OPEN ACCESS Int. J. Phytopathol. 12 (03) 2023. 283-294 DOI: 10.33687/phytopath.012.03.4249

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Available Online at EScience Press
International Journal of Phytopathology
ISSN: 2312-9344 (Online), 2313-1241 (Print)
https://esciencepress.net/journals/phytopath

MANAGEMENT OF COVERED KERNEL SMUT (*SPORISORIUM SORGHI*) DISEASE OF SORGHUM (*SORGHUM BICOLOR*) AT GABILLEY DISTRICT IN SOMALILAND

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ARTICLE INFO

Article History
Received: July 23, 2023
Revised: August 19, 2023
Accepted: December 22, 2023

Keywords
Apron star
Covered kernel smut
Severity
Seed treatment
Sorghum

ABSTRACT

Sorghum is a multi-purpose crop that plays an important role in the socio-economic life of farming communities in Somaliland. However, its production and productivity are threatened due to Covered kernel smut disease. A field experiment was carried out at Aburin Agricultural Research Center at Gabilay district in Somaliland in order to identify management options for Covered kernel smut disease of sorghum. The experiment consisted of 12 factorial treatment combinations of three varieties (i.e., Faruryogele, Abadro and Kuso) and three types of seed treatments which includes synthetic and bio-fungicides (i.e., Apron star 42WS%, Cow urine, and Neem seed kernel extract) and including Untreated control, laid out in RCBD with three replications. Parameters such as disease incidence, disease severity, phenological data, grain yield (kg)/plot, actual grain yield/plot, 1000 grains weight (g) and yield loss (%) were collected. The experiment result showed that the highest disease (44.0%) incidence was recorded on untreated Kuso variety while lowest disease (4.33%) incidence was Apron star with Abadiro. Similarly, the highest disease severity (37%) was scored from Untreated Abadiro whereas lowest disease severity (4%) was scored from Abadiro with Apron star and Faruryogele with Apron star. Untreated Abadiro variety reached the highest AUDPC (1036.0% days). The Apron star treated varieties had the lowest AUDPC and consistently showing markedly low infection rates indicating that they were more effective to the disease relative to the other seed treatments. The highest yield (1896 kg ha^{-1}) was recorded from Faruryogele with Apron star and lowest (933 kg ha^{-1}) was recorded from untreated Abadiro and Faruryogele. So, Apron star was effective to reduce the yield loss of sorghum and could be recommended to manage sorghum covered kernel smut. However, the experiment should be repeated across different environments over years in order to give the right recommendations and its rate may need to be well defined.

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INTRODUCTION

Sorghum [*Sorghum bicolor (L.) Moench*] is an important food crop, particularly in arid and semiarid tropics. It is a multipurpose crop providing staple food for human consumption, fodder for livestock, alcohol production (biofuel), as well as preparation of industrial products (Merkuz and Alemayehu, 2012). Globally, sorghum is the fifth most important cereal crop (Huang, 2018). The total mean annual production is 63.89 million tons worldwide (USDA, 2017). Africa has become the leading sorghum producer with an average annual production of greater than 25.6 million tones and with a larger area coverage than the other continents (USDA, 2017). This makes sorghum, quantitatively the second most important cereal grain in Africa after maize (Gebeyehu *et al.*, 2019). The sorghum production takes places across the continent, with the northern African countries of Nigeria, Sudan, Ethiopia and Burkina Faso accounting for nearly 70% of Africa's production (USDA, 2017).

About 48% of the world's production is used for animal feed and 42% is used for human consumption. Sorghum is eaten as thin porridge (*Kisara* in the Sudan and *Enjera* in Ethiopia) (Nuraldein, 2015). Moreover, in Africa grains are used for making alcoholic and nonalcoholic beverages (Grenier *et al.*, 2001). In Somaliland, sorghum is the first cereal crop both in total area and total tonnage followed by Maize (*Zea mays*) (SoMoA, 2019). The major sorghum growing areas in the country are the south and southwest, particularly: Gabilay and Awdal region are the most sorghum growing areas. Sorghum stands first both in area coverage and production in Somaliland with annual coverage and production of about 75553 ha (FSAU, 2019). Although 60% of the income in Somaliland comes from the animal sector, sorghum is important as a food and fodder crop, especially in this environment (SoMoA, 2019). For example, during the dry season (*Jiilal*in Somali language), the stems of sorghum are the only fodder source and an important family income, while the grains are used to obtain flour from which, after fermentation, a traditional bread is made (*Injera*/*Kimis*) (Manzelli *et al.*, 2005).

There are many diseases those attack sorghum globally, but the most destructive disease of sorghum is smut disease specially covered kernel smut (Reddy *et al.*, 2007). Among the major fungal diseases that cause panicle infection include covered kernel smut which is caused by (*Sphacelotheca sorghi*) (syn. *Sporisorium sorghi*), loose smut (*Sphacelotheca cruenta*) (syn. *Sporisorium cruentum*), head smut (*Sphacelotheca reiliana*) (*syn. Sporisoriumholci sorghi*) and long smut (*Sporosporium ehrenbergii*) have significant importance in affecting sorghum yield (Agrios, 2005).

