long smut appears as elongated, cylindrical, slightly curved sori, longer than normal grain (Fig. 20). The sori have a whitish thin membrane that ruptures to release a black powdery mass of spore balls that can be easily blown by the wind. The long smut sori are much longer (2-4 cm) than those of covered kernel smut, and these are unevenly distributed on the panicle, unlike the covered kernel smut sori. Each sorus contains 8-10 longitudinal filaments (remnants of the vascular elements of ovary) with teliospores held between the filaments and the membrane wall. Control measures Avoid seed from endemic fields for planting Grow resistant cultivars.	Normally in an infected panicle individual ovules are replaced by conical to oval smut sori (teliospores or chlamydospores) that are covered by persistent peridia that are larger than normal grain (Fig. 21). Initially each sorus is covered with a light pink or silver-white membrane, which later ruptures to reveal the brownish-black smut spores. The infected kernels (smut sori) break open, and the microscopic spores adhere to the surface of healthy seeds where they overwinter. Control measures Seed treatment with Carboxin 2g kg^{-1} seed. Grow disease resistant cultivars	Normally, all kernels in an infected panicle are smutted (Fig. 22). Partial infection is uncommon. Individual infected kernels are replaced by smallsmut sori that are 2.5 cm or longer, pointed and surrounded by a thin gray membrane. Some kernels may be transformed into leafy structures or escape infection completely. The smut sori are surrounded by a thin gray membrane. This membrane usually ruptures soon after the panicle emerges from the boot to release powdery, dark brown to black teliospores. These teliospores can be blown away by wind leaving a black, pointed, conical, often curved structure (columella) in the center of the gall. Control measures Seed treatment with carboxin 2.5g kg^{-1} seed. Grow disease resistant cultivars

Control measures

- In nature, both MStV-S and MMV-S are transmitted by a elphacid planthopper *Peregrinus maidis* in a persistent manner. The vector *P. maidis* is also a common pest on sorghum (shoot bug) in Asia and Africa that could become a potential threat to sorghum production. Several predators and parasites attack this pest.
- Spray Endosulphon or carbaryl to control plant hopper, which will help reduce the disease spread.

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, and 644 million of these are the poorest of the poor. ICRISAT and its partners help empower these poor people to overcome poverty, hunger, malnutrition and a degraded environment through better and more resilient agriculture.

ICRISAT is headquartered in Hyderabad, Andhra Pradesh, India, with two regional hubs and four country offices in sub-Saharan Africa. It belongs to the Consortium of Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

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