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Sorghum (*Sorghum bicolor* L. (Moench)) physiological Seed Quality as Influenced by Seed Source and Identification of Associated Fungal Diseases

[1]Fekede Tena, [2]Mosisa Tolossa and [3]Minyahil Kebede

[1]Ethiopian Institute of Agricultural Research, Seed Science Research Program, Holleta Agricultural Research Center, Holleta, Ethiopia

[2]Ethiopian Institute of Agricultural Research, Seed Science Research Program, Assosa Agricultural Research Center, P.O. Box 265, Assosa, Ethiopia

[3]Ethiopian Institute of Agricultural Research, Plant Pathology Research Program, Assosa Agricultural Research Center, P.O. Box 265, Assosa, Ethiopia

ABSTRACT

Background and Objective: Sorghum (*Sorghum bicolor* L. (Moench)) is a major cereal grain produced in Ethiopia. Production of low-quality seed and low area coverage of improved varieties of sorghum seed are major problems for the low production and productivity of sorghum crops. This study was conducted to assess seed quality and diseases of sorghum from formal and informal seed sources and fungal seed-borne pathogens associated with sorghum in major growing areas of Benishangul Gumuz Region, Ethiopia. **Materials and Methods:** Seed quality assessments were made using a multistage purposive sampling technique based on the production potential of districts and peasant associations. Fungal disease identification was done from the aforementioned samples by standard seed health testing method. The survey data were analyzed using descriptive statistics and the laboratory data were analysed by the generalized linear model. **Results:** The research centers, farmer to farmer, farm-owned seed and regional agricultural bureau are seed sources of the region. The correlation analysis in the current study indicates seed sources have a strong and negative correlation with thousand seed weights and have no correlation with vigor index one. The speed of germination (r = 0.89, r = 0.99); standard germination (r = 0.77, r = 0.92); shoot dry weight (r = 0.95, r = 1); average shoot length (r = 1, r = 0.96) and average root length (r = 0.99, r = 0.93) associated at a given coefficient of correlation with vigor index 1 and vigor index 2, respectively. Seed-associated pathogens were identified at the spps., level during the seed health test. **Conclusion:** The physiological and sanitary quality of the seeds in the current study was influenced by the seed source, as well as certain pre and post-harvest seed management practices. In order to achieve high-quality sorghum seeds and minimize seed health problems, it is crucial to maintain conducive field conditions and implement proper post-harvest practices in sorghum seed preservation.

KEYWORDS

Fungal seed pathogen, seed source variation, seed germination and vigor, fungal seed diseases, seed borne pathogen

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INTRODUCTION

Sorghum (*Sorghum bicolor* L. (Moench)) is an important cereal crop and is grown in semi-arid areas as a human food[1]. Ethiopia is centre of origin and diversity[2] and highly contributed to the global genetic pool of sorghum crops. Sorghum is a stable food crop in many countries of tropical Africa. Attributed to its drought resistance, sorghum is a crop of choice for regions and agro ecological zones with unreliable rainfall[3]. Sorghum is the third most important crop after teff and maize in terms of total area production in Ethiopia[4].

It is normally cultivated in altitudes as high as 2500 m and as low as near sea level. A significant feature of the Ethiopian sorghum is that the dominant crop in the lowlands where droughts and poor harvests are common occurrences[5]. Sorghum is among the major cereal crops used for human consumption and the production of different local beverages in Ethiopia and accounts for 23.26% of the total cultivated areas in Benishangul Gumuz Regional states[4].

Sorghum remains critically important for rural food security in the region. Most production is consumed by the households producing the crop and only a small proportion of the harvest enters the commercial market. The average yield of sorghum is 1314-3056 kg/ha, less than world yield, 2000 kg/ha. This is emanating from the use of low-quality seeds and the presence of a weak seed system in the country. The post-harvest constraint adds a burden to small-scale farming communities of sorghum producers. A major post-harvest problem of cereal crops and sorghum in particular is a lack of improved storage technology and the absence of disease management. This directly leads to low seed quality and indirectly to low production of seed as bad quality and disease-affected seed give poor field crop establishment in the coming season.

Most small-scale sorghum farmers in Ethiopia use the informal seed for crop production which is sometimes an unknown source. The low yield and low-quality sorghum seed in developing countries including Ethiopia is attributed to both pre-harvest and post-harvest factors that need the assessment of basic problems. The seed for crop production can be either formal or informal sources. In spite, the quality of seed from formal seed and informal seed sources is significantly different. It is believed that the seed from the formal seed system has a higher standard of genetic, physiological and health quality. Despite of that small-scale farmers in developing countries use seeds of low quality obtained from informal seed systems of unknown quality standards. The seed obtained from informal seed sources in another way usually cannot fulfill the field and laboratory standards of seed fortunately, can lead to low physiological quality and an outbreak of seed-borne disease outbreak in the next generation of seed production[6]. Therefore, this study aimed to assess major constraints for low seed quality production and productivity of sorghum seed, to assess the physical and physiological seed quality of sorghum from different seed sources and to assess seed-borne pathogens of sorghum in major growing areas.