Covered kernel smut occurs in most regions where sorghum is grown (Aschalew *et al.*, 2012; Merkuz and Getachew, 2012). Covered kernel smut is highly widespread and is considered as a major disease in all sorghum growing regions (Thakur *et al.*, 2007). The disease can cause a general level of yield loss of 5% of the potential of the crop in areas where susceptible sorghum varieties are grown, and seed dressings are not used. Moreover, heavy losses could occur in areas where the crop is extensively grown (Frederickson, 2000). According to (Aschalew *et al.*, 2012) annual yield losses due to covered kernel smut in Africa reaches 10% with localized losses of 60% or more.

In eastern Africa different Ethiopia researchers reported yield loss of covered kernel smut. For example, Merkuz (2001) reported yield loss ranged from 6.1 to 80.9 % on local sorghum varieties in North Gondar zone. Similarly, Eshetu (2003) reported yield loss ranged from 1.3 to 53.5% on commonly used sorghum varieties in northeastern Ethiopia.

In Somaliland the presence of covered kernel smut (*Sphacelotheca sorghi*) and long smut (*Tolyposporium ehrenbergii*) posed problems before head smut (FSAU, 2019). Smut diseases are spread by spores which are carried over from season to season through seed borne, and are also rarely soil borne (Hared, 2014). In globally seed treatments with fungicide are one of the cheapest and the most effective means of controlling seed and soil borne diseases (Desalegn, 2016). They are convenient for farmer's use, improve stands and seedlings raised from treated seeds are usually healthy than those from untreated seeds (Anaso, 1995). Covered and loose smuts diseases have particularly been found to be easily controlled by chemical seed treatments (Pande *et al.*, 1997).

Babeker (2004), stated that Neem (*Azadirachta indicia jus*) is a botanical pesticide, which can be used effectively as an insecticide, repellant, anti-feeding, growth inhibitor, fungicide and Nematicide. Thyme, lemongrass, as well as many others have been successfully used to control important seed borne fungi. To manage covered kernel smut various promising alternative options have been identified and recommended (Desalegn, 2016). Treating seeds with either Cow or Goat urine, fungicides and some botanicals had shown profound effects, but none of them were adopted widely to bring an impact (Tegegne *et al.*, 2006; Aschalew *et al.*, 2012).

However, in the study area, there is limited research on sorghum varieties with different levels of resistance combined with different types of seed treatments by applying integrated disease management options. Hence Evaluation of Integrated Disease Management of covered kernel smut of sorghum by using Varieties and anti-fungus synthetic fungicide, Botanical, fermented Cow urine as seed treatments to increase production and productivity at Gabilay district in Somaliland is important. The present study was initiated to conduct the experiment in Gabilay district, Somaliland.

MATERIALS AND METHODS

Description of the Experimental Site

This research was carried out at Aburin Agricultural Research site which is close to the three major dry land cropping districts of Somaliland. For example, Aburin is about 30km from Hargeisa city, 20km from Gabilay and 75km from Borama. It lies between 9°31'10.15 latitude and 43° 28'22.29 "E longitude and altitude 1452m above sea level and it has relatively favorable rain fall and fertile soil suitable for the production of sorghum, maize, millet and diversity of legumes and oil seed crops under rain fed condition (SoMoA, 2019; AARC, 2020).

Gabilay receives an annual rainfall that varies from 450 to 500 mm. Gabilay the average annual temperature is 21.4 °C. The driest month is December, with 2 mm of rain. In August, the precipitation reaches its peak, with an average of 91 mm. June is the warmest month of the year. The temperature in June averages 24.5 °C. At 17.6 °C on average, January is the coldest month of the year. There is a difference of 89 mm of precipitation between the driest and wettest months. The variation in annual temperature is around 6.9 °C (SoMoA, 2019; AARC, 2020).

Experimental Materials and Agronomic Practices

Three sorghum varieties namely, Abadiro, Faruryogele and Kuso varieties were obtained from Gallolay seed center in Gabilay district. The synthetic fungicide used for the experiment was Apron star 42WS% which was purchased from Hargeisa pesticide market, while the bio-fungicides as botanical used were Neem seed kernel extract and Cow urine respectively (locally available) whereas untreated seeds were used as control check. All Agronomic practices such as fertilizing, land preparation, weeding and cultivation were uniformly applied for all treatment in each plot (Merkuz and Getachew, 2012).

Experimental Design

The field experiment was laid out in a randomized complete block design (RCBD) with three replications. The treatments consisted of entire 12 factorial combinations of the three varieties (i.e., Faruryogele, Abadro and Kuso) and three types of seed treatments which include synthetic fungicide as Apron star 42WS% and bio-fungicides as Cow urine and Neem seed kernel extract and including Un-treated control. The seeds were inoculated with the pathogen spore and thereafter procedurally were also treated with Apron star 42WS% (fungicide), Neem seed kernel extract (botanical) and Cow urine (animal product) respectively (Aschalew *et al.*, 2012; Tegene *et al.*, 2014).

