Sustainable Agriculture Research; Vol. 9, No. 3; 2020
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Evaluation of Seed Quality Attributes of Sorghum Germplasm Accessions from Eastern, Coastal and Nyanza Regions, Kenya

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Received: March 25, 2020 Accepted: April 25, 2020 Online Published: May 8, 2020

doi:10.5539/sar.v9n3p9 URL: https://doi.org/10.5539/sar.v9n3p9

Abstract

Sorghum (*Sorghum bicolor* L.) is an important cereal crop in Kenya. Despite the crops importance, the yields attained by farmers in Eastern, Coastal and Nyanza regions of Kenya remain low. Access to good quality seeds of sorghum is one of the constraints facing the subsistence farmers. Good quality seed is important for increasing yield to attain food security. The aim of this study was to evaluate quality attributes of the seed used by farmers. A total of 108 germplasm accessions were obtained from 76 farmers. The seeds were tested for time and percentage of germination, seed vigour index, shoot and root dry weight. Data collected was subjected to analysis of variance. Means were separated using Fisher's Least Significance Difference test at $p \leq 0.05$. Seed samples of 26 accessions attained germination percentage below stipulated standards by Seeds and Plant Varieties Act CAP 326. Majority of seeds showed longer mean germination time with only nine accessions germinating in less than ten days. Seed vigour index was relatively high in most of the accessions, while biomass accumulation varied from high to very low among accessions. Though most of the seeds attained a high germination percentage, about 92% of seeds showed longer mean germination time. The environmental conditions in the fields, pre and post harvest handling practices impact on the seed quality hence the wide variability in germination percentage, germination time, seed vigour index and dry matter accumulation. Therefore the need to improve quality of seeds used by subsistence farmers by providing extension services on best pre and post harvest handling practices. Increasing production of sorghum in these regions will contribute significantly towards realizing food security. Further analysis could be carried out on genetic and sanitary quality aspects of the seeds planted by farmers in Eastern, Nyanza and Coastal regions.

Keywords: attributes, germplasm, seed quality, *Sorghum bicolor*

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is an important cereal grain used and grown in semi arid areas as food for many families due to its nutritive value (Rao *et al*., 2016; FAO, 2018). The ability of sorghum to adapt to drought, salinity and high temperatures makes it a critical crop in the dry regions where other cereal crops produce low yields (Mamoudou, 2006). In Kenya, the crop is cultivated and highly consumed in semi-arid regions with low annual rainfall of about 300mm which include Eastern (1385m ASL, 76mm month $^{-1}$), Coast (185m ASL, 87mm month $^{-1}$) and Nyanza (1190m ASL, 130mm month $^{-1}$) (Grieser *et al*., 2006). With its utilization closely related to maize, sorghum can be an alternative crop in marginal areas (Swigonova *et al.,* 2004). The crop has got a large germplasm which could provide opportunities for a sustainable crop production for food security (Kange *et al.,* 2014).

Sorghum production is mainly by subsistence farmers in marginalized regions in Kenya. Despite the many benefits associated with sorghum its production is still low (Muui *et al.*, 2019). Farmers obtain seed from informal seed system which include retaining seed on-farm from previous harvests to plant the following season and farmer-to-farmer seed exchange networks (Ochieng *et al.,* 2011; Muui *et al*., 2013, 2019). Where formal seed is available, the farmers cannot afford due to high seed prices. The informal seed supply system consists of farmer-managed seed production activities and is based on indigenous knowledge and local diffusion mechanisms. Maintaining crop production in terms of yield and quality grains which give the farmer maximum return requires good seed which carries the genetic, physiological, and physical quality aspects (Muasya *et al.,* 2008; Ahmed *et al.,* 2009). Good seed requires constant care to prevent loss of quality and to ensure high yield for farmers. Seed deterioration usually commences at physiological maturity and continues during harvest, processing and storage and is governed by the genetic constitution, environmental factors during seed development and storage conditions (McDonald, 1999; Muasya *et al.,* 2008).

Seed quality is considered as an important factor for increasing yield unit area to attain food security (Badigannavar *et al*., 2016). Quality seeds have the ability for efficient utilization of available inputs such as fertilizers and moisture eventually maximizing yields (Jisha *et al.*, 2013). Use of poor quality seed is one of the constraints to sorghum production in Kenya where majority of the farmers rely on the informal seed supply sources resulting to low yields (Ochieng *et al.*, 2011). Poor seed quality at farm level is caused by poor drying of harvested grains, threshing practices, storage conditions (Harrison and Perry, 1976; Songa *et al*., 1995). Also, many subsistence farmers in Sub-Saharan Africa do not apply fertilizers to their farms (Jama *et al*., 1998; Ochieng *et al*., 2011; Muui *et al.*, 2019). This is attributed to the fact that sorghum is often grown under marginal rainfall conditions and fertilizer prices are unfavourably high in relation to sorghum grain price. This practice of using little or no fertilizer affects both seed quality and yield of the crop negatively (Swinkels *et al.,* 1997).

Sorghum landraces germplasm provides a great genetic variability with high preferences based on unique characteristics (Ng'uni *et al*., 2012). Sorghum being a food crop with the potential of alleviating the problem of food insecurity, there is need for using quality seeds for sustainable production by the subsistence farmers (Mwadalu and Mwangi, 2013). This study aimed at assessing the quality of on farm saved sorghum seeds used by farmers at eastern, coastal and nyanza regions of Kenya. A total of 108 germplasm accessions were collected from farmers to determine germination percentage, germination time, seed vigour index, seedling shoot and root dry weight.

2. Materials and Methods

2.1 Description of experimental Site

The experiment was carried out in Kenyatta University situated in Nairobi County about 20 Km from Nairobi city along Nairobi-Thika road between August and October 2018. The county is characterized by a warm climate with temperatures varying between 12 ℃ and 18.7 ℃. The rainfall aggregate for the county is 1,000 mm per year. Its geographical coordinates are 1 °10' 0" S, 36 °50' 0" E with an elevation of 1,720m above sea level (ASL). The area has a bimodal rainfall pattern with an average of 1,000 mm per annum. The long rains occur between March and May while the short rains set in between October and December. The soils are acrisols, alisols, lixisols and luvisols (Shisanya *et al*., 2006).

2.2 Experimental Treatments and Design

2.2.1 Experimental Layout and Data Collection

The experiment was carried out in the laboratory and in a greenhouse. The two experiments were arranged in a Complete Randomised Design. A total of 108 sorghum germplasm accessions obtained from farmers comprising of 41 accessions from Eastern, 25 from Nyanza and 42 from Coastal regions of Kenya were used. The sorghum germplasm was collected from farmers in 2018 while conducting a baseline survey to assess the production systems for sorghum in the three regions (Muui et al., 2019).

2.3 Crop Management and Data Collection

Germination percentage and mean germination time experiments were carried out in the laboratory while seed vigour index, shoot and root dry weight was done in the greenhouse.