MATERIALS AND METHODS

Study location: This work was conducted at Assosa and Kamash Zone; Benishangul Gumuz Regional State of Ethiopia. It is agro-ecologically categorized as mid-high land with altitude ranges from 500-2800 m.a.s.l. The area receives rainfall of about 1275 mm. The temperature is 16.75 and 27.92°C (maximum) during rainy and non-rainy seasons, respectively. The study was carried out from November, 2019 to October, 2021.

Sampling procedures and data collection: A multistage purposive sampling technique was employed based on the production potential of districts and kebeles. A total of 69 seed samples were collected from two zones, 4 districts from each zone. The sampling source includes farmers, research centers and retailers. Six farmers and two unions/retailers from each district and two farmers and one retailer from one special district were selected. Secondary data were collected through key informant interviews using previous pre-prepared questionnaires.

Laboratory experiments: All seed quality parameters were measured according to the International seed testing association[7].

Moisture content: It was measured by using an electronic moisture tester immediately after the submitted sample was received in the laboratory following international rules for seed testing[7].

Analytical purity: About 90 g of working sample was obtained from 0.9 kg of sample and each sample was divided into categories of seed composition; pure seed, other crop seed, inert matter and weed seed. Then, the percentage of each fraction based on weight was calculated.

Thousand seed weight: About 1000 pure seeds were counted by the seed counter and weighed on a top loading sensitive precision balance (electronic technology Co., Ltd, Fujian, China).

Standard germination: One hundred pure seeds in four replicates were sown on a sterilized sand medium to test for standard germination. After 10 days, the germination percentage was calculated as Eq. 1 specified by Badigannavar *et al.*[6]:

$$\text{Standard germination} = \frac{\text{Sum of normal seeding}}{\text{Sum of planted seeds}} \times 100 \quad (1)$$

Shoot and root length of seedlings: Root length is computed by the sum of root length in replicates to the ratio of the total number of normal seedlings and the same procedure is employed to measure the shoot length of seedlings. Shoot length is measured from the tip of the cotyledon to the tip of the shoot and root length is from the cotyledon attachment to the tip of the root[8].

Dry weight of seedlings: The dry weight was measured using the procedure of the International seed testing Association[7]. Seedling dried in the heat sterilization oven 220v; (Dongguan Liyi Environmental Technology Co., Ltd., China) at 80+1°C was weighed nearest milligram and the mean of the seedling dry weight was calculated.

Speed of germination and vigor indices: The fast germinated seed lot, an indicator of the more vigor seed lot would be in the growing season. The speed of germination (SG) was calculated as follows[9]. The formula for its calculation given below under Eq. 2:

$$SG = \frac{\sum \text{Normal seeding}}{\text{Days of first count}} + \ldots + \frac{\sum \text{Normal seeding}}{\text{Days of final count}} \quad (2)$$

Seed vigor index 1 (Eq. 3) and vigor index 2 (Eq. 4) calculated by the formulae suggested by Abdul-Baki and Anderson[10]:

$$\text{Vigor index 1} = \text{Seeding length (cm)} \times \text{Germination (\%)} \quad (3)$$

$$\text{Vigor index 2} = \text{Seeding dry weight (g)} \times \text{Germination (\%)} \quad (4)$$

Seed health test: Seed-borne pathogens were measured by subjecting samples to the blotter paper method. The seeds were sanitized with 1% NaOCl and 75% alcohol solution for 2 min and rinsed with distilled water 3 times[7]. The 10 to 15 seeds were placed at estimated equal distances on the Petri dishes (Fig. 1a) and incubated at a temperature of 25°C for 7 days on blotter paper; this enhanced fungal growth and structural development (Fig. 1b). Then slides were prepared and colonies of fungi were identified on each seed by their cultural characteristics and spores using stereo- and compound-microscopes.

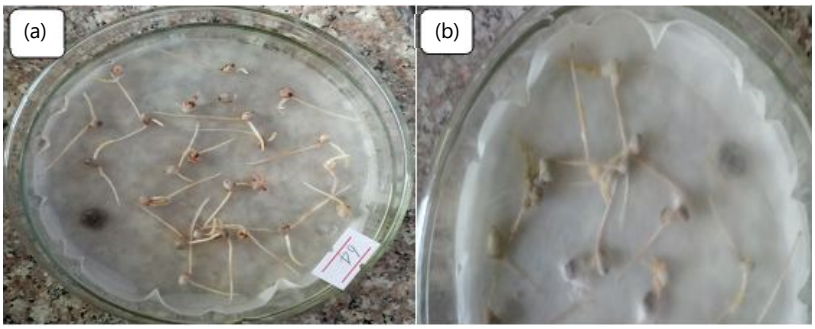

Fig. 1 (a-b): Seed health test method using blotter paper, where; (a) Sorghum seed plate on blotter paper and (b) Developed fungal mycelia after 7 days incubation