Seed Inoculation

Seeds of the three varieties were obtained from Gallolay seed center. The seeds were surface disinfected with 10% chlorox and infested with spores of covered kernel smut. The inoculum of the disease was obtained from the University of Haramaya Plant pathology laboratory. The viability of the spores was checked by using Germination Testing and Tetrazolium Staining method in the laboratory before inoculation. Inoculation was performed by applying spores of the fungus at rate of 2gr per kg of seeds in glass jar with tight cover. Seed inoculated with spores were kept in the laboratory at room temperature for about week (Merkuz and Alemayehu, 2012).

Seed Treatment

All the three varieties of infected sorghum seeds were treated with the following adopted seed treatment methods, separately for each, at the rate of 20 ml/200g seeds for 30 minutes (Aschalew *et al.*, 2012; Tegene *et al.*, 2014) for Neem seed kernel extract. The fermented cow urine was mixed with the same amount of water (20 ml water + 20 ml fermented cow urine) for 200 g seeds for 30 minutes (Tegegne *et al.*, 2006; Aschalew *et al.*, 2012; Tegene *et al.*, 2014). There were also Apron star 42WS% (fungicide) 10 g/4 kg of seeds (Tegene *et al.*, 2014), and untreated seed as control checks.

Experiment

The experiment had 12 treatments with combination of three sorghum varieties (Abadiro, Faruryo-gele and Kuso) and seed treated with fungicide (Apron star 42WS%), Neem seed kernel extract, Cow urine (fermented) and Untreated seed as control check (Table 1). All treatments were randomized by the method of (Gomez and Gomez, 1984). So that the infected seeds of the test materials were planted by using a Randomized Complete Block Design with three replications in factorial arrangements. Each plot size was 2.5 x3m having four rows with spacing of 75cm between the rows and 15cm between the plants.

Experimental Data Collection

Agronomic Parameters

Days to emergence

Seedling emergence was recorded by counting the number of days those seeds emerged. That is, the number of days was recorded starting from when was planted up to the date when almost all of the seeds in a plot emerged.

Days to 50% flowering

Days to 50% flowering were recorded by counting the number of days starting from the date when the seed was emerged up to the date when 50% of the plants in a plot flowered.

Days to physiological maturity

Days to physiological maturity were recorded by counting the number of days starting from the date when the seed was emerged up to the date when all or most of the plants were physiologically matured. In addition to the above phenological data, the plant height data was also recorded by measuring starting at the base of the plant to the end of the head. This was done when the plant terminates its growth or reaches its physiological maturity from both infected and healthy plants together.

Table 1. Treatment combinations used for seed treatments.

Sorghum varieties	Seed treatment	Treatment combination
Abadiro (A)	Untreated	A+untreated as check
	Apron star 42WS% (10g/4kg)	A+ Apron star 42WS%
	Cow urine (20ml cow urine+20ml water)/200g	A+ Cow urine
	NSKE (20ml/200g)	A+NSKE
Faruryogele (FG)	Untreated	FG+untreated as check
	Apron star 42WS%(10g/4kg)	FG+ Apron star 42WS%
	Cow urine (20ml cow urine+20ml water)/200g	FG+ Cow urine
	NSKE (20ml/200g)	FG+NSKE
Kuso (K)	Untreated	K+untreated as check
	Apron star 42WS% (10g/4kg)	K+ Apron star 42WS%
	Cow urine (20ml cow urine+20ml water)/200g	K+ Cow urine
	NSKE (20ml/200g)	K+NSKE

A = Abadiro, FG = Faruryo gele, K = Kuso, WS = Water Soluble, NSKE = Neem seed kernel extract

Epidemiological Parameters

During data collection the following Epidemiological data were collected and assessed:

Disease Incidence

The proportion of the infected plants was assessed during the onset of the disease. It was recorded by counting the number of plants showing the symptom and dividing by the total number of plants assessed in the plot. Finally, results were expressed in percentage of disease incidence using the following formula (Cochran, 1977; Ochola and Tusiime, 2011).

$$Disease\ Incidence = \frac{No.of\ infected\ plants}{Total\ no.of\ plants\ assessed} \times 100$$

Disease Severity

Severity was scored at physiological maturity by counting total, healthy and infected number of spikes in each infected head and dividing the number of infected spikes by the number of total spikes in each infected panicle then multiplying by 100 to know the effect of the disease on the proportional percentage of the spikes (House, 1985; Madhusudhan *et al.*, 2011).

$$Disease\ Severity = \frac{No.of\ infected\ spikes\ in\ panicle}{Total\ no.of\ spikes\ in\ panicle} \times 100$$

Yield and Yield Components

Total yield per plot

It was measured after when crop was harvested and threshed by weighing each plot separately.

1000 kernel weight

It was measured after the sorghum crop was harvested and threshed by counting one thousand kernel and weighing them together for each treatment. The actual moisture content of the grains was measured by using grain moisture meter for each plot. Then the final 1000 kernel weight was adjusted to13.5% moisture content (Hellevang, 1995) using the following formula:

$$Adj.1000\ kw\ (g) = \frac{(100 - AcMc)}{100 - 13.5\%\ Mc} \times 100$$

Where: Adj.1000 kw (g) = Adjusted 1000 kernel weight in gram, AcMc = Actual moisture content of the grains was measured instantly after threshing. Ac1000 kw (g) = Actual 1000 kernel weight in gram was measured instantly after threshing.

