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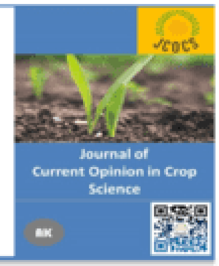

RESEARCH ARTICLE

The effect of seed packaging materials, storage period and conditions on the physiological sorghum seedlings

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ABSTRACT

Seed quality is fundamental to agricultural productivity and sustainability. Sorghum, as a versatile crop with a wide range of applications, requires high-quality seeds for optimal production. Understanding the seed storage condition, storage period and packaging materials on seed physiological quality is a basis of field crop establishment. This study aimed to evaluate the impact of packaging materials, storage conditions, and storage periods on the physiological quality of sorghum seedlings. One hundred grams of sorghum seed from 5.4 kg of cleaned sorghum seeds were packed in polyethylene bags, polypropylene bags, and aluminium foil. The seeds in packaging materials were stored at 3 different temperatures for 2, 4, and 6 months and the sample of ten grams was taken every 2 months of storage time for germination test. The data on normal seedlings, abnormal seedlings lengths, and seedling dry weight were recorded. The results showed that polyethylene bags at 10°C and 2 months of storage preserved seedling physiological quality more than aluminium foil and polypropylene bags. This may be attributed to the impervious properties of polyethylene hence preventing oxidative reactions and seed deterioration. To guarantee the successful field establishment and strong plant stand of sorghum crops, findings advise seed producers and farmers regarding appropriate seed storage procedures.

Keywords: packaging, physiological quality, polyethene, *sorghum bicolor*, storage.

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INTRODUCTION

Sorghum (*Sorghum bicolor* L.) is an important cereal crop globally, contributing significantly to food security and livestock feed. The physiological quality of sorghum seeds, which refers to their ability to germinate and establish healthy seedlings, is crucial for successful crop production. Various factors can influence seed quality, including packaging materials, storage conditions, and storage duration (Manjunatha et al., 2015). Good seed viability is important in crop establishments because it sets the basis for crop performance and yield potential (Finch, 2016). Mwamahonje et al. (2021) reported that plant breeders should consider long-term post-harvest storage in sorghum breeding programs for sustainable quality seed production. Packaging materials, storage conditions, and storage duration all play critical roles in maintaining the physiological quality of sorghum seedlings (Roy et al., 2023). Metal storage containers, particularly steel, and various plastics, as well as bags made of jute, polyethylene, polypropylene, cotton, or multilayer paper, are frequently used by farmers for packaging and storing sorghum seeds (Beta et al., 2019). Woven polypropylene bags are extensively used by farmers because of their affordability, lightweight nature, and capacity to facilitate aeration. However, their susceptibility to simple rupture makes stored grain vulnerable to significant insect infestations (Kiobia et al., 2020).

Common packaging materials for seed storage include polyethylene bags, jute bags, and metal containers. They protect seeds from external factors such as moisture, temperature fluctuations, and pests that can negatively impact seed viability and vigour (Chala and Bekana, 2017). The duration of seed storage is another critical factor that can influence seed quality. The longer the storage period, the higher the chances of seed deterioration due to natural ageing processes and environmental factors (Coradi et al., 2020). Temperature and humidity in storage conditions can have a significant impact on seed longevity and germination capacity. High temperatures and humidity levels can accelerate seed deterioration, reducing seed viability and vigour (Reed et al., 2022). These factors can significantly impact the overall viability of the seeds, ultimately affecting the productivity and performance of the resulting seedlings. Therefore, understanding the effects of packaging materials, storage conditions, and duration is essential for successfully establishing sorghum crops. However, the effect of different packaging materials on the physiological quality of sorghum seeds remains unclear.

The packaging materials should provide a suitable microenvironment that will ensure the seeds remain dormant and maintain their physiological quality until planting. Also, storing seeds at different temperatures can change their quality by speeding up oxidative reactions involving superoxide dismutase (SOD), catalase (CAT), and peroxidase (POX). These enzymes protect the seeds from oxidative stress while they are being stored and stop the production of reactive oxygen species (Stanisavljevic et al., 2020). Understanding the impact of seed packaging materials, storage conditions, and duration on the physiological quality of sorghum seedlings is critical for optimizing seed storage practices and ensuring farmers' access to quality seeds. In this study, we aimed to investigate the effect of different packaging materials, storage conditions, and storage periods on the physiological quality of sorghum seedlings by assessing seed germination ability, seedling vigour, and seed reserve mobilisation efficiency. The study will provide insights into the optimal storage conditions and duration for high seed quality. This information will benefit seed producers, farmers, and researchers working on sorghum seed conservation and crop production.

MATERIALS AND METHODS

Study area

The experiment was conducted at Tanzania Official Seed Certification Institute Laboratories in Morogoro town located 1.5 km from SUA main campus gate opposite to crop museum, Latitude: 6.8520° S Longitude:37.6576° E with an elevation of 500m - 600m from the sea level.

Experimental Design

A complete randomized design (CRD) in 3 ×3 ×3 factorial experiments with three replications was used. The treatments were storage conditions with three levels of 25°C, 20°C, and 10 °C, packaging materials were polypropylene bags, polyethylene, aluminium foil and Storage time had three levels (0, 2, 4, and 6) months.