2.3.1 Germination Percentage

From each of the 108 sorghum germplasm accessions, a sample of 400 seeds was selected at random from the 1,000-seed weight lot and grouped into four replicates of 100 seeds (ISTA, 2012). Each of the four replicates was placed in a germination tray with sterilized filter papers moistened with distilled water as a growth medium. The trays were illuminated with light during the whole period and temperatures maintained at 25 ± 5^0C. Distilled water was added as necessary to maintain the correct moisture content. Germination count was done at the end of the fourth day and seedling evaluation at the end of the tenth day. Germination percentage was calculated as follows:

Germination percentage (%) = (Number of seeds germinated/Number of seeds sown) x100

2.3.2 Mean Germination Time (Days)

The seeds used for testing germination percentage were also used in the determination of mean germination time. Emerged seedlings in each container were counted daily at an interval of 24 hours from the first day to the day no more germination occured. The mean germination time was calculated using the method described by Khan *et al*. (2010) as follows:

Mean germination time = (No. of germinated seedlings/Total no. of seeds sown) x Days after sowing

2.3.3 Seed Vigour Index

From the 108 sorghum germplasm accessions, a sample of 200 seeds was selected at random from 1,000-seed weight lot (same seed lot used for germination) and grouped into four replicates of 50 seeds. The fifty seeds were placed in plastic containers (pots) with sterilized forest soil as a growth medium for 21 days. Number of germinated seeds was recorded every 24 hours. Watering was done on daily basis and pots kept weed free throughout the experimental period. After 21 days, the seedlings were uprooted, soils washed off and a ruler used to measure the seedling height. Seed vigour index determination was done using the equation cited by Zhu et al., (2010) as follows:

Seeed vigour index (SVI) = Seedling height $\times\sum$ (number of germinated seedlings by end of test period/days after sowing)

2.3.4 Shoot and Root Dry Weight (Grams)

Seedlings used for seed vigour index were also used for dry weight measurement. A random sample of twenty five seedlings was taken and separated into shoot and root, dried in a forced-air oven at 72^0C for 48 hours. The samples were fully dried such that no significant changes occurred before the tests were done. The dried shoots and roots were weighed using an electronic balance (model 6354) and recorded in grammes.

2.4 Data Analysis

The data collected on germination percentage, germination time, seed vigour index, shoot and root dry weight were managed in the Ms excel spreadsheet and subjected to one-way analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 9.1. Means were separated using Fisher’s Least Significance Difference (LSD) test at $p\leq0.05$.

3. Results

3.1 Germination Percentage

There were statistical differences ($p\leq0.05$) in the germination percentage of the germplasm accessions evaluated across the three regions of Kenya; Eastern (41), Nyanza (25) and coast (42). In the Eastern region, thirty-eight of the tested accessions had more than 70% while three accessions had less than 70% with local102 having the lowest germination (18.67%) (Table 1). On the other hand, 29 of the tested accessions from coastal region had 70% germination whereas 13 accessions showed less than 70% germination with the lowest, 18%, from local accession gaddam*ssp*38. In Nyanza, 15 of the tested accessions had 70% germination. A relatively lower than 70% germination percentage was observed in ten germplasm accessions, but Ngware *spp*2 recorded the lowest germination percentage of 18.0%.

Table 1. Germination percentages for sorghum germplasm accessions obtained from Eastern, Coastal and Nyanza regions in 2018

Eastern region		**Coastal region**		**Nyanza region**	
Germplasm accessions	Germination (%)	Germplasm accessions	Germination (%)	Germplasm accessions	Germinatio n (%)
Local Variety68	97.67^{ab}	Gadam *Spp26*	60.33^{ghi}	Nyaktos *spp1*	60.33^{fg}
Local Variety69	84.67^{cdefg}	Gadam *Spp27*	66.67^{fgh}	Ngware *spp2*	66.67^{efg}
Local Variety70	77.67^{fghi}	Local Variety28	93.30^{ab}	Ngware *spp3*	18.00^{h}
Kivila Kyaivui71	84.33^{cdefg}	Local Variety29	33.33^{kl}	C-26 s*pp*4	33.33^{h}
Kikomo72	93.33^{abcd}	Mixed30	26.67^{kl}	Nyadundo5 3	26.70^{h}
Rasta73	86.67^{bcdef}	Gadam *Spp31*	86.67^{abcd}	Seredo6	86.67^{abc}
Kilala74	71.00^{hij}	Gadam *Spp32*	80.00^{bcdef}	Nyakabala *spp*7	80.00^{bcde}
Local Variety75	71.00^{hij}	Gadam *Spp33*	86.67^{abcd}	Nyaktos *spp*8	86.67^{abc}
Kitaa Kyaivui76	84.33^{bcdefg}	Gadam *Spp34*	58.00^{hi}	Nyakabala *spp*9	58.00^{g}
Kari Mtama-177	95.67^{abc}	Local Variety35	29.00kl	Ngware *spp10*	29.00^{h}
Local Variety78	82.33^{defgh}	Gadam *Spp36*	86.30^{abcd}	Ngware (white)*spp*11	86.33^{abcd}
local Variety Red79	80.0^{efgh}	Kautimbi *ssp37*	93.30^{ab}	Ngware spp12	93.33^{ab}
local variety80	97.67^{ab}	Gadam *Spp38*	18.00^{l}	Nyakabala *spp*13	18.00^{h}
Katengu81	100.00^{a}	Gadam *Spp39*	97.67^{a}	Nyakabala *spp*14	97.67^{a}
local Brown82	100.00^{a}	Kingundu *spp40*	95.33^{ab}	Ochuti *spp*15	95.33^{ab}
local Red83	86.67^{abcdef}	Local Variety41	100.00^{a}	Nyakabala *spp*16	100.00^{a}
Rasta spp84	100.00^{a}	Local Variety42	97.67^{a}	Nyakabala *spp*17	97.67^{a}
Muruge spp85	97.67^{ab}	Gadam *Spp43*	93.00^{a}	Othiwa *spp*18	93.33^{ab}
Muveta spp86	100.00^{a}	Local Variety44	95.33^{ab}	Gadam *Spp*19	95.33^{ab}
Muvela spp87	100.00^{a}	Local Variety45	75.67^{cdefg}	Nyakabala *spp*20	75.67^{cdef}
Mugeta spp88	100.00^{a}	Gadam *Spp46*	100.00^{a}	Andiwo *spp21*	100.00^{a}
Local Red89	66.67^{ij}	Local Variety47	60.00^{ghi}	Ngware *spp22*	60.00^{fg}
Local Red90	100.00^{a}	Local Variety48	93.30^{ab}	Oyundiwi-Jolejo*23*	93.33^{ab}
Ciumbichi91	71.00^{hij}	Local Variety49	69.00^{efgh}	Seredo *spp*24	69.00^{efg}
Vaasya92	64.67^{j}	Local Variety50	86.67^{abcd}	Gadam *Spp*25	86.67^{abc}
local brown93	100.00^{a}	KitaakyaIV VII51	87.00^{abcd}		
Rasta94	97.67^{ab}	Gadam *Spp52*	75.33^{cdefg}		
Muvuta spp95	91.3^{abcde}	Local Variety53	29.00^{kl}		
Serena96	100.00^{a}	Local Variety54	84.33^{abcde}		
Langi wa Mbesa97	100.00^{a}	Kivilakyaivui55	93.00^{ab}		
Rasta98	100.00^{a}	Local Variety56	49.00^{ij}		
Kaguru spp99	100.00^{a}	Local Variety57	73.33^{defgh}		
Rasta spp100	97.67^{ab}	Local Variety58	100.00^{a}		
Light brown101	100.00^{a}	Local Variety59	100.00^{a}		
Local102	18.67^{k}	Gadam *Spp60*	97.70^{a}		
Local103	100.00^{a}	Local Variety61	100.00^{a}		
Repaeted104 Cultivar	97.67^{ab}	Local Variety62	97.70a		
Local brown105	86.67^{bcdef}	Local Variety63	62.33^{hgi}		
Local Red106	100.00^{a}	Local Variety64	95.67^{ab}		
Local107	71.00^{hji}	Local Variety65	75.66^{cdefg}		
Local Red108	73.00^{hijg}	KitaaKya iv vii66	91.33^{abc}		
		Ithaa67	37.66^{jk}		
LSD	11.74		16.24		17.47