Actual total grain yield per plot (kg)

The yield for each plot also was calculated, similar to the thousand grain weight after the sorghum crop is harvested and threshed by weighing harvested grain of each plot at actual moisture content and then adjusting to 13.5% moisture content in a similar way but separately for all plots using the following formula:

$$AdjGY\ (kg) = \frac{(100 - Ac\ Mc)}{(100 - 13.5\%\ Mc)} \times AcGY$$

Where: AdjGY (kg) = Adjusted grain yield weight in kilogram per plot.

AcMc = Actual moisture content of the actual grain yield measured instantly after threshing.

AcGY (kg) = Actual grain yield weight in kilogram per plot measured immediately after threshing.

Relative yield loss (%)

Percentage of relative yield loss was calculated by using following formula:

$$RYL\ (\%) = \frac{PY(kg) - AcY(kg)}{PY\ (kg)} \times 100$$

Where: RYL (%) = Percentage of relative yield loss AcY (kg) = Actual grain yield in kilogram, was obtained by weighing the actual yield of both healthy and infected panicles together for each variety per plot.

PY (kg) = Potential grain yield in kilogram

Cost Benefit Assessment

Partial budgeting is a method of organizing experimental data and information about the costs and benefits of various alternative treatments. Partial Budget was analyzed for the treatment efficacy evaluation experiment. It was calculated only for the input costs that differ across the treatments, while the other common and constant input costs for all treatments were not included in the calculation as described by CIMMYT (1988).

Average yield

It was obtained by averaging the yield of the three replications for each treatment separately.

Adjusted yield

It was calculated by multiplying the actual yield kg ha-1 by 0.9 or 90% because it is assumed that farmers would obtain yields 10% lower than those obtained by the researchers (CIMMYT, 1988).

Gross field benefit

The gross field benefit was calculated by multiplying the adjusted yield kg ha-1 for each treatment by the current price of one-kilogram sorghum grain at Gabilay and Hargeisa local market in this case, which is 0.5-dollar kg^{-1} sorghum grain.

Total variable input costs

The total variable input costs were calculated by adding only the costs that vary across the treatment by multiplying their unit cost by the total requirement in hectare base. Because the term "partial budget" is a reminder that not all production costs are included in the budget, only those are affected by the alternative treatments being considered (CIMMYT, 1988). Therefore, in this experiment, the costs that vary were only those associated with input purchase and input preparation.

Net benefit

This was calculated by subtracting the total costs that vary from the gross field benefits.

The marginal rate of return

This was computed by dividing the difference in net benefit between the control and other treatments by the difference in total input cost between the control and each other treatment, finally the result was expressed in percentage.

$$MRR = \frac{(NBT - NBC)}{(TVICT - TVICC)}$$

Where: MRR = percentage of marginal rate of return NBT = net benefit of other treatments, NBC = net benefit of the control (untreated) TVICT = total variable input costs of other treatments TVICC = total variable input costs of the control (untreated).

Data Analysis for Experiment

Data obtained from field experiment was analyzed using GenStat software for analysis of variance (Freed, 1990). Least significance difference (LSD at 5% probability) was used to separate treatment means (Gomez and Gomez, 1984). Correlation analysis was performed to determine the relationship between the disease parameters and yield components while severity with yield per plot and yield loss regression was also carried out as per (Gomez and Gomez, 1984). Economic analysis was performed by CIMMYT partial budget analysis methodology CIMMYT (1988) to identify profitable seed treatments for tested varieties.

RESULTS AND DISCUSSION

Effect of Seed Treatments Methods on Incidence and Severity of Sorghum Covered Kernel Smut

The analysis of variance (ANOVA) showed that there were significant ($P \leq 0.05$) differences among treatments in disease incidence and severity (Table

2). Apron star treated plots had less smut infection while the highest incidences (44%) and severity (37%) were recorded in control check plots. The highest disease incidences (44% and 37.33%) were recorded on the treatment combination of varieties (Kuso and Abadiro) and without combination of seed treatments respectively. lowest disease incidences (4.33% and 9.33%) were recorded Abadiro treated with Apron star and Faruryogele with Apron star respectively.

The result also showed that the highest disease severities (37% and 35.33%) were recorded un-treated Abadiro and Kuso. Also, Lowest disease severities (4%) were recorded Abadiro treated with Apron star and Faruryogele treated with Apron star (Table 2). Generally, all the treated seeds were showed lower disease incidences and severities but the most effective one was Apron star. In addition to the Apron star, the fermented Cow urine and Neem Seed Kernel extracts showed significant role to reduce the incidence and severity of the disease and promoted growth and development of the crop, as a result increased the yield as compared with untreated plots.

Table 2. Mean values of Disease incidence and Disease severity of sorghum at Aburin dry land research Centre during 2019 to 2020 main cropping season.