Experimentation

The tested sorghum variety was Macia which was obtained from the Agricultural Seed Agency (ASA) a seed lot produced 2022/2023 growing season. Six kilograms of sorghum seeds were thoroughly cleaned and 5.4 kg of clean seeds were obtained for the storage experiment. Before packaging the initial seed, physiological quality test was carried out and the results were recorded, 200 g of seeds were placed in each of the three packaging materials in 3 storage conditions. The polypropylene bags, polyethylene bags, and ailuminum foil were tightly tied and labelled. Then the packed seeds were placed in the laboratory room for ambient storage of 25 ˚C ± 2˚C and at a controlled temperature of 20˚C ± 2˚C and 10˚C ± 2˚C for six months. The samples were drawn and analyzed for seedlings physiological quality after every two-month intervals. Fifteen grams of sorghum seeds were sampled from stored seeds in each packaging material across all storage temperatures and placed in a well-labelled paper bag. The label indicated the type of packaging materials, storage condition, and replication. The samples were taken to the laboratory for physiological quality analysis.

Germination test

Between papers (BT) method was employed with two pieces of blotter paper measured 20 cm by 30 cm were prepared and labelled on one of the papers on the top at the left side. The label indicated the sample number, type of packaging material, planting date, first and second counts, and reapplication number, then papers were soaked in distilled water for 5 minutes. The final count was made after ten days and the evaluation was done according to ISTA Rule's current version 2023. Seedlings that were well established with roots and shoots and the 2-part length having at least half of the seedling length were counted as normal seedlings while abnormal seedlings were those found with deformed either of the parts and albinism. The germination percent from each seed sample was calculated by following formula, Germination percentage = Number of normal seedlings / total number of seeds sown x 100 (Dehnavi et al. 2020; Venothini et al., 2024).

After evaluation of the seedlings, the same normal seedlings obtained from the germination test, 10 seedlings were selected randomly from each of the samples evaluated for recording other variables such as seedlings shoot length, seedlings root length, fresh weight and seedlings, dry weight. The remaining endosperm detached from the seedlings and placed in well-labelled paper bags before they were weighed followed by recording seedling roots and shoot length. Fresh weight measurement was done for each of the 10 seedlings per sample and the seedlings were tied in a bundle of 10 followed by labelling with white mask tape around their remaining endosperm before placing them in paper bags. The fresh weight was measured and recorded and the seedlings were placed in butter paper packets. The remaining endosperm returned to their respective paper bags and transferred to a hot air oven at 80°C ±1°C for 24 hours. After drying, seedlings and the remaining endosperms were taken to desiccators for 30 minutes to cool. Their dry weight was weighed, and recorded in grams and the mean values were obtained by dividing the total (Shoot length, Root Length, fresh weight, and Dry weight) by 10.

Seedling's Vigour Index I

It was calculated by mean root length and shoot length (cm) x Germination % (Abdul-Baki and Anderson formula, 1973).

Seedling's Vigour Index II

It was obtained by multiplying the seedling's dry weight (SDW) with the germination percentage for each seed sample.

Seed reserve mobilization rate to seedlings (SRMRS)

The seed reserves mobilization rate to seedlings was calculated and expressed in percentages according to Naik and Chetti et al. (2018).

$$\text{SRMRS (\%)} = \frac{\text{DMSL}}{\text{DMS}} \times 100$$

The conversion efficiency of seed reserves (CESR) was determined by dividing the dry matter of seedlings by the reduction of seed reserves to determine how much dry matter was converted to dry matter of seedlings.

$$\text{CESR (\%)} = \frac{\text{DMSL}}{\text{DMS-RDME}} \times 100$$

Where,
DMSL=Dry matter of seedlings; DMS=Dry matter of seeds; RDME=Remaining dry matter in endosperm
CESR=Conversion efficiency of seedlings rate
SRMRS=Seed reserve mobilization rate to seedlings

Data collection and analysis

The data collected included: the number of seedlings' roots, seedling shoot and root lengths, normal seedlings`, dead seeds, abnormal seedlings, and weight of seeds samples before and after oven-dry. The data were subjected to analysis of variance (ANOVA). The mean separation was done using Tukey at a 5% significance level. The analysis was performed using GenStat, the statistical package of the 16th edition.

RESULTS

The findings indicated significant differences between the packaging materials' impacts on germination, seedlings abnormalities, and vigour indexes at p< 0.05. The analysis of variance (ANOVA) for the parameters at, p<0.05, indicated that there was no effect of packaging materials on seedling length, seed reserve mobilization rate, or conversion efficiency of seed reserves. Polyethylene (PE) exhibited the highest germination rate of 74.87%, with low seedling abnormality at 12.02%, followed by AL which recorded 72.85% germination (Table 1).

The effect of extended storage reduced germination. After two months, indicate the decline in germination from 80% to 77.38%, then 70.03, and 62.87% after four months and six months, respectively. The abnormal seedling rate increased with prolonged storage intervals, from 11% before storage to 15.38% after 6 months. The pattern crosses the vigour index I, which ranged from 1750 initially and 1537 for the first 2 months' storage to 1210 after 6 months of seed storage, as well as the SRMRS, which was 0.98 before and 0.4183 after 6 months (Table 2).