Means followed by the same letter within the same column are not significantly different according to Fisher's Least Significance Difference (LSD) test at p≤0.05.

3.2 Mean Germination Time (Days)

The mean germination time (MGT) revealed statistical differences (p≤0.05) for the germplasm accessions evaluated across the three regions: Eastern, Nyanza and Coast. From Eastern region, local red83, ciumbichi91and local102 had the shortest MGT of 8.40, while Katengu81, local variety 75, KitaaKyaivui 7, Rasta 73 and Rasta *spp* 100 had the longest MGT of 21.00 (Table 2). At the Coastal region, mixed30 and local variety35 accessions had the shortest MGT of 5.60 while, local variety28, localvariety41, localvariety44, kitaakyaIV VII51, Kitaa kya ivuii66 and Kavilakyaivui55 exhibited the longest MGT of 21.00 respectively (Table 2). In Nyanza Othiwa *spp*18, Nyakabala *spp*9 and Gadam *spp*25 had the shortest MGT of 11.20 while Ngware *spp*12, Ochutis *spp*15, Oyundiwi-Joleho23 and Serodo *spp24* had the longest MGT of 21.00 respectively (Table 2).

Table 2. Mean germination time (days) of sorghum germplasm accessions obtained from Eastern, Coastal and Nyanza regions in 2018

Eastern region		**Coastal region**		**Nyanza region**	
Germplasm accessions	MGT (days)	Germplasm accessions	MGT (days)	Germplasm accessions	MGT (days)
Local Variety68	16.80^{bcd}	Gadam *Spp26*	18.20^{abc}	Nyaktos *spp1*	18.20^{abc}
Local Variety69	16.80^{bcd}	Gadam *Spp27*	16.80^{bcd}	Ngware *spp2*	19.60^{ab}
Local Variety70	14.00^{de}	Local Variety28	21.00^{a}	Ngware *spp3*	19.60^{ab}
Kivila Kyaivui71	18.20^{abc}	Local Variety29	19.60^{ab}	C-26 *spp*4	19.60^{ab}
Kikomo72	18.20^{abc}	Mixed30	5.60^{i}	Nyadundo5 3	16.80^{bc}
Rasta73	21.00^{a}	Gadam *Spp31*	16.80^{bcd}	Seredo6	19.60^{ab}
Kilala74	16.80^{bcd}	Gadam *Spp32*	18.20^{abc}	Nyakabala *spp*7	15.40^{dc}
Local Variety75	21.00^{a}	Gadam *Spp33*	16.80^{bcd}	Nyaktos *spp*8	19.60^{ab}
Kitaa Kyaivui76	21.00^{a}	Gadam *Spp34*	12.60^{efg}	Nyakabala *spp*9	11.20^{e}
Kari Mtama-177	18.20^{abc}	Local Variety35	5.60^{i}	Ngware *spp10*	16.80^{bc}
Local Variety78	16.80^{bcd}	Gadam *Spp36*	19.60^{ab}	Ngware (white)*spp*11	18.20^{abc}
local Variety Red79	18.20^{abc}	Kautimbi *ssp37*	19.60^{ab}	Ngware spp12	21.00^{a}
local variety80	15.40^{cde}	Gadam *Spp38*	8.40^{hi}	Nyakabala *spp*13	16.80^{bc}
Katengu81	21.00^{a}	Gadam *Spp39*	18.20^{abc}	Nyakabala *spp*14	19.60^{ab}
local Brown82	19.60^{ab}	Kingundu *spp40*	18.20^{abc}	Ochuti *spp*15	21.00^{a}
local Red83	8.40^{f}	Local Variety41	21.00^{a}	Nyakabala *spp*16	15.40^{dc}
Rasta spp84	15.40^{cde}	Local Variety42	18.20^{abc}	Nyakabala *spp*17	26.80^{bc}
Muruge spp85	19.60^{ab}	Gadam *Spp43*	19.60^{ab}	Othiwa *spp*18	11.20^{e}
Muveta spp86	16.80^{bcd}	Local Variety44	21.00^{a}	Gadam *Spp*19	12.60^{de}
Muvela spp87	16.80^{bcd}	Local Variety45	9.80^{gh}	Nyakabala *spp*20	19.60^{ab}
Mugeta spp88	16.80^{bcd}	Gadam *Spp46*	18.20^{abc}	Andiwo *spp21*	15.40^{dc}
Local Red89	19.60^{ab}	Local Variety47	19.60^{ab}	Ngware spp*22*	16.80^{bc}
Local Red90	19.60^{ab}	Local Variety48	15.40^{cde}	Oyundiwi-Jolejo*23*	21.00^{a}
Ciumbichi91	8.40^{f}	Local Variety49	16.80^{bcd}	Seredo *spp*24	21.00^{a}
Vaasya92	15.40^{cde}	Local Variety50	15.40^{cde}	Gadam *Spp*25	11.20^{e}
local brown93	19.60^{ab}	KitaakyaIV VII51	21.00^{a}		
Rasta94	16.80^{bcd}	Gadam *Spp52*	18.20^{abc}		
Muvuta spp95	16.80^{bcd}	Local Variety53	8.40^{hi}		
Serena96	16.80^{bcd}	Local Variety54	18.20^{abc}		
Langi wa Mbesa97	19.60^{ab}	Kivilakyaivui55	21.00^{a}		
Rasta98	21.00^{a}	Local Variety56	8.40^{hi}		
Kaguru spp99	14.00^{de}	Local Variety57	15.40^{cde}		
Rasta spp100	21.00^{a}	Local Variety58	21.00^{a}		
Light brown101	19.60^{ab}	Local Variety59	19.60^{ab}		
Local102	8.40^{f}	Gadam *Spp60*	19.60^{ab}		
Local103	19.60^{ab}	Local Variety61	21.00^{a}		
Repaeted104 Cultivar	19.60^{ab}	Local Variety62	15.40cde		
Local brown105	12.60^{e}	Local Variety63	12.60^{def}		
Local Red106	14.00^{de}	Local Variety64	16.80^{bcd}		
Local107	12.60^{e}	Local Variety65	11.20^{fgh}		
Local Red108	15.40^{cde}	Kitaa Kya iv vii66	21.00^{a}		
		Ithaa67	14.00^{def}		
LSD	3.312		2.98		3.08

Means followed by the same letter within the same column are not significantly different according to Fisher's Least Significance Difference (LSD) test at $p \leq 0.05$.

