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Importance and Management of Sorghum Smuts with Special Reference To: the Covered Kernel Smut (*Sphacelotheca sorghi* [Link] Clinton), Loose Kernel Smut (*Sphacelotheca cruenta* [Kuhn] Potter) and Head Smut (*Sphacelotheca reiliana* [Kuhn] Clinton)

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ABSTRACT

Sorghum known to be associated with one of the most important diseases of seed- and soil-borne pathogens *Sphacelotheca* spp. causing the smuts. Sorghum smuts remains to be an important biotic factor constraining its efficient productions in semi-arid tropics regions of the world especially Africa and Asia. The infections are entirely either through leaves, stalk, peduncle, panicle or the grain; while damages are almost entirely confined to the heads or panicles; reducing both the grain yield and forage value. The methods for controlling sorghum smuts are diverse depending on factors of the crop natures, the pathogens group, the socio-economic conditions, agricultural developments and environmental concerns. Even though; commonly various control measures like: chemical controls; cultural and traditional practices, biological controls and use of resistant varieties are practiced, the control of sorghum smut remains very challenging in many sorghum growing regions related to the pathogens infection mechanisms twinned with its severities and distributions. The controls of smuts are primarily believed possible through the use of resistant varieties and seed treatments. Direction on the use of resistant varieties, it has been difficult to find cultivars with multiple resistances against all the major diseases progress. Seed dressing with fungicide has been one of the cheapest and the most effective means of controlling seed-borne sorghum smut diseases yet lack of information, availability and cost of the chemicals were the major constraints for wider adoption by the target groups–resource poor, smallholder farmers from the developing countries. Therefore, for continued sustainable production of sorghum, the managements of these sorghum smuts are important through cultural practices, chemical control, biological control and use of resistant varieties by farmers must be emphasized. Therewith, the overall objectives of this article is to give a general overviews over the importance, occurrences, epidemiology and control measures used for the major economically important sorghum smut diseases of covered kernel smut, loos kernel smut and head smut.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L) Moench) is one of the world's major food crops, particularly in areas of high temperature and low rainfall, making the sorghum crop as a principal lowland crop due to its well thriving power than any other major food crops. Sorghum is the fifth most important cereal crop in the world in terms of production after wheat, rice, maize and barley. In the world it is cultivated annually on ca. 40 million ha, producing ca. 58 million MT of grain (USDA, 2019). In developed countries, it is used as a feed grain, and for food and feed in the less developed countries such as Africa and Asia. In 2018, Africa contributed about 58% of the world's sorghum total areas, indicating the importance of the crop over the continent, yet Africa only contributed about 41% to the total world's sorghum productions (USDA, 2019). This is mainly due to low productivity of the crop (1.6 tonnes) as compared to the world average production of 2.3 tonnes. The lower productiveness of the sorghum crop over the regions is tenably owing to several biotic and abiotic constraints plays together.

Also, it is a staple food for more than 500 million people in the semi-arid tropics of Africa and Asia and more than 80% of the world area of production is confined to these two continents. In sub-Saharan Africa, over 100 million people depend on sorghum as staple (Serna-Saldivar and Rooney, 1995; Smith and Frederiksen, 2000). It is the second most important staple cereal crop after maize in the regions, making a huge contribution to the domestic food supply chain and rural household incomes with a total acreage of 8.1 million ha. For instance, in Ethiopia, sorghum is the second staple cereal after Tef, *Eragrostis tef,* and ranks third after maize and Tef in total national production (Masresha *et al.*, 2011). In Ethiopia Sorghum as one of the major food crops it is largely grown from the lowlands (<1600 m.a.s.l) to the intermediate (<1900 m.a.s.l) areas having annual rainfall of <600 and >1000 mm respectively. It also shows good potential in the highlands (>1900 m.a.s.l with 800 mm annual rain fall) of Eastern Ethiopia (Aschalew *et al.*, 2012).

Despite, sorghum as one of the world's major food crops ranking fifth especially in the semi-arid tropics of Africa and Asia, where the crop is used as staple food, diseases could be mentioned as one biotic factor among others. Smuts are one of the most important diseases of sorghum, especially where untreated seed is planted. Sorghum has been found to be associated with seed-borne and soil-borne pathogen *Sphacelotheca* spp. which causes smuts, is reported to be serious in sorghum as in rice and maize. Amongst the *Sphacelotheca* spp. viz. covered kernel smut (CKS), loose kernel smut (LKS), head smut and long smut are the four common sorghum smuts known in affecting sorghum. 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 (Ramasamy *et al.*, 2007). These sorghum smuts are economically important and continue to be a major biotic constraint over sorghum growing areas particularly in the Africa in the effort to sustain high sorghum production levels, where they cause damage both on traditional and improved sorghum cultivars. Damages are confined almost entirely to the heads or panicles; reducing both the grain yield and forage value (Ahlawat, 2007). While, the fungus entirely infects leaves, stalk, peduncle, panicle and the grain either separately or together (Gwary *et al.*, 2007). Earlier estimates show sorghum smuts to account for between 5–10% yield loss and therefore economically important (Manzo, 1975; Selvaraj, 1980).