Table 1. Effect of packaging material on germination, seedlings abnormality, length vigour, and conversion efficiency of seed reserves of the stored sorghum seeds

P	GM	ABN	SL	VG I	VG II	SRMRS	CESR
AL	72.85[b]	13.22[b]	20.11[a]	1469[b]	10.84[b]	0.68[a]	0.81[a]
PO	69.99[a]	14.38[c]	20.06[a]	1411[a]	10.55[a]	0.68[a]	0.82[a]
PE	74.87[c]	12.02[a]	20.17[a]	1513[b]	11.32[c]	0.69[a]	0.83[a]
Mean	72.57	13.21	20.11	1464.4	10.904	0.682	0.817
SE	0.42	0.227	0.18	14.62	0.082	0.005	0.009
P value	<.001	<.001	0.9	<.001	<.001	0.191	0.257
CV	6.9	20.6	10.7	12	9	9.1	12.6

Means followed by the same letter in each column belong to the same group according to the Tukey grouping criterion at 5% probability (p < 0.05). P=Packaging material, GM=germination percent, ABN=Abnormal seedlings, SL=seedling length (cm), VGI= Vigour index I, VG II=Vigour index, SRMRS=Seed reserve mobilization rate to seedlings, and CESR=Conversion efficiency of seed reserves.

Table 2. Effect of storage time on germination, seedlings abnormality seedlings length vigour, and conversion efficiency of seed reserves of the stored sorghum seeds

ST	GM	ABN	SL	VG I	VG II	SRMRS	CESR
0	80.00[d]	11.00[a]	21.88[b]	1750[d]	15.60[d]	0.98[c]	1.30[c]
2 M	77.38[c]	12.55[b]	19.87[a]	1537[c]	15.06[c]	0.91[b]	0.99[b]
4M	70.03[b]	13.91[c]	19.41[a]	1360[b]	6.75[b]	0.42[a]	0.49[a]
6 M	62.87[a]	15.38[d]	19.21[a]	1210[c]	6.20[a]	0.42[a]	0.48[a]
Mean	72.57	13.21	19.74	1464.4	10.90	0.68	0.82
SE	0.617	0.286	0.206	16.22	0.085	0.006	0.009
P value	<.001	<.001	<.001	<.001	<.001	<.001	<.001
CV	5.9	20.1	10.6	11.5	8.1	8.6	12

Means followed by the same letter in each column belong to the same group according to the Tukey grouping criterion at 5% probability (p < 0.05). ST= storage time, GM= germination percent, ABN=Abnormal seedlings, SL=seedling length, VGI Vigour index I, VG II=Vigour index, SRMRS=Seed reserve mobilization rate to seedlings, and CESR=Conversion efficiency of seed reserves.

The findings showed that temperature affected the germination and vigour of sorghum seeds in a significant way (p<.001). The percentage of sorghum seeds that germinated at 10°C (73.78%) was significantly higher compared to those stored at 20°C (72.19%), and 25°C (71.57%). The temperature had a significant impact on the Vigour Index II (p<.001), the recorded trend decreased as temperature increased (11.2, 10.65, and 10.86) index at 10°C, 20°C, and 25°C), and at (p = 0.054) and (p = 0.031) for SRMRS and CER respectively were significant. The study found significant differences in packaging materials and storage duration interaction on seedling vigour index I, CESR (p≤0.031) and seed germination. The maximum number of aberrant seedlings (17.3%) were produced, while the lowest (11.67%). Furthermore, the CESR was higher (1.03) than (0.49), while the lowest was (0.46). The interaction did not have a significant effect on seedling length (Table 4).

Table 3. Effect of temperature on germination, seedlings abnormality, vigour and conversion efficiency of seed reserves of the stored sorghum seeds

TEMP	GM	ABN	SL	VG I	VG II	SRMRS	CESR
10	73.78[b]	12.99[a]	20.12[a]	1491[b]	11.20[b]	0.69[b]	0.84[b]
20	72.19[a]	13.17[a]	20.21[a]	1461[ab]	10.65[a]	0.67[a]	0.80[a]
25	71.73[a]	13.47[a]	20.01[a]	1441[a]	10.86[a]	0.68[ab]	0.81[ab]
Mean	72.57	13.36	20.11	1464	10.90	0.71	0.820
ES	0.353	0.353	0.18	14.62	0.082	0.012	0.009
P value	<.001	0.322	0.73	0.058	<.001	0.054	0.031
CV	5.3	20.6	10.7	12	9	9.1	12.6

Means followed by the same letter in each column belong to the same group according to the Tukey grouping criterion at 5% probability (p < 0.05). TEMP= temperature, GM=germination percent, ABN=Abnormal seedlings, SL=seedling length, VGI =Vigour index I, VG II=Vigour index, SRMRS=Seed reserve mobilization rate to seedlings, and CESR=Conversion efficiency of seed reserves.