3.3 Seed Vigour Index (SVI)

Different germplasm accessions exhibited significant differences ($p \leq 0.05$) in seed vigour index (SVI) in Eastern, Nyanza and Coastal regions (Table 3). Local103 accession was superior with an SV1 0f 3499.3 from Eastern region, while local102 had the lowest SVI of 322.3. At Coastal region, SVI superiority was exhibited by accession localvariety41 that recorded 4392.0 followed by the localvariety42 with 4044.3, while Gadam *spp*38 had the lowest SVI of 507.5. At Nyanza, Nyakabala *spp*9 and Ochuti spp*15* were the superior accessions with a high SVI of 4080.9 and 4060.0 respectively, while Serodo *Spp*24 had the least SVI of 2119.8.

Table 3. Seed vigour index (SVI) for sorghum germplasm accessions obtained from Eastern, Coastal and Nyanza regions in 2018

Eastern region		**Coastal region**		**Nyanza region**	
Germplasm accessions	**SVI**	**Germplasm accessions**	**SVI**	**Germplasm accessions**	**SVI**
Local Variety68	3196.6^{ab}	Gadam *Spp26*	2759.2^{hijk}	Nyaktos *spp1*	3570.8^{abcde}
Local Variety69	2503.9^{fgh}	Gadam *Spp27*	1713.3^{mnop}	Ngware *spp2*	3794.4^{abc}
Local Variety70	1847.0^{jklm}	Local Variety28	3083.9defghi	Ngware *spp3*	3340.4^{abcdef}
Kivila Kyaivui71	1287.2^{no}	Local Variety29	1271.5^{nop}	C-26 s*pp*4	3065.4^{cdef}
Kikomo72	1644.5^{lmno}	Mixed30	1321.2n^{op}	Nyadundo5 3	2849.2^{defg}
Rasta73	2001.0^{jkl}	Gadam *Spp31*	2994.5efghijk	Seredo6	3004.5^{cdef}
Kilala74	1264.2^{o}	Gadam *Spp32*	2416.3 ^{jklm}	Nyakabala *spp*7	3161.9^{bcdef}
Local Variety75	1877.1^{jklm}	Gadam *Spp33*	2689.6^{hijk}	Nyaktos *spp*8	3028.1^{cdef}
Kitaa Kyaivui76	2008.5^{ijkl}	Gadam *Spp34*	1908.9^{lmn}	Nyakabala *spp*9	4080.9^{a}
Kari Mtama-177	1977.6^{ijkl}	Local Variety35	624.7^{pq}	Ngware spp10	3893.3^{ab}
Local Variety78	1742.5^{lmnop}	Gadam *Spp36*	2823.6^{ghijk}	Ngware (white)*spp*11	3499.2^{abcde}
local Variety Red79	1767.7^{lmn}	Kautimbi *ssp37*	3017.8^{efghij}	Ngware spp12	3351.1^{abcdef}
local variety80	2643.8^{efgh}	Gadam *Spp38*	507.5^{q}	Nyakabala *spp*13	3640.1^{abcd}
Katengu81	2613.3^{efgh}	Gadam *Spp39*	3864.7^{abc}	Nyakabala *spp*14	3270.6^{abcdef}
local Brown82	2292.7^{hij}	Kingundu *spp40*	3224.0^{cdefgh}	Ochuti *spp*15	4060.0^{a}
local Red83	2605.4^{efgh}	Local Variety41	4392.0^{a}	Nyakabala *spp*16	3499.2^{abcde}
Rasta spp84	1723.3^{lmnop}	Local Variety42	4044.3^{ab}	Nyakabala *spp*17	3096.4^{bcdef}
Muruge spp85	3036.0^{abcde}	Gadam *Spp43*	2907.5^{fghijk}	Othiwa *spp*18	3536.5^{abcde}
Muveta spp86	2960.0^{bcdef}	Local Variety44	3566.6^{bcdefg}	Gadam *Spp*19	2769.1^{efg}
Muvela spp87	2273.3^{hijk}	Local Variety45	2787.5^{hijk}	Nyakabala *spp*20	2906.9^{defg}
Mugeta spp88	2666.7^{defgh}	Gadam *Spp46*	3781.7^{abcd}	Andiwo *spp21*	3273.4^{abcde}
Local Red89	1790.3^{klm}	Local Variety47	2248.4^{klm}	Ngware spp*22*	3485.5^{abcde}
Local Red90	3271.0^{ab}	Local Variety48	3320.9^{bcdefgh}	Oyundiwi-Jolejo*23*	2615.8^{gf}
Ciumbichi91	2526.8^{fgh}	Local Variety49	2917.4fghik	Seredo *spp*24	2119.8^{h}
Vaasya92	2823.7^{bcdefg}	Local Variety50	3299.1^{bcdefgh}	Gadam *Spp*25	13331.0^{h}
local brown93	2978.7^{bcdef}	KitaakyaIV VII51	3619.2^{bcdef}		
Rasta94	2708.5^{cdefg}	Gadam *Spp52*	2607.3^{hijkl}		
Muvuta spp95	3143.3^{abdc}	Local Variety53	1107.5^{opq}		
Serena96	3167.0^{abcd}	Local Variety54	2634.8^{hijkl}		
Langi wa Mbesa97	2286.0^{hij}	Kivilakyaivui55	3174.4^{ccdefghi}		
Rasta98	2708.5^{cdefg}	Local Variety56	1321.3^{nop}		
Kaguru spp99	2275.0^{hijk}	Local Variety57	2783.1^{hijk}		
Rasta spp100	2677.0^{defgh}	Local Variety58	3299.1^{bcdefgh}		
Light brown101	2405.6^{ghi}	Local Variety59	3545.7^{bcdefg}		
Local102	322.3^{p}	Gadam *Spp60*	3610.9^{bcdef}		
Local103	3499.3^{a}	Local Variety61	3131.7^{cdefghi}		
Repaeted104 Cultivar	3201.6^{ab}	Local Variety62	3198.3cdefgh		
Local brown105	2406.5^{ghi}	Local Variety63	2440.05^{ijklm}		
Local Red106	1835.0^{jklm}	Local Variety64	3736.3^{abcde}		
Local107	1854.7^{jklm}	Local Variety65	3078.1^{defghij}		
Local Red108	1436.9^{mno}	Kitaa Kya iv vii66	3289.8^{bcdefgh}		
		Ithaa67	1378.6^{nop}		
LSD	486.96		758.15		816.13

Means followed by the same letter within the same column are not significantly different according to Fisher's Least Significance Difference (LSD) test at $p \leq 0.05$.