The methods for controlling sorghum smuts and other cereal diseases in Africa are diverse depending on many factors such as nature of crop, group of pathogen, socio-economic considerations, agricultural development and environmental concerns. Even though; commonly various control measures like: cultural practices, chemical control, biological control and use of resistant varieties are practiced, the control of sorghum smut remains very challenging in many sorghum growing regions related to the pathogen infection mechanisms twinned with its severities and distributions of the pathogens. Many of these measures have been identified by (Selvaraj, 1980; Tony, 2006; Girma, 2008; Victor, 2009). The control of smuts are primarily believed possible through the use of resistant varieties and seed treatments, firstly in using resistant varieties progress in this direction has been very slow in the developing agriculture in some countries of Africa and Asia. It has also been difficult to find cultivars with multiple resistances against all the major diseases. Secondly, Seed dressing with fungicide is one of the cheapest and the most effective means of controlling seed-borne sorghum diseases of smut and surely they are convenient for farmer's use, improve stands and seedlings raised from treated seeds are healthier than those from un-treated seeds (Gwary *et al.*, 2007). Therefore, for continued sustainable production of sorghum, the management of these smuts are important through an integrated control approaches involving cultural practices, chemical control, biological control and use of resistant varieties by farmers must be emphasized. Therewith, the overall objective of this article is to give a general overviews over the importance, occurrences, epidemiology and control measures used for the major economically important sorghum smut diseases of Covered kernel smut (*Sphacelotheca sorghi*), Loose kernel smut (*Sphacelotheca cruenta*) and Head Smut (*Sphacelotheca reiliana*).

2. Sorghum smuts taxonomic positions and their importance

2.1. Covered kernel smut (*Sphacelotheca sorghi* [Link] Clinton)

Covered kernel smut (CKS) is a seed-borne panicle disease caused by the fungus *Sporisorium sorghi* Ehrenberg Link (synonym: *Sphacelotheca sorghi* [Link] G.P. Clinton) (University of Illinois Extension, 1990; Thakur, 2007a), which is classified within the order Ustilaginales, class Basidiomycetes (Duran, 1969; Frowd, 1980) (Table 1). The disease occurs at seedling stage and destroys all kernels in a head and replaces them with a cone shaped gall or may affect only portions of a panicle. At harvest time, these galls are broken and spores contaminate the outer surface of other kernels (Info net Bio vision, 2011). CKS is the most common disease of sorghum in different sorghum growing parts of the world where untreated seed is used for planting and highly widespread and considered to be a major disease in all sorghum-growing regions (University of Illinois Extension, 1990; Ahlawat, 2007; Thakur, 2007a; Kutama *et al.*, 2013). CKS causes greater grain loss than any other diseases in tropical zones (Frowd, 1980; Fredriksen and Odvody, 2000).

CKS is considered to be of major economic importance when the seeds are not treated in sorghum growing areas mainly in Africa and Asia and it considered to be only seed-borne spores cause infection (Thakur *et al.*, 2010). Published data on the actual incidence and severity of CKS in East Africa are limited. Even though, Tarr (1962) reported incidences of CKS in Africa of between 8–43%, while Paul and Daniel (1999) reported incidences of CKS, was found to be highly predominant in the Sudan (24.8%) and northern Guinea (29.5%) savanna. Selvaraj (1980) estimated losses up to 50% in some parts of Africa. Doggett (1980) in a review of sorghum diseases in East Africa wrote that CKS was conspicuous and it was worth utilising seed dressings. However, he was unaware of any estimates of yield loss, except for Wallace and Wallace (1953), who reported incidences ranging from 8–100% and losses greater that 30% in Tanzania. The ICRISAT/SAFGRA's eastern Africa surveys of 1986 reported that CKS was an important disease in the region. Similarly in Ethiopia, Kenya, Rwanda, Somalia and Uganda, the disease was ranked within the top five diseases including *Striga*, (Hulluka and Esele, 1992).