Table 4. Interaction effect of packaging materials and storage time on seeds and seedling physiological variables

P *ST	GM	ABN	SL	VG I	VG II	SRMRS	CESR
Initial	80.00[f]	11.00[a]	21.88[b]	1750[d]	15.60[f]	0.98[c]	1.30[c]
PE*2M	77.22[ef]	11.67[ab]	20.14[a]	1555[c]	15.28[ef]	0.93[bc]	1.03[b]
PO*2M	77.33[ef]	13.17[b]	19.78[a]	1529[c]	15.13[ef]	0.91[b]	0.98[b]
Al*2M	77.58[ef]	12.81[ab]	19.68[a]	1528[c]	14.79[e]	0.89[b]	0.97[b]
PE*4M	74.67[e]	12.28[ab]	19.64[a]	1466[c]	7.52[d]	0.43[a]	0.50[a]
PO*4M	65.81[bc]	16.00[c]	19.54[a]	1286[b]	6.15[b]	0.40[a]	0.50[a]
AL*4M	69.61[d]	13.44[c]	19.05[a]	1328[b]	6.58[bc]	0.44[a]	0.50[a]
PE*6M	67.58[cd]	13.14[b]	19.03[a]	1280[b]	6.88[cd]	0.42[a]	0.48[a]
PO*6M	56.81[a]	17.36[c]	19.03[a]	1080[a]	5.33[a]	0.41[a]	0.49[a]
AL*6M	64.22[b]	15.64[c]	19.68[a]	1269[b]	6.39[bc]	0.42[a]	0.46[a]
Mean	72.57	13.21	20.11	1464.4	10.90	0.68	0.82
ES	0.706	0.446	0.358	28.1	0.139	0.009	0.02
P value	<.001	<.001	0.497	<.001	<.001	0.031	<.001
CV	5.8	20.3	10.7	11.5	7.7	8.2	11.9

Means followed by the same letter in each column belong to the same group according to the Tukey grouping criterion at 5% probability (p < 0.05). P= packaging material, GM = germination percent, ABN = Abnormal seedlings, SL= seedling length, VGI Vigour index I, VG II = Vigour index, SRMRS = Seed reserve mobilization rate to seedlings, and CESR = Conversion efficiency of seed reserves.

Both packing materials and the temperature had a significant impact on the germination percent and vigour index II (P<0.001) and on the rate at which seed reserves were mobilized to support seedling growth (SRMRS) (P = 0.046). The maximum (0.71) mobilization rate was seen in seeds stored in polyethylene bags at 10°C, while the lowest (0.67) mobilization rate was seen in seeds stored in PO bags at 25°C. However, there was no association between seedling abnormalities, seedling lengths, and CESR (P = 0.595, 0.525, and 0.119 (Table 5). The combined effect was also significant for seedling length and seedling vigour index I (p≤0.024 and 0.01). Germination was 77.5%, vigour index II was 14.95, SRMRS was 0.9 and CESR was 1.0013 compared to the other combined effects of all parameters studied. The combined effect between two months of storage and a storage temperature of 10°C showed a better effect. The interaction between 6 months and 25°C showed the lowest power of the combined effects (Table 6).

The results indicated that there were no interaction s between storage time, temperature, and packaging materials on germination or abnormal seedlings. (Figure 1a & b). Interaction effect of packaging material, storage time, and temperature on seedling vigour index II (a) and seed reserves mobilization rate to seedlings (b) on stored sorghum seeds. Al10, Al20 and Al25 = Aluminium foil at storage temperature of 10°C, 20°C, and 25°C, PO10, PO20 and PO25=PO packaging material at storage temperature of 10°C, 20°C, and 25°C, and PE10, PE20 and

PE25=Polyethylene packaging material at storage temperature of 10°C,20°C and 25°C (Figure 1c & d).Interaction effect of packaging material, storage time and temperature on seedling abnormality (c) and seed germination (d) on stored sorghum seeds. Al10, Al20 and Al25 = Aluminium foil at storage temperature of 10°C, 20°C and 25°C, PO10, PO20°C and PO25°C =PO packaging material at storage temperature of 10°C,20°C and 25°C, and PE10°C, PE20°C and PE25=Polyethylene packaging material at storage temperature of 10°C,20°C and 25°C. The germination was decreased with the increase of abnormal seedling formation associated with albinism seedlings observed after 4 months and 6 months of sorghum seed storage (Figure 2).

Table 5. Interaction effect of packaging materials and temperature on seeds and seedling physiological variables.