3.4 Shoot Dry Weight (SDW)

There was a significant difference ($p \leq 0.05$) in shoot dry weight among various germplasm accessions from Eastern, Nyanza and Coastal regions (Table 4). In Eastern, Ciumbichi91 accession had the highest shoot dry weight of 0.046g, mixed30 accession from Coastal region was the leading in shoot dry weight of 0.073g while, at Nyanza, Ochuti15 was superior, recording 0.075g. Germplasm accessions with the least shoot dry weight were Gadam *spp*27 (0.0137g) and Seredo *spp*24 (0.0180g) from Coastal and Nyanza regions respectively.

Table 4. Shoot dry weight (SDW) (grams) of sorghum germplasm accessions obtained from Eastern, Coastal and Nyanza regions in 2018

Eastern region		**Coastal region**		**Nyanza region**	
Germplasm accessions	SDW (g)	Germplasm accessions	SDW (g)	Germplasm accessions	SDW (g)
Local Variety68	0.0241^{defghi}	Gadam *Spp26*	0.0470^{bcdefg}	Nyaktos *spp1*	0.0438^{efg}
Local Variety69	0.0297^{cde}	Gadam *Spp27*	0.0137^{q}	Ngware spp2	0.056^{bcd}
Local Variety70	$0.0162^{fghijkl}$	Local Variety28	$0.0280^{klmnopq}$	Ngware spp3	0.0435^{efgh}
Kivila Kyaivui71	0.0071^{lm}	Local Variety29	$0.0313^{hijklmnop}$	C-26 s*pp*4	0.035^{ghij}
Kikomo72	0.0122^{ijklm}	Mixed30	0.0730^{a}	Nyadundo5 3	0.035^{fhij}
Rasta73	0.0320^{bcd}	Gadam *Spp31*	$0.0354^{efghijklmnop}$	Seredo6	0.029^{ij}
Kilala74	0.0098^{jklm}	Gadam *Spp32*	0.0234^{nopq}	Nyakabala *spp*7	0.059^{bc}
Local Variety75	0.0260^{defghi}	Gadam *Spp33*	0.0450^{bcdefg}	Nyaktos *spp*8	0.044^{defg}
Kitaa Kyaivui76	$0.0181^{efghijkl}$	Gadam *Spp34*	$0.0290^{jklmnopq}$	Nyakabala *spp*9	0.054^{bcde}
Kari Mtama-177	$0.0235^{defghij}$	Local Variety35	0.0220^{opq}	Ngware spp10	0.045^{defg}
Local Variety78	0.0133^{hijklm}	Gadam *Spp36*	$0.0290^{jklmnopq}$	Ngware (white)*spp*11	0.064^{ab}
local Variety Red79	$0.0173^{efghijkl}$	Kautimbi *ssp37*	$0.0340^{fghijklmnop}$	Ngware spp12	0.049^{cdef}
local variety80	$0.0228^{defghij}$	Gadam *Spp38*	0.0190^{qp}	Nyakabala *spp*13	0.053^{bcde}
Katengu81	$0.0207^{defghijkl}$	Gadam *Spp39*	0.0470^{bcdefg}	Nyakabala *spp*14	0.041^{fgh}
local Brown82	$0.0190^{defghijkl}$	Kingundu *spp40*	$0.0289^{jklmnopq}$	Ochuti *spp*15	0.075^{a}
local Red83	0.0262^{cdefgh}	Local Variety41	$0.0430^{bcdefghilkl}$	Nyakabala *spp*16	0.058^{bc}
Rasta spp84	0.01365^{ghijkl}	Local Variety42	$0.0360^{efghijklmno}$	Nyakabala *spp*17	0.048^{cdef}
Muruge spp85	0.0263^{cdefg}	Gadam *Spp43*	$0.0370^{fghijklmnop}$	Othiwa *spp*18	0.040^{ghif}
Muveta spp86	0.0242^{defghi}	Local Variety44	$0.0328^{fghijklmnop}$	Gadam *Spp*19	0.043^{efg}
Muvela spp87	$0.0171^{efghijkl}$	Local Variety45	$0.0453^{bcdefghi}$	Nyakabala *spp*20	0.031^{ghij}
Mugeta spp88	$0.0214^{defghijk}$	Gadam *Spp46*	0.0540^{bcd}	Andiwo *spp21*	0.034^{ghij}
Local Red89	0.0301^{cde}	Local Variety47	0.0500^{bc}	Ngware spp*22*	0.038^{fghi}
Local Red90	$0.0230^{defghij}$	Local Variety48	$0.0045^{bcdefghij}$	Oyundiwi-Jolejo*23*	0.026^{jk}
Ciumbichi91	0.0460^{a}	Local Variety49	0.0510^{bcde}	Seredo *spp*24	0.018^{k}
Vaasya92	0.0450^{ab}	Local Variety50	$0.0430^{bcdefghijkl}$	Gadam *Spp*25	0.036^{ghij}
local brown93	0.0274^{cdefg}	KitaakyaIV VII51	0.0560^{b}		
Rasta94	$0.0230^{defghij}$	Gadam *Spp52*	$0.0456^{bcdefgi}$		
Muvuta spp95	0.038^{abc}	Local Variety53	$0.0390^{bcdefghijklm}$		
Serena96	0.0297^{cdef}	Local Variety54	0.0260^{mnopq}		
Langi wa Mbesa97	$0.0200^{defghijkl}$	Kivilakyaivui55	$0.03832^{cdefghijklm}$		
Rasta98	$0.0230^{defghij}$	Local Variety56	0.02113^{qp}		
Kaguru spp99	$0.0180^{efghijkl}$	Local Variety57	0.0517^{bcde}		
Rasta spp100	0.0237^{defghi}	Local Variety58	$0.0330^{fghijklmnop}$		
Light brown101	$0.0216^{defghijk}$	Local Variety59	$0.0382^{defghijklm}$		
Local102	0.0088^{klm}	Gadam *Spp60*	$0.0452^{bcdefghij}$		
Local103	0.0280^{cdef}	Local Variety61	$0.0280^{klmnopq}$		
Repaeted104 Cultivar	0.0260^{cdefg}	Local Variety62	$0.027l^{mnopq}$		
Local brown105	$0.0200^{defghijkl}$	Local Variety63	$0.0380^{defghijklm}$		
Local Red106	0.0120^{ijklm}	Local Variety64	$0.0440^{bcdefghij}$		
Local107	$0.0163^{fghijkl}$	Local Variety65	0.0490^{bcde}		
Local Red108	0.0144^{ghijkl}	Kitaa Kya iv vii66	0.0487^{bcdef}		
		Ithaa67	$0.0320^{ghijklmnop}$		
LSD	0.014		0.016		0.011

Means followed by the same letter within the same column are not significantly different according to Fisher's Least Significance Difference (LSD) test at $p \leq 0.05$.

3.5 Root Dry Weight (RDW) (Grams)

Root dry weight exhibited significant differences ($p \leq 0.05$) among germplasm accessions from Eastern, Coastal and Nyanza regions (Table 5). Vaasya92 (0.0152g), Nyakabala *spp*9 (0.0188g) and local variety45 (0.039g) from Eastern, Nyanza and Coastal regions respectively had more root dry weight. Kilala74 in Eastern recorded the least root dry weight of 0.0020g while in Nyanza Seredo *spp 24* had the least weight of 0.0036g.