2.2. Loose kernel smut (*Sphacelotheca cruenta* [Kuhn] Potter)

Loose kernel smut (LKS) is a seed-borne panicle disease caused by the fungus *Spacelotheca cruenta* Potter (synonym: *Sphacelotheca cruenta* [Kuhn] J.G. Kühn) (University of Illinois Extension, 1990 and Thakur, 2007b), which is classified within the order Ustilaginales, class Basidiomycetes (Duran, 1969; Frowd, 1980) (Table 1). LKS is less widespread and less damaging than CKS and head smut. Yet, LKS attacks all groups of sorghums, including johnsongrass, although certain varieties in some groups are immune or highly resistant, Sudangrass is usually not infected (Ahlawat, 2007).

Though LKS is considered to be less widespread and less damaging than CKS and head smut, LKS remained essentially a curiosity over the past for its distribution in Africa, Asia, Europe and North, Central and South America. LKS is common in most sorghum growing regions except Australia and some parts of Asia, including Malaysia and Indonesia (Thakur, 2007b). Published data on the actual incidence and severity of LKS in Eastern Africa are limited, yet in Western Africa about 15.5% of LKS incidence was reported from the Sahel savannas of Nigeria (Paul and Daniel, 1999). Earlier assessed reports indicated the possible grain yield losses due to LKS over some African sorghum growing areas were between 2–40%. King (1972) reported possible losses of 2% in Niger and Nigeria, while Alahaydoian and Ali (1985) estimated losses up to 40% in Somalia. Similarly, Sundaram (1980) reported possible losses rarely exceeding 10%, in "hot-spot" areas of some African countries.

Currently both CKS and LKS have been reduced to minor problems following the use of fungicide seed dressings. Efforts at controlling CKS and LKS using seed dressing chemicals reduced their incidence since the early 1970s (William *et al.*, 1976). However, inappropriate provision of extension services capable of disseminating relevant information to farmers, which are prerequisites for sustainable agricultural development have made these diseases to remain a serious constraint to sorghum production as most farmers are resource-poor (Abdulai and Hazell, 1995).

2.3. Head smut (*Sphacelotheca reiliana* [Kuhn] Clinton)

Head smut is a soil-borne panicle head disease caused by fungus *Sporisorium holci-sorghi* (synonyms: *Sphacelotheca reilianum* [Kuhn] J.G. Langdon and Fullerton, and *Sphacelotheca reiliana* [Kuhn] Clinton) (University of Illinois Extension, 1990; Ramasamy *et al.*, 2007), of two separate physiologic races being common to the former on maize and the later on sorghum, which both are classified within the order Ustilaginales, class Basidiomycetes (Duran, 1969, Frowd, 1980; Ramasamy *et al.*, 2007) (Table 1). Head smut is the most serious panicle disease which completely destroys the entire head and widely spread pathogen both on maize and sorghum crops, being more common on the latter (University of Illinois Extension, 1990).

This smut is common in many parts of sorghum growing regions of the world. Africa has been suggested as the origin of the pathogen, although different races infect sorghum, corn and sudangrass over a wide geographical area, including Europe, North and South America, Mexico, Africa, Asia, Australia, New Zealand, and Indies (Ramasamy *et al.*, 2007). Head smut incidence is comparatively high in all sorghum - growing areas in Africa and particularly in low-lying fields. In some fields up to 10% of the plants may be infected. But overall, infection does not exceed 1 to 2 %, and it is considered to be of minor importance since then (Sundaram, 1980). Head smut incidences was been reported from 20 to 40% in Mexico (Narro *et al.*, 1992). In recent years head smut severity has increased due to cultivation of some susceptible sorghum cultivars or the appearance of more virulent races. Different races of the fungus exist which may result in a sorghum hybrid being resistant in one area but not another (Info net Bio vision, 2011). In the United States, four physiological races have been identified among sorghum isolates on the basis of their reactions on a series of host differentials (Ramasamy *et al.*, 2007).

Mostly smutted plants have weakened root systems and commonly exhibit more severe stalk and root rots than smut-free plants. The fungus develops only in actively growing meristematic tissue. The smut spores also may cling to the surface of sorghum seed, introducing the smut fungus into the soil of fields not previously infested. Apparently, seed-borne spores are not important in causing infection (University of Illinois Extension, 1990; Ahlawat, 2007). The infection is systemic and progresses with the plant growth and finally expresses in the inflorescence at the boot leaf stage (Ramasamy *et al.*, 2007). The smut gall produces thousands of spores, which become soil-borne and initiate systemic infection of seedlings in subsequent years (Info net Bio vision, 2011). Even with a relatively low percentage of infection in the fields (10%), yield reduction can be significant. Infection rates up to 80% have been reported. Once the infection occurs, there are no effective treatments for reducing or eliminating the damage on affected plants (Field Facts, 2010).