P*TEMP	GM	ABN	SL	VG I	VG II	SRMRS	CESR
PE*10	76.71^{d}	12.04^{ab}	20.37^{a}	1566^{c}	11.95^{c}	0.71^{b}	0.87^{b}
PE*20	73.79^{c}	11.56^{a}	20.02^{a}	1480^{abc}	10.72^{a}	0.66^{a}	0.79^{a}
PE*25	74.10^{cd}	12.46^{abc}	20.13^{a}	1493^{bc}	11.29^{b}	0.69^{ab}	0.82^{ab}
AL*10	73.94^{c}	12.88^{abcd}	19.88^{a}	1478^{abc}	10.92^{ab}	0.68^{ab}	0.82^{ab}
AL*20	72.79^{bc}	13.35^{bcde}	20.24^{a}	1471^{abc}	10.78^{ab}	0.68^{ab}	0.80^{a}
AL*25	71.83^{abc}	13.44^{bcde}	20.19^{a}	1457^{ab}	10.82^{ab}	0.68^{ab}	0.80^{a}
PO*10	69.25^{a}	14.04^{cde}	20.09^{a}	1428^{ab}	10.74^{a}	0.68^{ab}	0.82^{ab}
PO*20	70.00^{a}	14.6^{e}	20.38^{a}	1432^{ab}	10.44^{a}	0.67^{a}	0.81^{ab}
PO*25	70.71^{ab}	14.5^{de}	19.7^{a}	1374^{a}	10.48^{a}	0.67^{a}	0.81^{ab}
Mean	72.57	13.21	20.11	1464.4	10.90	0.68	0.82
ES	0.611	0.39	0.31	24.39	0.121	0.008	0.01
P value	<.001	0.60	0.525	0.30	<.001	0.046	0.12
CV	5.8	20.3	10.7	11.5	7.7	8.2	12

Means followed by the same letter in each column belong to the same group according to the Tukey grouping criterion at 5% probability ($p < 0.05$). GM=germination percent, ABN=Abnormal seedlings, SL=seedling length, VGI= Vigour index I, VG II=Vigour index, SRMRS=Seed reserve mobilization rate to seedlings, CESR=Conversion efficiency of seed reserves. Statistical analysis showed that there were no interaction effects on seedling anomaly ($p=0.743$), while the effects between storage time and temperature were evident on germination, seedling vigour index II, SRMRS and CESR ($p<0.001$).

Table 6. Interaction effect of storage time and temperature on seeds and seedlings' physiological variables

ST *TEMP	GM	ABN	SL	VG I	VG II	SRMRS	CESR
Initial	80.00^{e}	11.00^{a}	21.88^{c}	1750^{e}	15.60^{d}	0.97^{e}	1.30^{e}
2M*10°C	77.50^{de}	12.47^{ab}	20.68^{bc}	1603^{d}	14.95^{d}	0.9^{d}	1.00^{d}
2M*20°C	76.58^{d}	12.72^{ab}	19.57^{ab}	1500^{cd}	14.95^{d}	0.91^{d}	0.98^{d}
2M*25°C	78.06^{de}	12.44^{ab}	19.34^{ab}	1510^{cd}	15.30^{d}	0.92^{d}	1.00^{d}
4M*10°C	71.36^{c}	13.67^{bc}	19.36^{ab}	1384^{bc}	7.58^{c}	0.46^{c}	0.57^{c}
4M*20°C	72.58^{c}	13.67^{bc}	19.60^{ab}	1417^{c}	6.08^{ab}	0.37^{a}	0.42^{a}
4M*25°C	66.14^{b}	14.39^{bcd}	19.26^{ab}	1279^{ab}	6.60^{ab}	0.43^{bc}	0.50^{bc}
6M*10°C	66.28^{b}	14.81^{cd}	18.54^{a}	1225^{a}	6.68^{b}	0.43^{bc}	0.48^{ab}
6M*20°C	59.61^{a}	15.31^{cd}	19.79^{ab}	1178^{a}	5.96^{a}	0.43^{bc}	0.51^{bc}
6M*25°C	62.72^{a}	16.03^{d}	19.34^{ab}	1225^{a}	5.96^{a}	0.40^{ab}	0.45^{ab}
Mean	72.57	13.21	20.11	1464.4	10.9	0.68	0.82
ES	0.713	0.441	0.356	28.1	0.147	0.01	0.0164
P value	<.001	0.743	0.024	0.01	<.001	<.001	<.001
CV	5.9	20.1	10.6	11.5	8.1	8.6	12

Means followed by the same letter in each column belong to the same group according to the Tukey grouping criterion at 5% probability ($p < 0.05$). GM=germination percent, ABN=Abnormal seedlings, SL=seedling length, VG I =Vigour index I, VG II=Vigour index, SRMRS=Seed reserve mobilization rate to seedlings, and CESR=Conversion efficiency of seed reserves.