Table 5. Root dry weight (RDW) (grams) of sorghum germplasm accessions obtained from Eastern, Coastal and Nyanza regions in 2018

Eastern region		**Coastal region**		**Nyanza region**	
Germplasm accessions	RDW (g)	Germplasm accessions	RDW (g)	Germplasm accessions	RDW (g)
Local Variety68	0.0052^{jklmn}	Gadam *Spp26*	0.014c	Nyaktos *spp1*	0.0074^{dc}
Local Variety69	0.0121^{abcd}	Gadam *Spp27*	0.004c	Ngware spp2	0.0070^{dc}
Local Variety70	0.0056^{hijklmn}	Local Variety28	0.006c	Ngware spp3	0.0053^{def}
Kivila Kyaivui71	0.0024^{mnop}	Local Variety29	0.009^{c}	C-26 s*pp*4	0.0081^{dc}
Kikomo72	0.0037^{lmnop}	Mixed30	0.010^{c}	Nyadundo5 3	0.0052^{def}
Rasta73	0.0037^{lmnop}	Gadam *Spp31*	0.010^{c}	Seredo6	0.0060^{dce}
Kilala74	0.0020^{no}	Gadam *Spp32*	0.007^{c}	Nyakabala *spp*7	0.0068^{dce}
Local Variety75	0.0102^{bcdefg}	Gadam *Spp33*	0.0077^{c}	Nyaktos *spp*8	0.0051^{def}
Kitaa Kyaivui76	0.0060^{ghijklm}	Gadam *Spp34*	0.014^{c}	Nyakabala *spp*9	0.0188^{a}
Kari Mtama-177	0.0039^{lmnop}	Local Variety35	0.005^{c}	Ngware spp10	0.0071^{dc}
Local Variety78	0.0053^{hijlkmn}	Gadam *Spp36*	0.006^{c}	Ngware (white)*spp*11	0.0080^{dc}
local Variety Red79	0.0026^{mnop}	Kautimbi *ssp37*	0.010^{c}	Ngware spp12	0.0072^{dc}
local variety80	0.0087^{cdefghij}	Gadam *Spp38*	0.0004^{c}	Nyakabala *spp*13	0.00706^{dc}
Katengu81	0.0058^{ghijklm}	Gadam *Spp39*	0.016bc	Nyakabala *spp*14	0.0073^{dc}
local Brown82	0.01110^{abcde}	Kingundu *spp40*	0.007^{c}	Ochuti *spp*15	0.0120^{b}
local Red83	0.00508^{ghijklm}	Local Variety41	0.011^{c}	Nyakabala *spp*16	0.0091^{c}
Rasta spp84	0.0125^{abc}	Local Variety42	0.117^{c}	Nyakabala *spp*17	0.0080^{dc}
Muruge spp85	0.0110^{abcde}	Gadam *Spp43*	0.010^{c}	Othiwa *spp*18	0.0068^{dc}
Muveta spp86	0.0097^{bcdefg}	Local Variety44	0.009^{c}	Gadam *Spp*19	0.007^{dc}
Muvela spp87	0.0045^{jklmn}	Local Variety45	0.039^{a}	Nyakabala *spp*20	0.0033^{f}
Mugeta spp88	0.0065^{fghijklm}	Gadam *Spp46*	0.011^{c}	Andiwo *spp21*	0.0071^{dc}
Local Red89	0.0106^{bcdef}	Local Variety47	0.014^{c}	Ngware *spp22*	0.008^{dc}
Local Red90	0.0049^{ijklmn}	Local Variety48	0.010^{c}	Oyundiwi-Jolejo*23*	0.0038^{ef}
Ciumbichi91	0.0058^{hijklmn}	Local Variety49	0.014^{c}	Seredo *spp*24	0.0036^{f}
Vaasya92	0.0152^{a}	Local Variety50	0.007^{c}	Gadam *Spp*25	0.0089^{c}
local brown93	0.0029^{mnop}	KitaakyaIV VII51	0.015^{c}		
Rasta94	0.0085^{cdefghijk}	Gadam *Spp52*	0.009^{c}		
Muvuta spp95	0.0065^{ghijklm}	Local Variety53	0.010^{c}		
Serena96	0.0079^{defghijkl}	Local Variety54	0.006^{c}		
Langi wa Mbesa97	0.0048^{ijklmn}	Kivilakyaivui55	0.010^{c}		
Rasta98	0.0085^{cdefghijk}	Local Variety56	0.010^{c}		
Kaguru spp99	0.0054^{ijklmn}	Local Variety57	0.012^{c}		
Rasta spp100	0.0106^{bcdef}	Local Variety58	0.007^{c}		
Light brown101	0.0045^{klmnop}	Local Variety59	0.008^{c}		
Local102	0.0034^{mno}	Gadam *Spp60*	0.011^{c}		
Local103	0.0138^{ab}	Local Variety61	0.005^{c}		
Repaeted104 Cultivar	0.0058^{hijklmn}	Local Variety62	0.006^{c}		
Local brown105	0.0090^{cdefghi}	Local Variety63	0.011^{c}		
Local Red106	0.0030^{mnop}	Local Variety64	0.031^{ab}		
Local107	0.0067^{ghijklm}	Local Variety65	0.014^{c}		
Local Red108	0.0035^{lmnop}	Kitaa Kya iv vii66	0.010^{c}		
		Ithaa67	0.012^{c}		
LSD	0.005		0.015		0.003

Means followed by the same letter within the same column are not significantly different according to Fisher's Least Significance Difference (LSD) test at $p \leq 0.05$.

4. Discussions

In this study, there was a high variability in the germination percentages for the sorghum seeds obtained from Eastern, Coastal and Nyanza regions of Kenya. A majority of the seeds exhibited a high germination percentage of 70% which is within the set standards by the Seeds and Plant Varieties Act of CAP 326 of the Kenyan constitution for sorghum varieties. However, part of the germplasm had low germination percentages indicating presence of low quality seeds used by farmers. Previous studies have reported that farmers obtain sorghum seeds from previously saved seeds, local markets, borrow from neighbors (Ochieng *et al.,* 2011; Catherine *et al*., 2013; Kange *et al.,* 2014; Muui *et al.,* 2019). Majority of subsistence farmers in semi arid areas produce crops without fertilizers (Jama *et al*., 1998; Muui *et al*., 2013). Results of a baseline survey assessing production systems at coastal, Nyanza and eastern regions revealed that most farmers do not use fertilizers (Muui *et al.,* 2019). This results to low yields and poor quality seeds since most soil nutrients have already been depleted (Songa *et al*., 1994; Craine *et al*., 2018). High humidity under elevated temperatures in these regions may have contributed to rapid deterioration of the seeds. There is evidence that elongated exposure to high temperatures and moisture would significantly reduce seed germination potential in many crops (Nagel *et al.,* 2016). Besides, post-harvest seed handling and packaging also influence the rate of seed deterioration and hence has a direct impact on seed germination potential (Kange *et al.,* 2014). Studies conducted in eastern, coast and Nyanza reported that most farmers have low education and therefore do not understand the best agronomic and post harvest handling practices which could help increase the quality of seed (Muui *et al.,* 2013; 2019).