Table 1. Taxonomic position of smut pathogens.

Pathogens classifications		Covered kernel smut	Loose kernel smut	Head smut
Kingdom	—		Mycota (Fungi)	
Phylum	—		Basidiomycota	
Division	—		Eumycota (True fungi)	
Sub-division	—		Basidiomycotina	
Class	—		Ustomycetes (Smuts)	
Order	—		Ustilaginales	
Family	—		Ustilaginaceae	
Genus	—		*Sphacelotheca*	
↓		↓	↓	↓
Species	—	***sorghi***	***cruenta***	***reiliana***

Source: Waller and Cannon (2002); Bryan (2003a); Bryan (2003b); Bryan (2003c); and Ashok and Ashok (2010).

3. Ecologies and epidemiology's of sorghum smuts

3.1. Ecology and epidemiology of covered kernel smut

The pathogen for CKS is seed-borne and the infection is systemic, which begins at the seedling stage and progresses to the inflorescence. Smut sori are generally smooth; oval, conical or cylindrical; and vary in size from those small enough to be concealed by the glumes to those over 1cm long. They may be white, gray, or brown (University of Illinois Extension, 1990; Thakur, 2007a; Kutama *et al.*, 2013). 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. Initially, each sorus is covered with a light pink or silver-white membrane, which later on ruptures to reveal the brownish-black smut spores and central hard column called Columella composed of host tissues. The infected kernels break open, and the microscopic spores adhere to the surface of healthy seeds where they remain attached till the seed to overwinter (Thakur, 2007a; Nautiyal, 2008; Thakur *et al.*, 2010).

The only sources of inoculum for CKS of sorghum are seeds infested with teliospores of *Sphacelotheca sorghi* (Kutama *et al.*, 2013). Soil-borne teliospores are not considered important in infecting seedlings, but only seed-borne spores cause infection (University of Illinois Extension, 1990; Thakur, 2007a; Kutama *et al.*, 2013). The ideal position of the teliospore to infect a sorghum plant is on the testa of the seed. The coleoptile is easily infected up to 5mm in length, after which infection is rarely achieved. The longest reported coleoptile length at which infection occurred is 20mm (McKnight, 1966). When a smut-infested kernel is planted, the teliospores (mostly 4 to 7 microns in diameter) germinate along with the seed or sometimes directly by producing germ tubes, forming a 4–celled promycelium (epibasidium) bearing lateral sporidia (Table 2). Then the sporidia germinate and infect systemically along with the developing sorghum seedling plant but does not show any disease symptom until heading (University of Illinois Extension, 1990; Thakur, 2007a; Thakur *et al.*, 2010; Kutama *et al.*, 2013).

Incidence of the disease for CKS of sorghum usually occurs when sorghum seed is planted in progressively warmer, wet soils that are 60° to 90°F (15.5° to 32°C). Optimum temperature for the spore to germinate varies on the spore morphologies or distinct physiologic races and spores retain viability for four years when kept in dry condition (University of Illinois Extension, 1990; Thakur, 2007a).

3.2. Ecology and epidemiology of loose kernel smut

The pathogen for LKS infection is systemic, which begins at the seedling stage and progresses until heading. The pathogen were also been long known as a seed-borne (El Hilu *et al.*, 1992), yet the pathogen for LKS is both soil-borne and externally seed-borne (Vishunavat, 2013). The major difference between CKS and LKS is that the plants affected by LKS are stunted, have thin stalks and heads emerge earlier than healthy plants and also abundant tillering was observed with LKS infection (Ahlawat, 2007). Galls formed by LKS are long and pointed, which individual kernels are replaced by small smut galls (or sori) that are 2.5 cm or longer, pointed and surrounded by a thin gray membrane (Thakur, 2007b). Some smut spores (mostly 6 to 10 microns in diameter) adhere to the surface of healthy kernels on neighboring plants in the same field or ones nearby before and during harvest (Table 2). When such infested kernels are planted, the teliospores germinate along with the seed by first forming a thick, usually 4–celled promycelium bearing lateral sporidia (University of Illinois Extension, 1990). The fungus for LKS is heterothallic and is able to hybridize with both the CKS and head smut fungi, complicating the problem of developing resistant hybrids (University of Illinois Extension, 1990; Thakur, 2007b).

When the seed contaminated with teliospores from LKS are sown in the field, the spores germinate to produce sporidia. These sporidia germinate and infect the developing sorghum seedling. Most infections, however, result from the teliospores producing hyphae which penetrate young seedlings before emergence (University of Illinois Extension, 1990; Thakur, 2007b). Secondary infection may occur in LKS when spores from a smutted head infect late-developing heads of healthy sorghum plants, causing them to become smutted. Localized infection of floral parts from airborne spores may also occur (University of Illinois Extension, 1990).