Statistical analysis: The survey data were analyzed using descriptive statistics (percentile) by SPSS software (version 20). The proportion of crop production at study areas, percentage of farmer's seed sources, frequency of land preparation, the proportion of sowing methods, post-harvest storage practice viz percentage duration of storage in the range of months and seed treatment (presence and absence of seed treatment) were analyzed by descriptive statistics. For laboratory experiments, the treatments were laid out in a completely randomized design. One hundred seeds from the working sample of each source were randomly replicated 4 times and sown on sterilized sand medium[7]. The data of seed quality tests obtained from the laboratory were analysed with the Analysis of Variance (ANOVA) technique using SAS version 9.3 and mean comparisons among treatments were done using Tukey's studentized range test at a 5% level of significance. Pearson's correlation coefficient (r) between seed source, seed analytical purity and physiological seed quality was also done using SAS version 9.3.

RESULTS

Proportion of crop production: Among 52 farmers housed, the proportion of sex respondents showed that 78.8% of the farmer households were males and 21.2% were female-headed households. The highest 57.69% of the respondents used to cultivate crops in areas less than 3 ha and 23.08% used 1-2 ha of land. About 1.92% of the farmers used to cultivate an area of less than one ha. About 1-2 ha of land was allocated for sorghum production by 44.23% of the farmers in the area followed by 26.92% of farmers cultivated on an area of less than one hectare. The last 7.69% of the farmers used to cultivate the crop in areas greater than three hectares.

Farmers seed sources: There were four seed sources in the area. The highest 83.3% of local sorghum seed varieties were obtained from farm-owned seed followed by 11.1% of the local varieties seed sources were provided through the exchange in cash or in kind from other farm-owned seed farmers. Whereas, the highest (81.2%) of improved variety was provided by the research centre for the farmer and 18.8% of the seed was provided by Agricultural Bureaus by developmental agents (Fig. 2). The higher 60% of the seed demand of the area covered by improved varieties followed by 40% was local verities.

Cultural and local practice of sorghum producers

Land preparation and ploughing: The land preparation and frequency of ploughing play a key role in quality seed production. The research revealed that the highest 58.3% of the respondents in the survey area had undergone one tilling practice for sorghum production and 82.4% of them used human power. Similarly, 58.3% of respondents tilled the land twice by using animal power and 53.8% of the respondents till the sorghum production field three times by using animal power. About 4.2% of the farmers rent tractors for land ploughing and this contributes to less sorghum seed production in the areas.

Sowing methods across survey areas: The highest 55.8% of the farmer used to sow seed using recommended spacing, while 38.5% of the respondents used to sow seed in broadcasting. The lowest 5.8% were using zero tillage practice (Fig. 3).