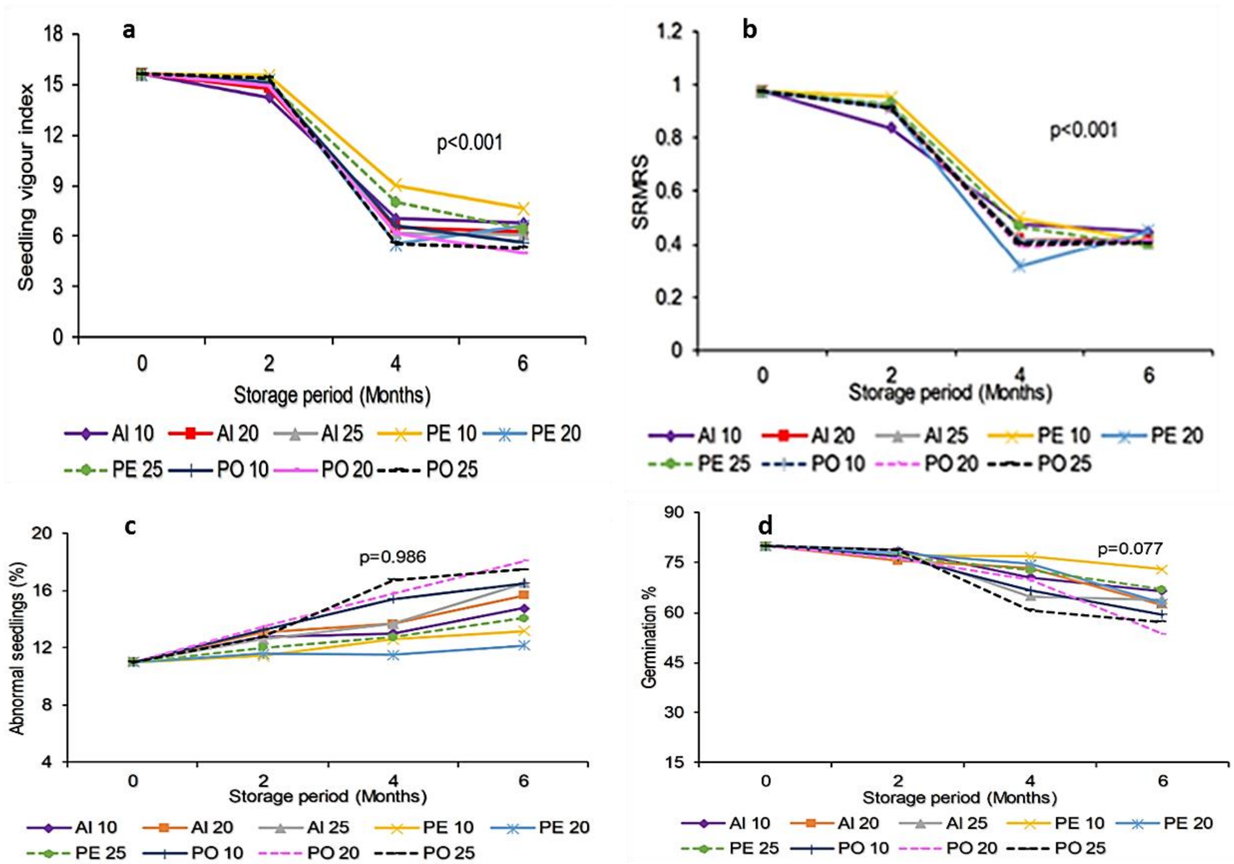

Figure 1. Interaction effect of Packaging material, storage time, and temperature on (a) seedlings vigour index II and (b) SRMRS for stored sorghum seeds, (c) seedlings germination, and (d) abnormal seedlings.

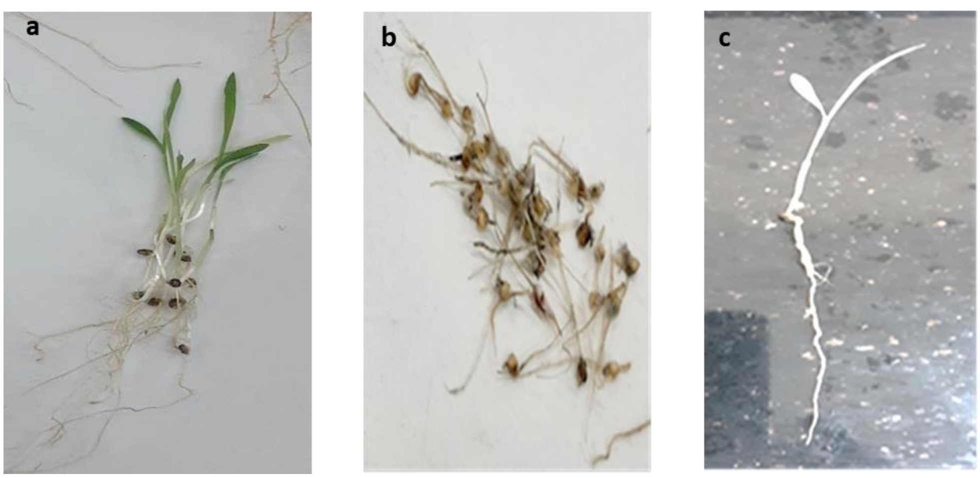

Figure 2. The type of seedlings evaluated for the stored sorghum seeds: (a) normal seedlings, (b) abnormal seedlings with deformed seed structure and (c) abnormal seedlings with albinism.

DISCUSSION

Seeds stored in polyethylene bags for six-month periods had the highest seed physiological quality when compared to those stored in aluminium foil and polypropylene which expressed a decrease in seed physiological quality. The porous packaging materials like jute, nylon, and paper lost their quality considerably in storage and the increase in storage periods under relatively high temperatures and humidity was found to cause a reduction in the vigour and viability of the stored Pericopsis elata seeds (Tandoh et al., 2017). The effect of packaging materials on seedling vigour index II shows the decline in seedling vigour that may have resulted from reduced availability of stored reserves, as well as the damage caused by storage-induced stresses. These findings are in line with Ali et al. (2018) who reported that seed viability and vigour significantly depend on the type of storage container.