Seedling infection for LKS occurs over a wide range of soil moisture and pH at a temperature of 68° to 77°F (20° to 25°C). Spore germination occurs at optimal temperatures of 28–32°C, and the fungus can easily be cultured on agar medium. It produces yeast-like colonies and numerous sporidia on nutrient agar or potato agar (University of Illinois Extension, 1990; Ahlawat, 2007; Thakur, 2007b).

3.3. Ecology and epidemiology of head smut

Unlike CKS and LKS the pathogen for head smut is soil-borne, but like CKS and LKS the infection is systemic, which begins at the seedling stage and progresses with the plant growth and finally expresses in the inflorescence at the boot leaf stage which then survives in the form of teliospores in smut sori (Ramasamy *et al.*, 2007). Infection first appears when the young head, enclosed in the boot, is usually completely replaced by a large smut gall covered by a thick whitish membrane. The membrane soon ruptures, often before the head emerges, exposing a mass of dark brown to black, powdery teliospores intermingled with a network of long, thin, dark, broom like filaments of vascular tissue in place of the panicle. The head is either completely or partially replaced by a large whitish gall. The gall is first covered with a whitish membrane, which soon breaks and allows spores to be scattered by the wind or rain (University of Illinois Extension, 1990; Ahlawat, 2007; Info net Bio vision, 2011). Wind or rain quickly scatters the smut spores to the soil and plant debris, where they live through the winter. Parts of an infected panicle not included in the smut gall or sorus usually show a blasting (sterility) or proliferation of individual florets (University of Illinois Extension, 1990; Ahlawat, 2007). The infection of seedlings can also takes place by teliospores already adhere to seed during the last season. The healthy soil thus can be infected through seed infection. Apparently, seed infection is not important in causing infection (Ahlawat, 2007)**.** Similarly it is also stated as, seed infection is not important in causing infection as the results of that the pathogen cannot be transmitted from one plant to the other in the field and affected plants have no grain development (Field Facts, 2010).

The soil-borne inoculums are the major source of infection although pathogen may be externally seed-borne. Once this fungus infests soil, the spores can survive for a decade and hence planting of disease free or chemically treated seed does not prevent further infection (Ramasamy *et al.*, 2007). When sorghum seed is planted the following spring, the smut spores (9 to 14 microns in diameter) already in the soil germinate along with the seed to form a 4–celled or branched promycelium that bears sporidia terminally and near the septa (Table 2). The sporidia may sprout to form yeast-like secondary sporidia or may germinate to form a germ tube that penetrates meristematic tissue in the sorghum seedling (Ahlawat, 2007; University of Illinois Extension, 1990; Ramasamy *et al.*, 2007).

Soil temperature and moisture are main factors responsible for survival of spores. Dry cool soil favors survival while moist and warm soil reduces survival. The disease is more in crop grown in clay loam soil (high moisture) than in sandy loam soil (Vishunavat, 2013). In a dry soil with a temperature of approximately 24°C until the plants reach the 3–4 leaf stage is considered the most ideal for infection. Soil temperatures below 21°C and above 31°C seriously reduce the percentage of infection (Ramasamy *et al.*, 2007). While in the moist soil the spore germination is high with the temperature range of 81° to 88°F (27° to 31°C) (University of Illinois Extension, 1990; Ahlawat, 2007; Ramasamy *et al.*, 2007). In the laboratories the temperatures of 23–30°C have been shown to be optimum for germination, when the spores form a basidium containing four cells, also known as a promycelium. This structure produces yeast-like haploid basidiospores which reproduce via budding. Switching from the yeast-like stage to a mycelial growth stage has been shown to occur in response to a soil water potential decrease. When hyphae from two compatible strains (differing at mating loci a & b) meet, hyphal conjugation tubes are developed and fuse to form a diploid infection hypha (Samuel, 2014).

Table 2. Characteristic comparison of the three types of smut of sorghum.