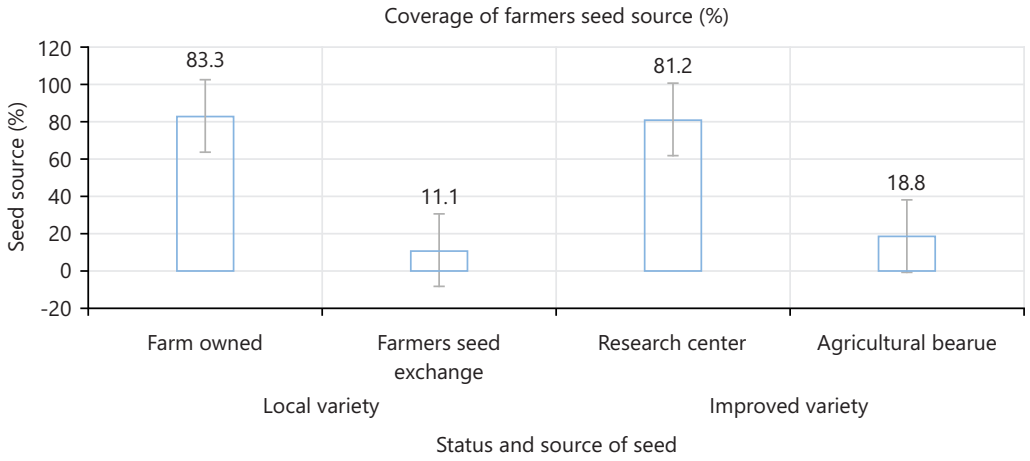

Fig. 2: Seed sources and their contribution to sorghum production

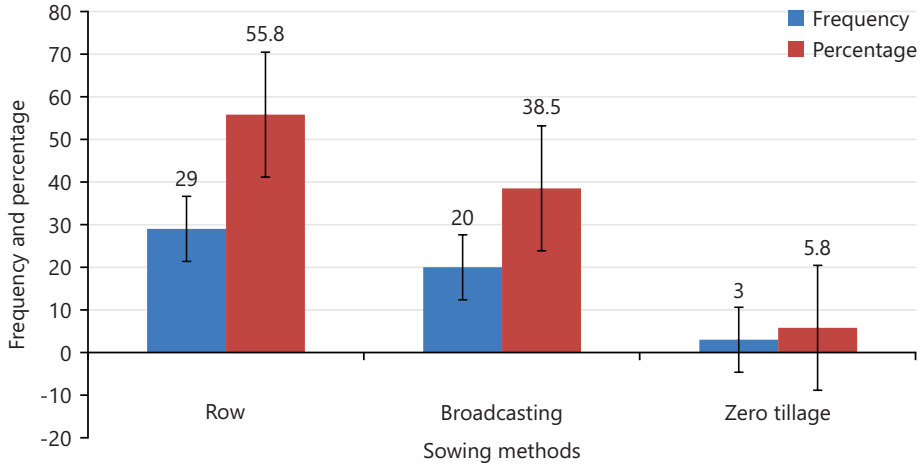

Fig. 3: Frequency of farmers and percentage of respective frequencies based on sowing method
Frequency represent a number of farmers practicing each type of sowing methods out of assessed farmers, while percentage represent number of farmers in percentile

Duration of seed storage and treatment: Proper seed storage is used to keep seeds without losing quality and genetic potential. About 40% of the farmer stored seeds from 4-6 months and all of them were treated with chemicals. On the other hand, 60% of the respondents stored seeds from 4-6 months without seed treatments and 19.4, 2.8, 8.3 and 2.8% of the respondents stored seeds for 6-8, 8-10, 10-12 and above 12 months respectively without seed treatments.

Physical and physiological seed quality

Physical purity: Highly significant differences were observed for seeds obtained from different districts ($p<0.001$) for pure seed. The highest 99.07% pure seeds were recorded for the seed of the Yaso district followed by the Homosha district. Statistically, there were no differences among the other districts.

Thousand seed weight (TSW): Mean 1000 seed weight ($p<0.001$) showed significant differences for seeds obtained from different districts. The highest average 1000 seeds weights of samples collected were recorded from Sedal District whereas the lowest were recorded for Bambasi district. The TSW of samples from Agalometi, Kamash and Sedal Districts statistically showed non-significant differences (Table 1).

Standard germination: The proportion of normal seedlings, abnormal seedlings and dead seeds of different seed sources under laboratory tests were recorded. Likewise, purity test, highly significant differences ($p<0.0001$) were observed for seed sources of different districts.

Table 1: Analytical purity, thousand seed weight and speed of germination and standard germination of seeds from different districts

District	Analytical purity (%)	Thousand seed weight (g)	Speed of germination	Standard germination (%)
Assosa	97.44^{cb}	24.25^{fe}	185.56^{ab}	71.27^{cb}
Agalometi	97.18^{cb}	36.34^{ab}	153.92^{c}	59.81^{d}
Bambasi	96.58^{c}	21.45^{f}	200.05^{a}	77.49^{a}
Homosha	98.13^{ab}	28.89^{de}	150.41^{c}	67.77^{cb}
Kamashi	97.30^{cb}	38.09^{ab}	166.36^{cb}	67.36^{c}
Mao Komo	97.16^{cb}	31.74^{db}	162.97^{cb}	72.19^{cb}
Sirba	96.90^{cb}	42.02^{a}	151.93^{c}	72.87^{ab}
Yaso	99.07^{a}	30.41^{de}	196.68^{a}	69.84^{cb}
LSD	1.45	6.9	28.24	5.17
CV	1.49	19.30	15.62	6.21
±SE	0.12	2.43	21.21	4.92

Means followed by the same letter within a column are not significantly different at 5% level of significance, LSD: Least significant difference and CV: Coefficient of variation (%)

Table 2: Shoot and root length, seedling dry weight, vigor index I and vigor index II of seeds from different districts

District	ASL (cm)	ARL (cm)	SDW (g)	VI	VII
Assosa	6.63^{ab}	3.12^{b}	1.18^{ab}	360.51^{b}	84.85^{ab}
Agalometi	6.05^{bc}	2.81^{bc}	1.15^{ab}	264.5^{e}	68.75^{bc}
Bambasi	7.08^{a}	3.65^{a}	1.30^{a}	420.6^{a}	94.46^{a}
Homosha	5.79^{c}	2.74^{bc}	1.00^{b}	293.04^{e}	70.55^{bc}
Kamash	6.32^{abc}	2.69^{c}	1.04^{b}	309.78^{ec}	59.82^{c}
Maokomo	6.07^{bc}	2.76^{bc}	1.02^{b}	323.26^{bc}	65.48^{bc}
Sirba	6.65^{ab}	2.94^{bc}	1.17^{ab}	351.29^{bc}	81.94^{ab}
Yaso	6.10^{bc}	2.69^{c}	1.00^{b}	309.45^{ec}	71.23^{bc}
LSD	0.84	0.4	0.24	50.68	20.35
CV	14.55	14.78	23.73	15.9	29.03
±SE	1.23	0.22	0.12	21.1	11.99

Means followed by the same letter within a column are not significantly different at 5% level of significance, LSD: Least significant difference, CV: Coefficient of variation, ASL: Average shoot length, ARL: Average root length, SDW: Seedling dry weight, VI: Vigour index I and VII: Vigour index II

Speed of germination: Significant differences in mean speed of germination were observed for seeds obtained from different districts ($p<0.05$). The highest mean values of speed of germination for samples collected from Bambasi and Yaso Districts were recorded followed by Assosa District. But all the others showed statistically non-significant differences.