The germination of seeds was significantly impacted by the packaging materials, seedling abnormalities, and seedlings' vigour index I and vigour index II under the three packaging materials in which polyethylene indicated a good ability to maintain seed viability with a lower number of abnormal seedlings. These findings agree with Aladele et al. (2020) who report on okra seeds stored in polyethylene bags which had the highest germination percentage under short-condition storage. Natural ageing processes and the accumulation of oxidative damage over time can be the cause of the decrease in germination; likewise, seed vigour showed a decline as the storage duration increased. Seed physiological quality decreased with the increase in storage time affecting the germination percentage, seedlings abnormality, vigour index and seed reserves mobilization rate to seedlings (SRMRS) of stored sorghum seeds. The study shows that seed storage time prompts seed ageing which results in reduced seedling growth and this may be the consequence of the decline in weight of mobilized seed reserve. This is comparable to Naing, et al. (2019), who found that the four-months storage period had a greater impact on seed quality than the type of container used for storage for head rice. Moreover, results of this study showed that seed vigour significantly decreased with prolonged storage periods which eventually caused seed deterioration due to seeds' natural ageing. Among the factors influencing seed deterioration, temperature, and seed moisture content are most important in terms of loss of viability during storage, ultimately affecting seed vigour and germination potential (De Vitis et al., 2020). The conditions under which seeds are stored can greatly impact their quality (Gebeyehu, 2020). Seeds stored at 10°C consistently exhibited higher germination rates compared to those stored at 20°C and ambient temperature. The controlled environment provides optimum conditions for seed preservation, minimizing the detrimental effects of temperature fluctuations and humidity variation (Delouche et al., 2021). A study by Rahmawati and Aqil (2020) revealed seeds stored at both low temperatures and relative humidity respectively to the initial seed quality, had a significance on seed quality regardless of the packaging material used, however when stored under ambient conditions in an air-tight container appeared to be the best option for seed producers and farmers (Sharma et al., 2023). Packaging materials and storage period had a positive interaction effect on germination, abnormality of seedlings, vigour index, and CESR.

In the comparison of aluminum, polypropylene, and polyethylene packaging materials, fewer abnormal seedlings were recorded in polypropylene materials and 2 months' storage time. Polyethylene (PE) is a non-porous polymer used for packing seeds that prevent seeds from gaseous exchange and moisture intake, therefore reducing seed oxidative process, PE in combination with two months of seed storage produced superior results. These findings correlate to those of Chhabra & Singh. (2019), who showed, that the deleterious effects of seed ageing occur largely due to oxidative processes which can lead to the deterioration of the seed reserves. The increased storage time and temperature may have contributed to a decline in germination percentage for the stored sorghum seeds. Storage at high temperatures and high seed moisture content results in decreased seed viability as a result of accelerated ageing (Azam et al., 2018). The reduced mobilization rate and conversion efficiency of seed reserves in stored sorghum seeds over storage time and ambient storage indicated that the stored seed food reserves were undergoing degradation and hence became less accessible to the developing seedlings. Inhibition of seedling growth occurs when less seed reserve is used and/or efficiency (Mašková, & Herben, 2018). According to Wang et al. (2018), poor storage conditions greatly affect seed vigour. The reduced germination percentage, increased seedling abnormalities, lower vigour index, slower seed reserves mobilization rate, and decreased conversion efficiency observed in seeds stored in polypropylene bags at 25°C, may be attributed to inadequate moisture regulation and increased respiratory activity resulting from limited barrier properties of polypropylene (PO) packaging. Seeds stored in polyethylene bags at 10°C exhibited higher performance in all measured parameters, indicating that the combination provides optimal conditions for preserving seed quality during storage, Buleti et al. (2019) reported double gouge polyethylene prevents air exchange and seed damage hence maintaining germination which is the parameter of seed physiological quality. As the storage time and temperature increased, the conversion efficiency of seed reserves to support seedling growth was significantly compromised. The decrease in SRMRS indicates that stored seeds may experience difficulties in effectively utilizing their stored energy reserves for optimal seedling establishment. Reporting the type of abnormality in seedling testing has not been given priority, so there is little information from seed storage results, but also the albino seedlings in the ISTA grouping are reported as abnormal despite their potential, (Prasad, 2023). Albinism has been reported in crops as a bottleneck in hybridization for Plant breeding and plant development programs. Physiological changes occur during seed storage, impairing various functional elements and systems, reducing performance capabilities, and ultimately leading to germination failure (Delouche, et al., 1973). However, numerically the formation of abnormal seedlings increased as the germination percentage decreased in both packaging materials and storage time. Polyethylene had a lower number of abnormal seedlings compared to polypropylene and aluminium packaging. The occurrence of seedling abnormalities under storage conditions indicates the presence of stress factors that compromise seed physiological quality.