Characters	Covered kernel smut	Loose kernel smut	Head smut
Pathogen	*Sphacelotheca sorghi*	*Sphacelotheca cruenta*	*Sphacelotheca reiliana*
Host	Stunted, heading premature	Not stunted, heading normal	Not stunted, heading premature
Ear infection	All or most grains smutted	All or most grains smutted	The entire inflorescence is converted into a big sorus
Site	Ovary	Ovary	Inflorescence
Sori	Small	Small	Very large
Membrane	Rather tough and persists	Ruptures easily	Ruptures easily
Collumella	Short collumella present	Long collumella present	Collumella absent but a network of vascular tissue present
Spores (surface and diameters)	4–7µ, surface apparently smooth	6–10µ, minutely echinulate	9–14µ, conspicuously echinulate
Viability of spores	More than 10 years	About 4 years	Upto 4 years
Spread	Externally seed-borne	Externally seed-borne	Soil- and seed-borne
Method of infection	Seedling, from seed-borne teliospore	Seedling, from seed-borne teliospore, or shoot infection from air-borne teliospores	Seedling, from soil-borne teliospores

Source: Ainsworth (1965), University of Illinois Extension (1990), El Hilu Omer and Frederiksen, (1992).

4. Managements and controls of sorghum smuts

4.1. Chemical controls

Seed dressing with suitable formulated different fungicides chemicals have been recommended and well proved since 1950s over many parts of the world being the most effective means for controlling the seed-borne sorghum diseases of CKS and LKS. Convenient for farmer's use, improved stands and seedlings for an improved sorghum grain yields been able to raises from treated seeds were proved being healthier than those from un-treated seeds. Since then, the incidences, severities and losses from CKS and LKS have been substantially reduced as a result the practices of seed dressings by farmers.

Chemical control of CKS and LKS has been recommended in many African countries since the 1950s, and appears to be of importance in all 12 southern African countries (Doggett, 1980). This disease can be controlled effectively with seed-dressing fungicides have been identified and many others are available for evaluation. Various conducted research results showed the incidences and severities of CKS and LKS varies significantly between the tested different sorghum cultivars as well as between seed dressing chemicals. In Kenya, seed dressing for CKS controls with a suitable fungicide such as thiram, showed predicted incidence and severity in the treatment which did not incorporates a CKS control elements respectively was 39.9% (29.3%) compared to 11.1% (8.5%) for the crops grown from fungicide seed treatments; and 7.5% (4.6%) for the crops grown under blanket protection treatments (Hayden, 2002). In Nigeria, sorghum plants treated with Apron star [Metalaxyl] recorded the lowest mean sorghum CKS and LKS incidence of 4.8% with severity of 0.9%, while un-treated plants recorded the highest mean CKS incidence of 11.25% with mean severity of 5.2% representing disease reduction of 57% and 83%, respectively (Gwary *et al.*, 2007). While, another research results from Ethiopia also indicated that sorghum plants treated with thiram [lindane (Fernasa-D)] and Apron plus [Thiamethoxan + Mefenoxam + Difenocunazole] reduced both CKS and

LKS incidence in early-planted sorghum, but trace incidence was observed in late-planted sorghum, particularly in CKS. Yet both fungicides consistently showed high effect in reducing CKS and LKS incidence in early and late-planted sorghum (Girma, 2008). Similarly, in India, both CKS and LKS diseases were proved to be effectively controlled by solar heat treatment, treatment with Formalin (0.5% for 2 hrs) or copper sulphate solution (0.5–3.0 % for 15 min), seed dressing with mercurial fungicides like Agrosan GN (1:500) (Nautiyal, 2008).

Seed dressing with fungicides generally proved worldwide to be one of the most effective means of controlling seed-borne sorghum diseases of CKS and LKS. They are convenient for farmer's use, improve stands and seedlings raised from treated seeds are healthier than those from un-treated seeds (ICRISAT, 1982). Though, seed dressing was identified as a possible control measure for CKS and LKS, but lack of information, availability and cost of the chemicals were major constraints to wider adoption by the target groups i.e. resource poor, smallholder farmers from many African as well as some Asian countries (Hayden and Wilson, 2000). Furthermore, extension officers were found to have a poor knowledge of sorghum smut and its control.

4.2. Cultural and traditional practices

Since the infection of CKS and LKS are mainly seed-borne and occurs only at the seedling stages; and no chemical controls are practical for small-scale resource-poor farmers, the logical approaches to control CKS and LKS are exploring and adopting the available various cultural and traditional practices. While, head smut is predominantly soil-borne chemical controls has been found somewhat ineffective for total control of the disease. Countably various culturally and traditionally available protective measures that could reduce the occurrences of sorghum smut diseases been long used by small-scale resource-poor farmers.