Length of shoot, root length and seed vigor indices: The length of shoot was measured from the sprout of plumule from seed coat to the tip of the seedling and root length was measured from the point from the sprout out of radical from seed to tip of root. Accordingly, a significant difference was obtained for seed samples collected from different districts ($p<0.01$). The highest mean value of shoot length was recorded for the sample collected from Bambasi followed by Assosa, Kamash and Sedal District. The lowest mean values of average shoot length were recorded from the Homosha district. But there was no significant difference among the mean value of samples collected and tested for average root length ($p<0.01$).

Several physiological tests such as standard germination, seedling shoot length, seedling root length and seedling dry weight were measured to assess the vigor of sorghum seed obtained from different districts. Significant variation was observed for normal seedlings, root length, vigor index-I and vigor index-II except root length for seed sources from different districts (Table 2). According to the vigor test analysis, collected seed samples seeds showed significant differences for vigor index -I and vigor index II ($p<0.001$). The highest mean values of V-I and V-II were obtained from a sample collected from the Bambasi District followed by Assosa and Sedal Districts for V-II only. The lowest mean values were recorded from seed samples of Agalometi and Kamashi Districts for V-I and V-II, respectively.

Table 3: Pure seed, inert matter, thousand seed weight, speed of germination and standard germination of seeds from different seed sources

Seed sources	PS (%)	TSW (g)	SP	SG (%)
O	91.31[b]	34.49[a]	152.29[c]	64.19[c]
RC	98.01[a]	29.45[b]	208.51[a]	86.06[a]
R	85.03[c]	25.79[b]	177.46[b]	68.16[b]
LSD	0.99	3.82	17.13	2.77
CV	3.06	22.73	16.80	7.57
±SE	5.45	1.2	15.5	4.23

Means followed by the same letter within a column are not significantly different at 5% level of significance, LSD: Least significant difference, CV: Coefficient of variation, O: Farm owned seed, RC: Research center, R: Retailers, Ps: Pure seed, TSW: 1000 seed weight, SP: Speed of germination and SG: Standard germination

Table 4: Shoot and root length, seedling dry weight, vigor index I and vigor index II of seeds across seed sources

Seed sources	ASL (cm)	ARL (cm)	SDW (g)	VI	VII
O	5.75[b]	2.63[b]	1.14[b]	269.6[c]	73.37[b]
RC	11.00[a]	3.80[a]	2.04[a]	622.58[a]	171.20[a]
R	6.21[b]	2.76[b]	0.65[c]	269.6[c]	44.30[c]
LSD	0.53	0.28	0.08	29.36	6.22
CV	10.64	13.89	10.02	12.66	10.23
±SE	1.11	1.43	1.78	15.23	2.45

Means followed by the same letter within a column are not significantly different at 5% level of significance, LSD: Least significant difference, CV: Coefficient of variation, O: Farm owned seed, RC: Research center, R: Retailers, ASL: Average shoot length, ARL: Average root length, SDW: Seedling dry weight, VI: Vigour index I and VII: Vigour index II

Seed quality by seed sources: Seed collected from different districts were tested for seed quality and analyzed based on seed sources and compared with early generation seed (EGS). The research center, farm owned saved seeds and retailers are the three main seed sources of sorghum in the region. Based on this category the seed quality was tested in the laboratory. Accordingly, there was a significant variation ($p<0.0001$) in purity analysis between seed sources.

Thousand seed weight and average shoot length did not show significant differences ($p = 0.05$) among seed sources. However, all parameters of seedling vigor showed significant variation. Seed from the research center (EGS) recorded the highest mean values of 208.51, 86.06, 11, 2.04, 622 and 171.2% for parameters such as SP, SG, ASL, SDW, V-I and V-II, respectively (Table 3 and 4). Both mean purity percent values of seeds from retailers and farm owned seeds did not meet the quality and standards authority of Ethiopia.

Seed quality by variety type: The effects of improved and local varieties were analyzed for seed samples of sorghum collected from different districts. All the seed quality parameters such as pure seed, TSW, speed of germination, standard germination, average shoot, root length, V-I and V-II were highly significantly different ($p<0.001$). The average mean values of all seed quality parameters of improved varieties of sorghum recorded higher values than local varieties except for mean values of TSW (Table 5 and 6). The improved varieties used in the area are Assosa-1 and Adukara which have been released from Assosa Research centers.

Correlation of seed source with seed physical and physiological quality

Seed health: During laboratory seed health tests sorghum seed associated pathogens were identified at the species level. Eighteen species of fungi were identified. The most occurring fungi in all seed samples were *Aspergillus flavus*, *Chaetomium globosum*, *Curvularia lunata* and *Rhizopus stolonifer*. The seed sample collected from mid-altitude in Maokomo District was not infected with seed born fungi as the other samples (seed samples had improved seed variety due to low temperature which is not favorable for fungi developments).