Treatment combination	Disease incidence	Disease severity
Abadiro with Apron star	4.33^{f}	4.00^{d}
Abadiro with Cow urine	20.00^{cde}	17.00^{b}
Abadiro with NSKE	24.33^{c}	12.00^{bc}
Untreated Abadiro	37.33^{b}	37.00^{a}
Faruryogele with Apron star	9.33F	4.00^{d}
Faruryogele with Cow urine	21.67^{cde}	11.67^{bc}
Faruryogele with NSKE	22.67^{cde}	13.00^{bc}
Untreated Faruryogele	23.33^{cde}	34.67^{a}
Kuso with Apron star	17.33^{e}	6.00^{cd}
Kuso with Cow urine	24.00^{cd}	11.67^{bc}
Kuso with NSKE	18.00^{de}	10.33^{bcd}
Untreated Kuso	44.00^{a}	35.33^{a}
Mean	22.19	16.39
Cv%	16.17	23.4
LSD	3.03	6.48

Means within the same column followed by the same letter(s) are not significantly different; LSD (0.05) = Least significant Difference at P≤0.05; CV= Coefficient of Variations

This current observation is agreed with work of (Gwary *et al.*, 2007) who reported that the lowest covered kernel smut incidence and severity were recorded from Apron star treated plots while the highest covered kernel smut incidence and severity were recorded from control plots.

Desalegn (2016), who evaluated the efficacy of cow urine against covered kernel smut, along standard check Apron star and control check, found that Cow urine treatment controlled the disease as equal as Apron star. The researchers further discussed that this locally available material could be used as an alternative option to the chemical fungicide Apron star in sorghum covered kernel smut management.

Effect of Seed Treatments Methods of *Sporisorium sorghi* on Grain Yield and Thousand Kernel Weight

The analysis of variance showed that there were significant (P ≤ 0.05) differences among treatments in yield per plot, actual grain yield, relative yield loss percentage and thousand kernel weight (Table 3). On average, the highest (1896 kg ha^{-1}) yield plots were Faruryogele treated with Apron star and the lowest (933kg ha^{-1}) yield plots were untreated Abadiro and Faruryogele respectivel*y.* Similarly, the yield on the rest plots was ranged from 1867 kg ha^{-1}(Abadiro with Apron star) to 1055kg ha^{-1} (untreated Kuso). Also yield loss was ranged from 2% (Abadiro with Apron star) to 51% (untreated Faruryogele). The highest yield loss was recorded untreated Faruryogele whereas lowest yield loss was recorded Abadiro treated with Apron star. So Faruryogele is the most productive variety when treated with Apron star, but it showed higher yield loss when it's not treated.

This present research result is in agreement with the study of Sundaram (1980), who reported that sorghum covered kernel smut is the most serious disease if prophylactic control measures are not taken. Tegene *et al.* (2014) likewise reported that plants in the control plots were highly affected by the disease and most of the florets were changed into smut sori ending with limited normal seeds or low yield.

Also, the highest thousand kernel weight in all three varieties namely Abadiro, Faruryogele and Kuso (32.40g, 31.6 g, and 30g) were obtained from plots sown seeds treated with Apron star with less amount of yield loss while untreated plots were showed lowest thousands kernel weight. Similarly, good grain yield and insignificant yield loss was recorded in plots sown seeds treated with neem seed kernel extract and cow urine as compared to the control check.

This result is closely related to the observation by Desalegn (2016) who reported that35.05 g thousand grain weight were obtained from plots sown seeds treated with Apron Star, without any yield loss. Similarly, higher grain yield and insignificant yield loss was recorded in plots sown with seeds treated with aqueous extract of neem and cow-urine as compared to the control plots sown with untreated seeds.

Table 3. Mean values yield of three sorghum varieties using different seed treatment methods.

Treatment combination	Yield per plot(kg/ha)	Actual total grain yield per plot(kg/ha)	Relative yield loss (%)	Thousand kernel weight (g)
Abadiro with Apron star	1867^{a}	583.6 ^{ab}	2.00^{f}	32.40^{a}
Abadiro with Cow urine	1422^{bcd}	488.9 ^{bc}	23.87^{cd}	31.83 ^{b}
Abadiro with NSKE	1511^{bc}	471.1 ^{cd}	21.33^{de}	31.20 ^{cd}
Untreated Abadiro	933^{f}	351 ^{ef}	42.53^{ab}	30.87^{de}
Faruryogele with Apron star	1896^{a}	626.7 ^{a}	8.00^{ef}	31.60^{bc}
Faruryogele with Cow urine	1556 ^{b}	500.9 ^{bc}	20.53^{de}	31.13 ^{cd}
Faruryogele with NSKE	1200 ^{ef}	401.3^{cdef}	37.57^{abc}	31.17 ^{cd}
Untreated Faruryogele	933 ^{f}	328 ^{f}	51.00^{a}	29.70 ^{f}
Kuso with Apron star	1600^{b}	487.6 ^{bc}	3.00^{f}	30.83^{de}
Kuso with Cow urine	1244^{cde}	412 ^{cdef}	21.17^{de}	30.77 ^{de}
Kuso with NSNE	1200d^{ef}	443.3 ^{cde}	23.93^{cd}	30.57^{e}
Untreated Kuso	1055^{ef}	376 ^{def}	32.67 ^{bcd}	30.03^{f}
Mean	1368.1	1455.9	23.9	33.6
Cv%	10.4	12.6	32.8	2.9
LSD	0.18	0.22	13.31	0.46

Means within the same column followed by the same letter (s) are not significantly different; LSD (0.05) = Least significant Difference at P≤0.05; CV= Coefficient of Variations.