Use of disease free seeds; deep ploughing; adjusted time of sowing, related to decreased soil temperature and high rainfall season; crop rotations with nonhost crops; frequent irrigation after sowing; maintaining the soil fertilities, with the emphasis on sufficient nitrogen; crop sanitations; collection of the smutted ear heads in cloth bags and burial in soil or burning before the spores are scattered; promptly remove and burn, especially head smut galls before the spores are scattered can reduce the occurrence of disease (University of Illinois Extension, 1990; Ahlawat, 2007; Girma, 2008; Field Facts, 2010; Info net Bio vision, 2011; Mohan *et al.*, 2013). Crop rotations are critically considered for head smut since the fungus spores may live in the soil for several years grow sorghum in the same field only once in 2–4 years (University of Illinois Extension, 1990; Mohan *et al.*, 2013). In addition incineration of infected samples in the field, and rejection of seed samples that test positive under seed washing test (Thakur *et al.*, 2010).

Small-scale resource-poor farmers traditionally practice various methods to control sorghum smuts. Over the pasts, effects` of cow and goat urine stored at different days and diluted with water have been evaluated on both CKS and LKS (Girma, 2008). The study revealed that cow urine stored for seven days significantly reduced CKS and LKS incidence by up to 81% in 1999 and 26–70% in 2000 and increased grain yield, respectively, by up to 95% in 1999 and up to 38% in 2000. Irrespective of storage durations, goat urine treatments significantly reduced smut incidence by 50 and 85% in 1999 and 55 to 82% in 2000, respectively. Sorghum grain yield increased, respectively, to 20 and 140% in 1999 and 28 and 67% in 2000 compared to the control. Additionally, it was also concluded that soaking one kilograms of sorghum seed for 20 minutes in either cow or goat urine diluted with water in a 1:1 (v/v) mixture appeared most effective than 1:2 and 1:3 (v/v) in reducing CKS and LKS. Subsequent tests after soaking sorghum seeds with cow and goat urine and stored for 2–3 weeks also revealed increased seedling height, percent germination and seedling emergence compared to the control treatment. Thus, it was concluded that farmer's practical knowledge has significant role in sorghum smut management. However, this simple practice is not widely adopted.

4.3. Biological controls

The biological control of soil-borne plant pathogens has drawn much attention in the past few decades and is currently considered as a promising alternative to synthetic pesticides because of its safety for the environment and the human health (Brimner and Boland, 2003). In the 1960s the use of antifungal wild plant species to control plant diseases is indeed not widely common compared to insecticide application (Dales, 1996). Yet, small-scale farmers over the years practiced the use of locally available botanical plants as bio-pesticide against different types of diseases on different crops (Gaby, 1982). Potential anti-fungal natural plants either as crude or extracted forms were been tested against both sorghum CKS and LKS. For instance farmers in Ethiopia, traditionally use crude extract as slurry form from *Dolichos kilimandscharicus* L. (Bosha); and as powder form from *Dolichos kilimandscharicus* (root), *Phytolacacca dodecandra* (berries) and *Maerua subcordata* (root) to treat sorghum seed effectively controlled as effective as the standard chemicals used both for CKS and LKS (Girma and Pretorius, 2007).

Evaluation of three potential botanicals against sorghum CKS in Ethiopia, Bako indicated that the use botanicals tested for *Maesa lanceolata* (Abbayyi) leaf extract compared with thiram (fungicide) as standard check and untreated check, as a seed treatment using *Maesa lanceolata* either applied alone or diluted with water in ratio of 75:25 v/v as botanical against sorghum CKS significantly reduced the infection percentage and increased the yield significantly ranging from 40 to 41% compared to the other treatments (Aschalew *et al.*, 2007; Aschalew *et al.*, 2012). This botanical is proved to reduce or avoid the loss due to this disease which could potentially useful for resource poor farmers of similar agro-ecological areas of Sub Saharan Africa.

4.4. Sources of resistance

Other measures employed for the control for all the sorghum smut diseases include the use resistant cultivars and/or hybrids were reported worldwide since 1960s (Rosenow, 1963; Edmunds and Zummo, 1975; Selvaraj, 1980; Info net Bio vision, 2011). The biggest challenge imposed regarding its effective methods of management in controlling the head smut disease in sorghum crop unlike to both CKS and LKS, is that sorghum head smut is one of the few smuts not controlled by seed treatment or management other than host resistance. Consequently, sorghum head smut is considered as a potentially important disease because of pathogen variability (Ramasamy *et al.*, 2007).