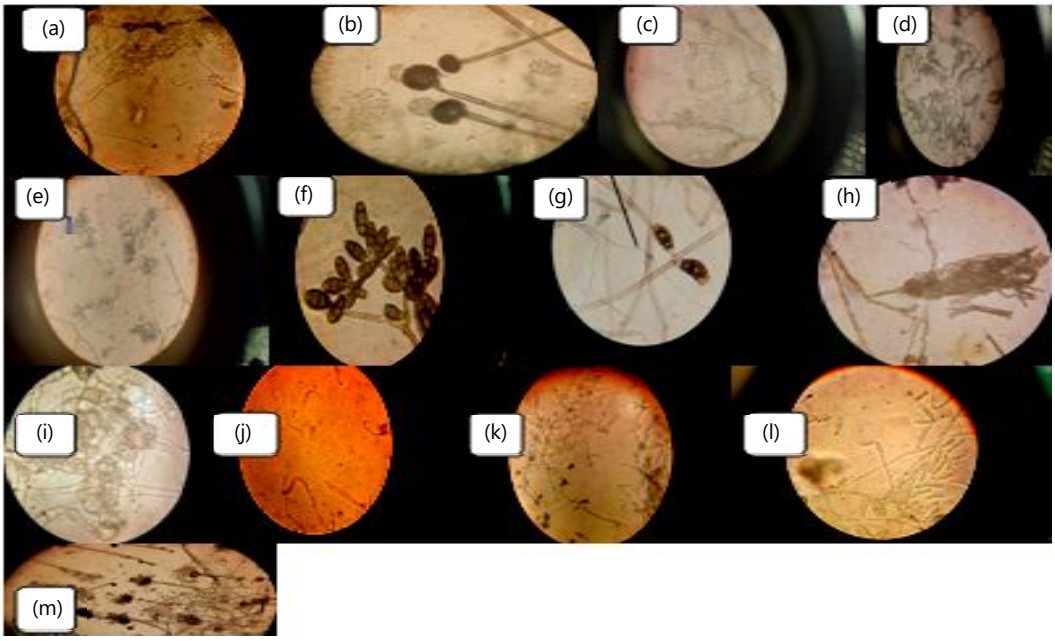

Fig. 4 (a-m): Mycellia and spore of identified diseases

a: *Acremonium strictum*, b: *Aspergillus flavus*, c: *Bipolaris sacchari*, d: *Cladosporium cladosporioides*, e: *Cladosporium sphaerospermum*, f: *Curvularia lunata*, g: *Curvularia pallescens*, h: *Epicoccum nigrum*, i: *Fusarium oxysporum*, j: *Fusarium semitectum*, k: *Fusarium solani*, l: *Penicillium digitatum* and m: *Rhizopus stolonifer*

Table 5: Analytical purity and physiological quality of sorghum seed from improved and local varieties

TV	Ps (%)	TSW (g)	SP	SG (%)	ASL (g)	ARL (g)	SDW (g)	VI	VII
IV	97.77^{a}	25.79^{b}	208.51^{a}	84.06^{a}	11.01^{a}	3.80^{a}	2.04^{a}	622.58^{a}	171.20^{a}
L	97.33^{b}	32.91^{a}	160.19^{b}	65.44^{b}	5.89^{b}	2.67^{b}	0.99^{b}	280.93^{b}	64.26^{b}
LSD	0.22	5.1	17.91	3.49	0.43	0.23	0.13	28.15	8.49
CV	4.43	29.24	18.60	8.91	10.56	14.02	18.72	13.74	16.69
±SE	6.11	4.94	0.25	1.61	0.11	0.89	0.78	1.22	3.21

Means followed by the same letter within a column are not significantly different at 5% level of significance, LSD: Least significant difference, CV: Coefficient of variation, IV: Improved variety, L: Local variety, Ps: Pure seed, TSW: 1000 seed weight, SP: Speed of germination, SG: Standard germination, ASL: Average shoot length, ARL: Average root length, SDW: Shoot dry weight, VI: Vigor index I and VII: Vigor index II

Table 6: Pearson's correlation (r) of seed source, analytical purity and physiological quality

	Source	ASL	ARL	SDW	VI	VII	PS	TSW	SPG	SG
Source	1									
ASL	0.07^{ns}	1								
ARL	0.16*	1.00*	1							
SDW	-0.30*	0.93**	0.90*	1						
VI	0.00^{ns}	1.00*	0.99^{ns}	0.95*	1					
VII	-0.22^{ns}	0.96*	0.93*	1.00*	0.98*	1				
PS	-0.48*	0.84^{ns}	0.79^{ns}	0.98^{ns}	0.87^{ns}	0.96*	1			
TSW	-1.00^{ns}	-0.15^{ns}	-0.24*	0.22^{ns}	-0.09*	0.13*	0.41^{ns}	1		
SPG	0.45**	0.92*	0.95^{ns}	0.72*	0.89^{ns}	0.77**	0.57*	-0.52*	1	
SG	0.17^{ns}	0.99*	1.00^{ns}	0.89*	0.99^{ns}	0.92*	0.78^{ns}	-0.26*	0.96**	1