Association of Disease Parameters and Yield Components

Estimates of correlation coefficients of incidence, severity, actual total grain yield, thousand kernel weight and yield loss were calculated (Table 4). Disease Incidence was highly significant ($P \leq 0.01$) and negatively correlated with yield per plot (r =-0.65), actual total grain yield (r = -0.67) and thousand kernel weight (r = -0.45). Similarly, disease severity was showed highly significant ($P \leq 0.01$) and negative correlation with the total yield per plot (r = -0.76), actual total grain yield (r = -0.65) and thousand kernel weight (r = -0.63). Generally, the association showed that the two disease parameters (incidence and severity) were inversely related to the yield components. This indicates that the reductions in yield components were aggravated by the disease.

On the other hand, the relative yield loss percentage had highly significant ($P \leq 0.01$) and positive correlation with incidence (r = 0.48) and severity (r = 0.75) but it had Negative correlation with total yield per plot (r = -0.79) and actual total grain yield (r = -

0.69). Likewise, thousand kernel weight also showed highly significant and negative correlation with relative yield loss (r = -0.59). This indicated that yield loss was mainly due to high incidence and severity of the disease. Merkuz and Getachew (2012) reported also that the Estimate of correlation coefficients of incidence and severity with yield loss, thousand seed weight and germination were computed. Incidence and severity were significantly positively correlated for yield loss. Incidence and severity were significantly negatively correlated with thousand seed weight (g).

Regression analysis also was done for both severity with total yield per plot and relative yield loss. The coefficient of determination (R2) showed that the severity reported for total yield per plot to the extent of 57.33%, whereas the severity also accounted for about 75.9% for the relative yield loss percentage. Further regression analysis indicated that there was significant linear relationship of severity with total yield per plot with (y = -0.0163x + 1.297) and with relative yield loss (y = 0.9952x + 7.6558) (Figure 1 and 2).

Table 4. Association of yield parameters of the varieties with seed treatment at Aburin dry land research Centre during 2019-2020 main cropping season.

Variables	Incidence	Severity	TYPP	ATGY	RYL	1000kw
Incidence	1					
Severity	0.65***	1				
TYPP	-0.65***	-0.76***	1			
ATGY	-0.67***	-0.65***	0.92***	1		
RYL	0.48***	0.75***	-0.79**	-0.69**	1	
1000kw	-0.45***	-0.63**	0.66***	0.67**	-0.59**	1

***, ** And *= Correlation is highly significant, significant at 0.001and ns=non-significant.
TYPP=Total yield per plot, ATGY= actual total yield per plot, RYL= relative yield loss, 1000KW=1000 kernel weight

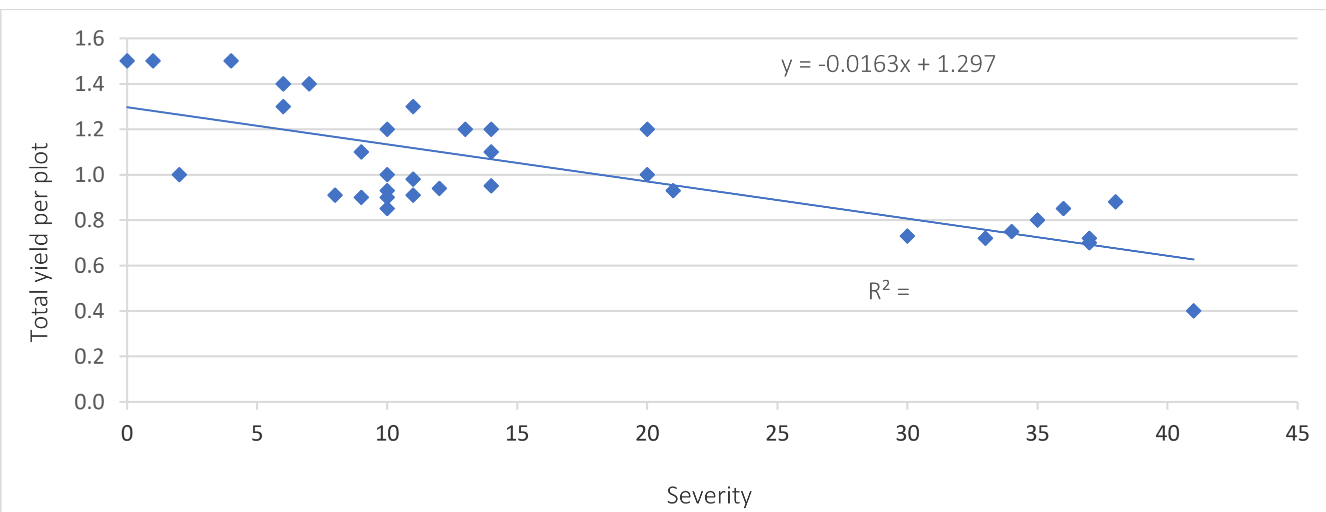

Figure 1. Linear regression of total yield per plot over severity all the varieties with the different seed treatment methods.