Progress in this direction has been very slow and it has been stayed so difficult to find cultivars with multiple resistances against all sorghum smut diseases mainly because the recurrent appearances of new virulent races and unusual erosion of host resistance, for these reasons the propensity for the development of new races has increased concern about transmission by infected sorghum seeds. During the 1960s, different sorghum smut resistant hybrids versions were developed using different first generation crosses as a source of resistance to against sorghum smuts diseases and widely distributed in southern Texas, USA (Rosenow, 1963; Reyes *et al.*, 1964). While, Rosenow (1963) cautioned about possible new races and found evidence of different genes for resistance, but he was cautiously optimistic that with the new sources of resistance, when deployed through hybrids that, "the disease should be brought under control, and smut should again become a minor sorghum disease." Undoubtedly, Frederiksen and Reyes (1980) confirmed many identified sorghum lines were remain resistant and stayed useful in 1988, and changes in the pathogen population have not caused an unusual erosion of the host resistance, which on account of the identified populations and cultivars of the sorghum were bred for higher levels of smut resistance in Texas only for a little longer period. Similarly, other success stories over the source of resistance against sorghum smuts diseases were reported in Africa from local sorghum collections. That, superior sources of resistance to sorghum CKS and LKS cultivars has also been reported from local sorghum collections in Ethiopia following artificial inoculation under filed conditions (Aschalew *et al.*, 2007; Eshetu *et al.*, 2006).

Identification of sources of resistance by employing reliable screening methods and utilization of selected sources of resistance in the breeding programs are the basic steps followed for the development of cultivars with resistance to targeted pathogens. Yet, there are no standard protocols to screen for resistance to sorghum smuts diseases. The most common methods are to mix dry teliospores with dry seed prior to planting and assess the percentages of infected sorghum plants. It is important that every sorghum plants are exposed to adequate amounts of inoculums. However, researchers have utilized different ratios and the results are often inconsistent, with escapes common (Claflin and Ramundo, 1996). Even when the same methods are used, sorghum smuts disease incidences vary over seasons, making it difficult to compare results. Researchers have designated different infection rates to distinguish between resistance and susceptibility, especially when the infections rates are low (Gorter, 1961). For example research's form India, by Mathur *et al.*, (1964) and Singh and Yadar (1966) assigned an infections point below 10% as resistant and above 15% as very susceptible, while Ranganathaiah and Govindu (1970) assigned resistant at 0–1% and susceptible at above 10%.

CONCLUSION AND SUGGESTIONS

Sorghum crop is known in the world for its production importance, especially in areas where high temperature and low rainfall in which peoples' and their animals depends on sorghum as a staple food and income generation were greatly influenced even by the crops' natural agro ecological adaptation to where temperature and rainfall (moisture) stresses exists will limit significantly when these factors and others, are coupled with diseases of economically important like sorghum smuts inhibitedly triggers the sorghum crop productions. Sorghum smut diseases are caused by a species of the fungus *Sporisorium* sp, viz. covered smut (*Sphacelotheca sorghi*), loose smut (*Sphacelotheca cruenta*), head smut (*Sphacelotheca reiliana*) and long smut (*Tolyposporium ehrenbergii* – biosynonym are *Sorosporium ehrenbergii*) are the causal fungus of sorghum smut diseases known in general in affecting the sorghum crop productions. Of the four sorghum smuts, 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.

The control of sorghum smuts diseases are imposed economical in controlling them due to the biologic natures of their infection mechanisms'. Where, Smuts generally overwinter as teliospores on contaminated seed, in plant debris, or in the soil. However, some smuts overwinter as mycelium inside infected kernels or in infected plants. The teliospores are not infectious but produce basidiospores, which on germination either fuse with compatible ones and then infect or penetrate the tissue and then fuse to produce dikaryotic mycelium and the typical infection.

Different measures practiced for the control of sorghum smut diseases are like collection and burning of smutted heads before the spores are scattered, crop rotation and deep ploughing during summer months are useful to avoid damage by sorghum smuts. Sometimes due to high cost and unavailability, usage of fungicides under small-scale farmers is very rare, thus farmers over the years also started to practice the use of locally available botanical plants as bio-pesticide against different types of diseases on different crops. Generally, the controls of the sorghum smuts disease are effectively and primarily possible through use of seed treatments; and the uses of resistant or immune hybrids, varieties or cultivars; especially where the control of the disease allows the affordability, where economically sound in applying the measures especially for nations of developed countries unlike the developing counties.

The seed treatments may involve either chemical dusting or dipping, if the fungus is present as teliospores on the seed surface or in the soil, or hot water if the fungus is present as mycelium inside the seed. Of the three sorghum smuts diseases, CKS and LKS are easily controlled by seed treatment with a protectant fungicide. While, the other main reasons complicating the problem in developing the control measures in developing immune or resistant hybrids, varieties or cultivars against the three smuts viz. the CKS, LKS and head smut are that, the number of physiologic races of the three sorghum smuts are heterothallic and able to hybridize with one another. Which necessarily demands economical approaches to consider in developing varieties more often, which are resistant for three major sorghum smuts in accordance with their geographic distributions and specific ecology where they habitat.

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