*,**,^{ns}Significant, highly significant and non significant at p<0.01, Source: Indicate seed obtained from own stock, research center and retailers, ASL: Average shoot length, ARL: Average root length, SDW: Shoot dry weight, VI: Vigor index one and VII: Vigor index I, PS: Pure seed, TSW: Thousand seed weight, SPG: Speed of germination and SG: Standard germination

Seed born fungi such as *Bipolaris sacchari, Cercospora sorghi, Penicillium* wax and *Phomasorghina* observed on few samples as compared to others. Seed born fungi such as *Acremonium strictum* (Fig. 4a), *Aspergillus flavus* (Fig. 4b), *Bipolaris sacchari* (Fig. 4c), *Cladosporium cladosporioides* (Fig. 4d), *Cladosporium sphaerospermum* (Fig. 4e), *Curvularia lunata* (Fig. 4f), *Curvularia pallescens* (Fig. 4g), *Epicoccum nigrum* (Fig. 4h), *Fusarium moniliforme*, *Fusarium oxysporum* (Fig. 4i), *Fusarium solani* (Fig. 4k)

and *Penicillium digitatum* (Fig. 4l) were found in all samples collected from Kamash zone districts. While seed born fungi such as *Acremonium strictum*, *Aspergillus flavus*, *Aspergillus niger* (Fig. 4c), *Rhizopus stolonifer* (Fig. 4m), *Chaetomium globosum*, *Cladosporium cladosporioides* (Fig. 4d), *Cladosporium sphaerospermum*, *Curvularia lunata* (Fig. 4f), *Curvularia pallescens* (Fig. 4g), *Epicoccum nigrum* (Fig. 4h) and *Fusarium moniliforme* were occurred in all sample collected from Assosa zone (Fig. 4).

DISCUSSION

Out of the total area designated for crop production, 23 households (44.2%) allocated 1 to 2 hectares of land for sorghum seed production, indicating that sorghum crops play a significant role in ensuring food security in Benishangul Gumuz. The seed suppliers available to farmers in the area included both formal and informal sources. Improved seed suppliers in the study area were the Agricultural Research Center and the Agricultural Office of the respective districts, while 100% of local seed suppliers relied on farmers' seed exchange and farm-owned seeds.

The present work was similar to some other studies conducted in sub-Saharan Africa, where farm-owned seed contributes the largest proportion of the informal seed sector[11]. Local seed exchange data indicates that approximately 80% of farmers save their seeds for planting in the next season[12].

Despite the availability of formally certified seed supplies, quantitative and qualitative data from a seed system security assessment indicated that informal seed sources play a significant role in sustaining food security[13]. Moreover, these seed sources have substantially impacted the physiological quality of seeds. The current work aligned with laboratory studies conducted by Bekele *et al.,*[14] which demonstrated that seed sources significantly affect moisture content and hundred-seed weight.

The research revealed that 58.3% of respondents in the survey area underwent one tilling practice for sorghum production and 82.4% of them used human power. This is likely a major reason for the low production and productivity of the crop in the area. In terms of sowing methods, farmers in the study area practice row planting, broadcasting and even zero tillage. Although zero tillage is considered a form of conservation tillage in modern agriculture, it could also be a contributing factor to low seed quality, as the production of quality seed requires repeated land preparation[7].

The major contributors to maintaining seed quality are seed storage and seed treatment, which are essential for minimizing quality loss[7]. In the current study, approximately 40% of farmers stored seeds for 4-6 months and all of them treated the seeds with chemicals. Under these conditions, the quality of the seeds was comparatively higher than that of untreated seeds and seeds stored for longer durations. Studies from sub-Saharan Africa, particularly in Sudan, supported the findings of the current study, indicating that the quality of sorghum seeds is affected by the type and duration of storage[15].

The mean physical purity of the studied samples from different districts ranged from 96.58 to 99.07%, with an average of 96.58%. This indicates that these seeds had maximum impurities and did not meet the minimum prescribed standard of 98%, according to the standards authority of Ethiopia. Similar research on other cereal crops also found significant differences in physical purity and other crop seed contamination among wheat seed samples collected from various sources (both formal and informal seed systems) in Ethiopia[16].

The mean germination percentage ranged from 77.49 to 59.81%, with a mean normal germination rate of 59.81%. Generally, these results were below the minimum seed certification standard for certified seed (85%), according to the Standards Authority of Ethiopia[17]. The low germination percentage observed in the current study may be attributed to the long-duration storage of untreated seeds. More than 60% of farmers store seeds without treatment for extended periods. Additionally, the region is characterized by

humid and warm climatic conditions with high temperatures. These factors can enhance the enzymatic activity of seeds under poor storage conditions, leading to a non-significant difference in the speed of germination between samples from different seed sources. Similar findings from other authors indicate that sorghum seed respiration at the beginning strictly depends on temperature (T). The temperature also significantly affects the total CO_2 respired to reach the first germination event, which increases as temperature declines from the optimum[17].