Partial Budget Analysis

Average yield

On average, the highest average yields (1896 kg ha-1 and1867 kg ha-1) were obtained Faruryogele treated with Apron star and Abadiro with Apron star whereas the lowest average yield (933kg ha^{-1}) was obtained untreated Abadiro and Faruryogele respectivel*y.*

Adjusted yield

The adjusted grain yield of all the treatments were varied from 1706.4kg ha^{-1} to 839.7kg ha^{-1} (Table 5). The highest (1706.4kg $^{-1}$) adjusted yield was Faruryogele variety treated with Apron star followed by Abadiro with Apron star while the lowest (839.7kg $^{-1}$) adjusted yield was recorded untreated Faruryogele and untreated Abadiro variety.

This result is line with Desalegn (2016) who reported that the adjusted grain yield was varied from 1804.50 kg ha^{-1} (control) to 3511.80 kg ha^{-1} (Apron star) while adjusted grain yield of other treatments were in between the control and the Apron star treated plots for Gubye variety.

Gross field benefit

The gross farm benefit was ranged from 853.2-dollar ha^{-1} to 419.8-dollar ha $^{-1}$ (Table 5). The highest (853.2-dollar ha^{-1}) gross farm benefit was scored Faruryogele treated with Apron star followed by Abadiro with Apron star whereas the lowest (419.8-dollar ha^{-1}) gross farm benefit was recorded untreated Faruryogele. Generally, all the untreated plots were showed less gross field benefit compared to the treated plots.

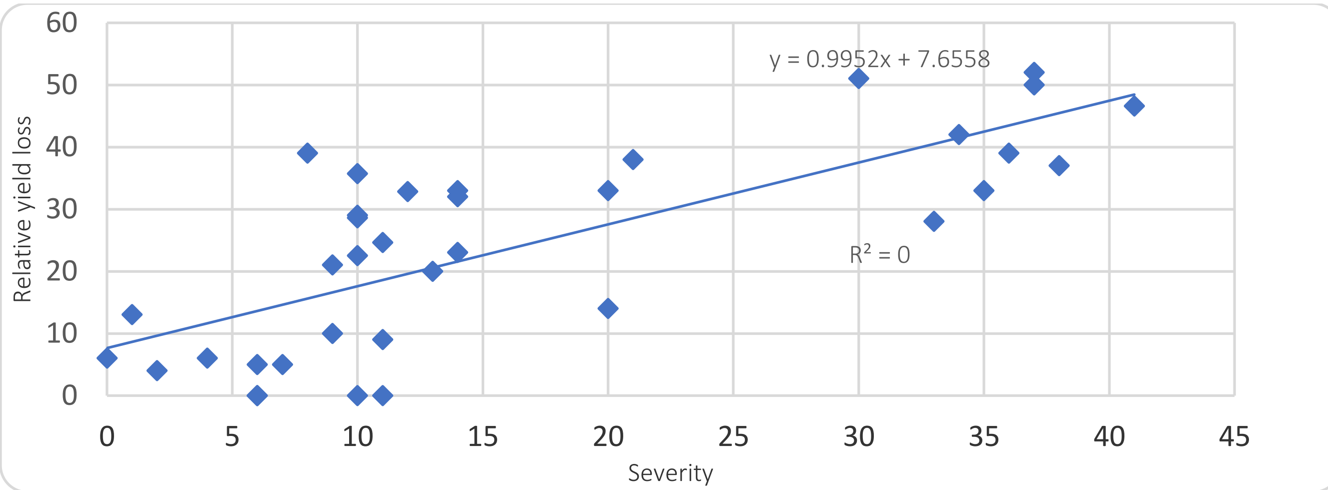

Figure 2. Linear regression of yield loss percentage over severity all the varieties with the different seed treatment methods.

Desalegn (2016) also reported that the highest gross farm benefit (19314.90-birr ha-1) was obtained from the Apron star treated plots for evaluation of different seed treatments on Gubye variety. On the other hand, the lowest gross field benefit (9924.75-birr ha1) was obtained from the untreated (control) plots.

Total variable input costs

In this experiment, the costs that differ were only those associated with input buying and input preparation. The maximum variable cost recorded were Apron star (36 dollar) followed by neem seed kernel extract ($9 and fermented cow urine (7.5) for all the varieties while lowest were untreated seeds which was zero.

Net benefit

As a result, showed, the highest net benefit of all the treatments were obtained from Apron star treated plots of Faruryogele, Abadiro and Kuso those showed 841.2-dollar ha^{-1}, 828.2-dollar ha^{-1}- and 708-dollar ha^{-1} respectively (Table 5). The lowest net (419.8-dollar ha^{-1}) benefit was recorded untreated Abadiro plots followed by untreated Faruryogele (439.9-dollar ha^{-1}). Therefore, after getting net benefit the marginal rate of return is more significant in order to recommend the most effective management method.