The mean time of germination for a seed indicates the time taken by a seed to develop critical structures crucial for germination success, survival, and for faster and uniform establishment. In this study, the mean germination time observed ranged from short, moderate to long. The shorter the mean germination time, the greater the seed vigour. A prolonged MGT may be an indication of deteriorated seed quality as a result of exposure of the seeds to harsh or unfavourable conditions in the field and after harvesting (Bewley and Black, 2012). Such conditions slows the rate of emergence and growth of the seedlings (Amirmoradi and Feizi, 2017); and eventually limits the seedlings from taking advantage of the available nutrients and resources for maximum yield within a short time (Bradford, 2002).

The seed vigour index variation in this study could be attributed to the diverse conditions during production, source of seeds and post harvest handling practices. Increased seedling vigour is an indication of effective germination, seedling emergence early seedling growth and improved grain yield (Lamichhane *et al.,* 2018). Harsh conditions during the late stage of seed development might have also contributed to hormonal imbalance within the seeds which promotes physiological seed dormancy (Cotado and Munné-Bosch, 2020). Longer storage is associated with deterioration of seed stored microRNAs and other important proteins that have a role in the maintenance of high seed viability (Sahu *et al.,* 2017; Sano and Rajjou, 2020).

The shoot biomass of seedlings varied from high to low attributed to pre and post harvest handling practices. A high shoot biomass is an indicator of increased seed vigour and subsequent crop growth cycles (Maucieri *et al*., 2016). Rapid development of the shoot is associated with the development of more leaves, which is important for the interception of photosynthetic active radiation that enhances rates of photosynthesis resulting in high biomass accumulation (Ceotto *et al*., 2013). Furthermore, genotypes with higher shoot dry matter have the capability of withstanding drought due to improved water and nutrient use efficiency (Verma *et al*., 2018). Majority of the germplasm displayed moderate to low root dry matter. Low root biomass has been reported to be as a result of reduced root growth in germplasm consisting of low quality seeds (Joshi *et al*., 2017). According to Blaha and Pazderu (2013), high seed quality leads to development of seedling with roots of greater biomass an indication of ability to withstand stress condition and also facilitate formation of high quality grains for the subsequent generations.

5. Conclusion and Recommendations

The ability of sorghum to perform well in semi arid areas makes it an important cereal crop to achieve food security. Farmers in Eastern, Nyanza and Coastal regions plant sorghum seeds obtained from diverse informal sources. The environmental conditions in the field and, pre and post harvest handling practices impact on the seed quality hence the wide variability in germination percentage, germination time, seed vigour index and dry matter accumulation in seedlings. This shows the need to improve and monitor the quality of seeds used by subsistence farmers. The quality of sorghum seeds could be improved by providing extension services on best pre and post harvest handling practices. Increasing production of sorghum in these regions will contribute significantly towards realizing food security. Further analysis could be carried out on genetic and sanitary quality aspects of the seeds planted by farmers in Eastern, Nyanza and Coastal regions.

Acknowledgements

The authors acknowledge farmers from Eastern, Nyanza and Coastal regions of Kenya for providing sorghum germplasm accessions and the County agricultural officers for allowing access to the regions. National Research Fund (NRF), Kenya is gratefully acknowledged for funding this study.

References

Ahmed, H. M. I., Gregg, B. R., & Louwaars, N. P. (2009). Seed Systems for Underutilized crops. *Acta Horticulture (ISHS), 806*, 459-464. https://doi.org/10.17660/ActaHortic.2009.806.57

Amirmoradi, S., & Feizi, H. (2017). Can mean germination time predict seed vigor of canola (*Brassica napu* L.) seed lots? *Acta Agrobotanica, 70*(4), 1729. https://doi.org/10.5586/aa.1729

Badigannavar, A., Girish, G., Ramachandran, V., & Ganapathi, T. R. (2016). Genotypic variation for seed protein and mineral content among post-rainy season-grown sorghum genotypes. *The Crop Journal*, *4*(1), 61-67, https://doi.org/10.1016/j.cj.2015.07.002

Bewley, J. D., & Black, M. (2012). *Physiology and biochemistry of seeds in relation to germination: volume 2: viability, dormancy, and environmental control.* Springer Science and Business Media.

Blaha, L., & Pazderu, K. (2013). *Influence of the root and seed traits on tolerance to abiotic stress*. In Agricultural Chemistry. IntechOpen. https://doi.org/10.5772/55656

Bradford, K. J. (2002). Applications of hydrothermal time to quantifying and modeling seed germination and dormancy. *Weed Science, 50*(2), 248-260. https://doi.org/10.1614/0043-1745(2002)050[0248:AOHTTQ]2.0.CO;2

Catherine, W. M., Reuben, M. M., & Duncan, T. K. (2013). Identification and evaluation of sorghum (*Sorghum bicolor* (L.) moench) germplasm from Eastern Kenya. African *Journal of Agricultural Research, 8*(37), 4573-4579.

Ceotto, E., Di Candilo, M., Castelli, F., Badeck, F. W., Rizza, F., Soave, C., & Marletto, V. (2013). Comparing solar radiation interception and use efficiency for the energy crops giant reed (*Arundo donax* L.) and sweet sorghum (*Sorghum bicolor* L. Moench). *Field Crops Research, 149*, 159-166. https://doi.org/10.1016/j.fcr.2013.05.002

Cotado, A., Garcia, M. B., & Munné-Bosch, S. (2020). Physiological seed dormancy increases at high altitude in Pyrenean saxifrage (Saxifraga longifolia Lapeyr.). *Environmental and Experimental Botany*, *171*(August 2019), 103929. https://doi.org/10.1016/j.envexpbot.2019.103929

Craine, J. M., Elmore, A. J., Wang, L., Aranibar, J., Bauters, M., Boeckx, P., & Fang, Y. (2018). Isotopic evidence for oligotrophication of terrestrial ecosystems. *Nature Ecology and Evolution*, *2*(11), 1735. https://doi.org/10.1038/s41559-018-0694-0

FAO. (2018). Food and Agricultural Organization of the United Nations Faostatstatistics database. Retrieved from http://www.fao.org/faostat/en/#data/QCProductionofselectedcerealcrops

Grieser, J. **(**2006). The FAO local climate estimator. Environment and Natural Resources Service Working Paper No. 9. Food and Agriculture Organization 2006. Retrieved from www.fao.org/sd/2002/en1203a_en.htm

Jama, B., Amandou, I., Amadalo, B., Wolf, J., Rao, M. R., & Buresh, R. J. (1998). The Potential of Improved Fallows to Improve and Conserve the Fertility of Nutrients-Depleted Soils of Western Kenya. Agricultural Research and Development for Sustainable Resource Management and Increased Production. *Proceedings of the 6th biennial KARI scientific conference*. Retrieved from https://inis.iaea.org/search/search.aspx?orig_q=RN:38037858