Moreover, germination percentage and speed of germination are not an indicator of seed field establishment, hence, parameters like shoot and root length, a measure of seed vigor are required to determine the quality of a seed lot[7]. In a current study, a significant difference ($P<0.01$) in shoot and root length was obtained for seed samples collected from different districts and seed sources. The importance of the vigor index stems from the assumption that vigorous seeds yield strong, healthy and uniform seedlings. These seedlings are more likely to establish well in the field and demonstrate greater longevity.

The vigor index of any seed reflects the combined properties that determine its potential activity level and ability to thrive under various field conditions[18]. Seedlings with well-developed shoot and root systems are better equipped to withstand adverse conditions, resulting in improved seedling emergence and establishment. Consequently, seedlings with a higher vigor index are anticipated to germinate and emerge more rapidly, helping them to escape unfavorable field conditions[16].

Mean seed weight serves as an indicator of the amount of dry matter allocated to seed development. This weight may be influenced by factors such as soil fertility and planting density. Additionally, variability in seed quality can lead to differences in germination percentage, germination time, vigor index and thousand seed weight. These variations can be attributed to environmental conditions in the field and handling practices before and after harvest, which aligned with the findings of Muui *et al.*[19].

Therefore, there is a need to improve the quality of seeds used by subsistence farmers through better pre- and post-harvest handling practices. Formal seed sources are comparatively of higher quality than informal seed systems; however, in agreement with other authors, local governments should focus on strengthening informal seed systems to provide seeds to their farmers, as this system has the greatest potential to help them[20-22]. Farm-owned seed a predominant seed source serves as a major source of local sorghum varieties provided by informal seed providers. In agreement with the current study, sorghum seeds of farmers' varieties were typically obtained as gifts from parents and relatives, after which the farmers relied on their stock as the predominant seed source[23].

The correlation analysis in the current study indicates that seed sources specifically, seeds from owned stock, research centers and seeds obtained from retailers (i.e., the local market) exhibit a strong negative correlation with thousand seed weight and no correlation with vigor index one. This suggests that seeds from retailers in this study have low physiological quality, whereas seeds from research centers and farmers' owned stock have comparatively high physiological quality, as indicated by the coefficient (r) of correlation determination.

Most physiological seed quality has a strong positive correlation with vigor indices, which are the best indicators of seedling field establishment. This includes factors such as speed of germination ($r = 0.89$, $r = 0.99$), standard germination ($r = 0.77$, $r = 0.92$), shoot dry weight ($r = 0.95$, $r = 1$), average shoot length ($r = 1$, $r = 0.96$) and average root length ($r = 0.99$, $r = 0.93$) for vigor index 1 and vigor index 2, respectively (Table 6).

The most frequently occurring fungal disease in current study were *Acremonium strictum, Aspergillus flavus, Aspergillus niger, Rhizopus stolonifer, Chaetomium globosum, Cladosporium cladosporioides, Cladosporium sphaerospermum, Curvularia lunata, Curvularia pallescens, Epicoccum nigrum* and *Fusarium*

moniliforme. Seed borne pathogens of sorghum i.e *F. moniliforme* followed by *T. harzianum* and *C. globosum* infection were also reported in Denmark[24-26]. Similar with the current study, 13% of the samples tested positive for *A. favus, A. niger* and *C. lunata*[25], contrary to the presence of the most economically important *Fusarium* sp., which makes less trust for informal seed sources typically of local markets, particularly retailers. Moreover, the attributes of seed quality like genetic purity, viability, germination percent, vigor, moisture content and seed health are very important for the increment of seed yield. Therefore, it is recommended that farmers use seeds from certified seed sources and seeds from known sources with known quality standards.

CONCLUSION

The seed health and quality assessment across various seed sources showed clear disparities in both the physical quality and disease incidence among the samples. Seeds from the research center had the highest overall quality, with excellent purity (98.01%), germination rates (86.06%) and minimal signs of disease, making it the most reliable option for planting. In contrast, seeds from farmers seed (64.1%) and retailers (68.16%) displayed lower germination rates and a higher presence of fungal infections, raising concerns about their viability and potential to affect crop health. In conclusion, investing in high quality, disease free seeds from reputable sources is critical for maximizing crop productivity and minimizing the risks associated with poor seed health.

SIGNIFICANCE STATEMENT

The current study investigated the quality of seeds and the presence of seed-borne fungal pathogens in both formal and informal seed sources. These findings provide valuable information for farmers, as well as public and non-public organizations involved in sorghum seed production. The factors discussed in this study, such as storage conditions, seed treatment before sowing and the source of seeds used in seed production, can serve as a helpful guide for small-scale sorghum farmers, youth and farmers' cooperatives involved in sorghum seed and grain production. Furthermore, the findings of this study can assist policymakers in developing and revising seed regulations and standards, particularly in relation to guidelines for both formal and informal seed systems.

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