This current observation is agreed with Desalegn (2016) who reported the highest net benefit (19109.90-birr ha^{-1}) was obtained from Apron star treated plots followed by fermented cow urine treated plots (18655.80-birr ha^{-1}), neem leaf crude extract treated plots (18269.45-birr ha^{-1}) and papaya leaf crude extract treated plots (18239.75-birr ha^{-1}. Birr is Ethiopian currency (1 USD=30 Birr).

Marginal rate of return

The objective of a partial budget analysis in plant disease management is to recommend management methods that are effective, economically superior and socially acceptable to farmers. So that the highest (103.12-dollarha^{-1}) marginal rate of return was recorded Faruryogele with Cow urine followed by Abadiro with Cow urine while the lowest (19.43-dollar ha^{-1}) marginal rate of return was recorded Kuso with Apron star. Generally, the Apron star gave the highest net benefit, and the Cow urine and Neem seed kernel extract plots also gave marginal rate of return almost more than Apron star.

Table 5. Partial Budget Analysis.

Treatment combination	Average grain yield (kg/ha)	Adjusted yield (kg/ha)	Price (dollar/kg)	Gross farms get benefit (dollar/ha)	Total variable input cost/ha	Net benefit Dollar/ ha	Marginal rate of return
Abadiro with Apron star	1867	1680.3	0.5	840.2	12	828.2	34.03
Abadiro with Cow urine	1422	1279.8	0.5	639.9	2.5	637.4	87.04
Abadiro with NSKE	1511	1359.9	0.5	679.9	3	676.9	85.7
Untreated Abadiro	933	839.7	0.5	419.8	0	419.8	------
Faruryogele with Apron star	1896	1706.4	0.5	853.2	12	841.2	33.44
Faruryogele with Cow urine	1556	1400.4	0.5	700.2	2.5	697.7	103.12
Faruryogele with NSKE	1200	1080	0.5	540	3	537	32.37
Untreated Faruryogele	933	839.7	0.5	439.9	0	439.9	------
Kuso with Apron star	1600	1440	0.5	720	12	708	19.43
Kuso with Cow urine	1244	1119.6	0.5	559.8	2.5	557.3	33
Kuso with NSKE	1200	1080	0.5	540	3	537	20.73
Untreated Kuso	1055	949.5	0.5	474.8	0	474.8	-------

Therefore, to reduce yield loss that was caused by covered kernel smut, so as to increase return, farmers can use all of the effective and economically feasible (Apron star, fermented Cow urine and Neem seed kernel extract) seed treatment methods.

Azanaw *et al.* (2020) reported that even though Thiram and Apron plus are beneficial they are dominated by Cow urine treated plots.

Marginal rate of return was gained on Cow urine soaked (29715), so for additional 1-birr (Ethiopian currency) cost on cow urine it hosts 297.15 Ethiopian birr (1 USD=30 Eth Birr). Researchers concluded these indicate that use of the fungicides and cultural practice Cow urine are cost effective or are profitable on sorghum production for covered smut control.

CONCLUSION AND RECOMMENDATIONS

With respect to seed treatments, fungicide, botanical and Cow urine mostly showed a significant difference in controlling sorghum covered kernel smut as compared to the control check. Sorghum seeds treated with Apron star had less smut incidence, severity and produced significantly higher yield compared to untreated seeds. So that the disease incidence and severity of Apron star treated seeds for all the varieties were ranged from 4.33% to 17.33% and 4.0% to 6.0% respectively while yield was ranged from1896kg ha^{-1} to 1600kg ha^{-1}. Furthermore, Apron star seed treatment showed an effect enhancing seed germination and promote better crop stand and reduced relative yield loss all of the varieties.

Next to the Apron star, seeds treated with Cow urine suppressed smut incidence, severity and mostly resulted in high yield compared to the untreated seeds. Approximately to that of Cow urine, Neem seed kernel extract also reduced smut incidence of the varieties and it also offered high yield most of the varieties compared to the control check.

In terms of economics, the highest net benefit was obtained from Apron star treated seed of all the varieties followed by Cow urine while the lowest net benefit was obtained from untreated seed most of the varieties. Generally, the Apron star gave the highest net benefit, but the Cow urine and Neem seed kernel extract plots gave marginal rate of return almost more than of the other seed treatment method.

The tested sorghum varieties had a different adaptability to seed treatments. The sorghum variety which was identified that its resistant (Faruryogele) well adapted with seed treatments to the disease will use for farmers to produce better yield, so as to improve their livelihoods, as well as this variety will be used by supplementing seed treatments specially Apron star following by Cow urine and Neem seed kernel extract.

In the future the above-mentioned varieties should be tested across wide environmental conditions including in greenhouse, to ensure the stability of their resistance, and along with resistant checks.

ACKNOWLEDGEMENTS

Our deepest gratitude goes to Bahir Dar University and Somaliland Government for their assistance during the study.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

AUTHORS CONTRIBUTIONS

All the authors have contributed equally to the research and compiling the data as well as editing the manuscript.

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