Jisha, K. C., Vijayakumari, K., & Puthur, J. T. (2013). Seed priming for abiotic stress tolerance: an overview. *Acta Physiologiae Plantarum*, *35*(5), 1381-1396. https://doi.org/10.1007/s11738-012-1186-5

Joshi, D. C., Singh, V., Hunt, C., Mace, E., van Oosterom, E., Sulman, R., & Hammer, G. (2017). Development of a phenotyping platform for high throughput screening of nodal root angle in sorghum. *Plant methods, 13*(1), 56. https://doi.org/10.1186/s13007-017-0206-2

Kange, A. M., Cheruiyot E. K., Ogendo, J. O., Arama, P. F., & Ochola, S. O. (2014). Pre- and post harvest factors affecting sorghum production (Sorghum bicolor L. Moench) among smallholder farming Communities. *International Journal of Agronomy and Agricultural Research*, *5*(4), 40-47. https://doi.org/10.1186/s40066-015-0034-4

Khan, A. Z., Shah, P., Mohd, F., & Zubair, M. (2010). Vigour tests used to rank seed lot quality and predict field emergence in Wheat, *Pakistan Journal of Botany*, 3147-3155. https://www.researchgate.net/publication/287739275pdf

Lamichhane, J. R., Debaeke, P., Steinberg, C., You, M. P., Barbetti, M. J., & Aubertot, J. N. (2018). Abiotic and biotic factors affecting crop seed germination and seedling emergence: a conceptual framework. *Plant and soil*, 1-28. https://doi.org/10.1007/s11104-018-3780-9

Mamoudou, H. D., Hurry, G., Alfred, S., Alphons, G. J., & Van, B. (2006). Sorghum grain as human food in Africa: relevance of content of starch and amylase activities. *African Journal Biotechnology, 5*, 384-395. Retrieved from http://www.academicjournals.org/AJB

Maucieri, C., Cavallaro, V., Caruso, C., Borin, M., Milani, M., & Barbera, A. (2016). Sorghum biomass production for energy purpose using treated urban wastewater and different fertilization in a Mediterranean environment. *Agriculture, 6*(4), 67. https://doi.org/10.3390/agriculture6040067

McDonald, M. B. (1999). Seed deterioration: physiological, repair and assessment. *Journal of Seed Science and Technology, 27*, 177-237.

Muasya, R. M., Lommen, W. J. M., Muui, C. W., & Struik, P. C. (2008). How weather during development of common bean (*Phaseolus vulgaris* L.) affects the crop's Maximum attainable seed quality. *NJAS-Wageningen Journal of Life Sciences, 56*, 85-100. https://doi.org/10.1016/S1573-5214(08)80018-8

Muui, C. W, Muasya, R. M., Nguluu, S., Kambura, A, Kathuli, P., Mweu, B., & Odhiambo, D. O. (2019). Sorghum Landraces Production Practices in Nyanza, Coast andEastern Regions, Kenya. *Journal of Economics and Sustainable Development, 10*(10).

Muui, C. W., Muasya, R. M., & Kirubi, D. T. (2013). Baseline survey on factors affecting sorghum production and use in eastern Kenya. *African Journal of Food, Agriculture Nutrition and Development*, 13, 7339-7342. https://doi.org/10.18697/ajfand.56.11545

Mwadalu, R., & Mwangi, M. (2013). The potential role of sorghum in enhancing food security in semi-arid eastern Kenya: A review. *Journal of Applied Biosciences*, *71*(1), 5786-5799. https://doi.org/10.4314/jab.v71i1.98826

Nagel, M., Kodde, J., Pistrick, S., Mascher, M., Börner, A., & Groot, S. P. C. (2016). Barley seed aging: Genetics behind the dry elevated pressure of oxygen aging and moist controlled deterioration. *Frontiers in Plant Science, 7*. https://doi.org/10.3389/fpls.2016.00388

Ng'uni, D., Geleta, M., Hofvander, P., Fatih, M., & Bryngelsson, T. (2012). Comparative genetic diversity and nutritional quality variation among some important Southern African sorghum accessions (*Sorghum bicolor* L. Moench). *Australian Journal of Crop Science, 6*(1), 56-64. Retrieved from https://www.researchgate.net/publication/259752716

Ochieng, L. A., Mathenge, P. W., & Muasya, R. M. (2011). A survey of on-farm seed production practices of sorghum (*Sorghum bicolor* L. Moench) in Bomet district of Kenya, *African Journal of Food, Agriculture, Nutrition and Development, 11*(5), 5232-5253. https://doi.org/10.4314/ajfand.v11i5.70448

Rao, P. S., Vinutha, K. S., Kumar, G. S., Chiranjeevi, T., Uma, A., Lal, P., & Jose, S. (2016). Sorghum: A multipurpose bioenergy crop. Sorghum: State of the art and future perspectives, *Agronmonogr, 58*. https://doi.org/10.2134/agronmonogr58.2014.0074

Sahu, A. K., Sahu, B., Soni, A., & Naithani, S. C. (2017). Active oxygen species metabolism in neem (Azadirachta indica) seeds exposed to natural ageing and controlled deterioration. *Acta Physiologiae Plantarum, 39*(9). https://doi.org/10.1007/s11738-017-2494-6

Sano, N., & Rajjou, L. (2020). Lost in Translation : Physiological Roles of Stored mRNAs in Seed Germination. *Plants (Basel), 9*(3). https://doi.org/10.3390/plants9030347

Shisanya, C. A. Jaetzold R. Schmidt, H., & Hornetz, B. (2006). Natural conditions and farm management information, vol. II, part B: Central Kenya, 1-493. Retrieved from https://library.wur.nl/isric/fulltext/isricu_i00023897_001.pdf

Swigonova, Z., Lai, J., Ma, J., Ramakrishna, W., Llaca, V., Bennetzen, J. L., &Messing, J. (2004). Close split of sorghum and maize genome progenitors. *Genome Research, 14*, 1916-1923. https://doi.org/10.1101/gr.2332504

Swinkels, R. A., Franzel, S., Shepherd, K. D., Ohlsson, E., & Ndufa, J. K. (1997). The economics of short rotation improved fallows: evidence from areas of high population density in Western Kenya. *Agricultural* *systems*, *55*, 99-121. https://doi.org/10.1016/S0308-521X(96)00098-4

Verma, R., Kumar, R., & Nath, A. (2018). Drought Resistance Mechanism and Adaptation to Water Stress in Sorghum [Sorghum bicolor (L.) Moench]. *International Journal of Bio-resource and Stress Management, 9*(1), 167-172. https://doi.org/10.23910/IJBSM/2018.9.1.3C0472

Zhu, S. Y., Hong, D. L., Yao, J., Zhang, X. L., & Luo, T. K., (2010). Improving germination, seedling establishment and biochemical characters of aged hybrid rice seed by priming with KNO3 + PVA. *African Journal of Agricultural Research*, *5*(1), 078-083. Retrieved from http://www.academicjournals.org/AJAR

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