The Polyethylene combined with temperature and storage time shows a lower percentage of abnormal seedlings for six-month storage when compared to aluminium foil and polypropylene bags. The efficient moisture regulation, reduced breathability, low temperature, and enhanced, barrier properties of polyethylene bags are responsible for maintaining viability, vigour, and seed reserve mobilization rate (SRMR). The findings suggest that polyethylene bags at 10°C storage and 2 months' storage time provide better protection against temperature variations and maintain seedlings' physiological quality compared to aluminium foil and maintain polypropylene bags, not only that but also against 20°C, 25°C, and across the three-storage time.

CONCLUSION

The findings of this study highlight the significant impacts of packaging materials, storage temperature, and duration on the physiological quality of sorghum seedlings. Proper packaging using suitable materials can protect the seeds from external factors potentially impacting seed viability and germination. Additionally, storage conditions, particularly temperature and moisture, greatly influence seed long life and overall seed quality. Based on our analysis, it is evident that utilizing appropriate packaging materials like PE containers can effectively preserve the physiological quality of sorghum seeds. Moreover, maintaining ideal storage conditions, including cool temperatures at 10°C can significantly maintain seed longevity and germination capacity.

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AUTHORS CONTRIBUTION STATEMENT

All three authors contributed to come with this work; Yohana Mbughi experimented, collected data, processed, analyzed and submitted the manuscript, while Newton Kilasi and Sixbert Mourice supervised the entire research study implementation process.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

REFERENCES

Abdul-Baki, A. A., & Anderson, J.D. (1973). Vigor determination in soybean seed by multiple criteria 1. *Crop Science*, *13*(6), 630–633.

Aladele, S. E., Olosunde, A. A., Olubiyi, M. R., Afolayan, G. R., Kuyebi, A. O., & Aluko, I. J. (2020). Impact of storage conditions and packaging materials on seed germination and field emergence of okra (*Abelmoschus callei*) at different seasons. *Journal. Bio. Life Sci*ence *11*(1), 1-17.

Ali, M. R., Rahman, M. M., Wadud, M. A., Fahim, A. H. F., & Nahar, M. S. (2018). Effect of seed moisture content and storage container on seed viability and vigour of soybean. *Bangladesh Agronomy Journal, 21*(1), 131-141.

Golam Azam, M., Sohidul Islam, M., Hasan, K., Kaum Choudhury, M., Jahangir Alam, M., Obaidullah Shaddam, M., & El Sabagh, A. (2018). Effect of storage containers and lengths of storage on the germination, moisture content and pest infestation of wheat seed. *Cercetari Agronomice in Moldova*, *51*(3), 13–23. https://doi.org/10.2478/cerce-2018-0022

Beta, T., & Ndolo, V. U. (2019). Postharvest technologies. In Sorghum and millets (pp. 69-84). AACC International Press.

Buleti, S. I., Mamati, E. G., & Abukutsa-Onyango, M. (2019). Determination of appropriate packaging materials for cowpea seed storage. *Journal of Stored Products and Postharvest Research, 10*(4), 29-34.

Chala, M., & Bekana, G. (2017). Review on seed process and storage condition about seed

moisture and ecological factors. *Journal of Natural Sciences Research, 7*, 84-90.
Chhabra, R. S., & Singh, T. (2019). Seed Aging, Storage and Deterioration: An Irresistible Physiological Phenomenon. *Agricultural Reviews*, 40(03). https://doi.org/10.18805/ag.r-1914
Coradi, P. C., Lima, R. E., Padia, C. L., Alves, C. Z., Teodoro, P. E., & Carina da Silva Cândido, A. (2020). Soybean seed storage: Packaging technologies and conditions of storage environments. *Journal of Stored Products Research*, *89*, 101709. https://doi.org/10.1016/j.jspr.2020.101709
De Vitis, M., Hay, F. R., Dickie, J. B., Trivedi, C., Choi, J., & Fiegener, R. (2020). Seed storage: maintaining seed viability and vigor for restoration use. *Restoration Ecology*, *28*(S3). https://doi.org/10.1111/rec.13174
Delouche, J. C., Matthes, R. K., Dougherty, G. M., & Boyd, A. H. (2021). "Storage of Seed in Sub-Tropical and Tropical Regions" (2021). Seed Technology Papers. 205. https://scholarsjunction.msstate.edu/seedtechpapers/205
Finch-Savage, W. E., & Bassel, G. W. (2016). Seed vigour and crop establishment: extending performance beyond adaptation. *Journal of Experimental Botany*, *67*(3), 567-591.
Gebeyehu, B. (2020). Review on: Effect of seed storage period and storage environment on seed quality. *International Journal of Applied Agricultural Sciences*, *6*(6), 185-190.
Gunakeshari L., Volenec, J., Ambrose, K., & Dieudonne Baributsa. (2023). Assessing germinating seeds of legume and cereal crops to enhance oxygen depletion: a novel approach in hermetic storage. *Sustainability*, *15*(23), 16403–16403. https://doi.org/10.3390/su152316403
Kiobia, D. O., Silayo, V. C. K., Mutabazi, K. D., Graef, F., & Mourice, S.K. (2020). Performance of hermetic storage bags for maize grains under farmer-managed conditions: good practice versus local reality. *Journal of Stored Products Research*, 87, p.101586.
https://doi.org/10.1016/j.jspr.2020.101586
Manjunatha, B. L., Rao, D. U. M., Sharma, J. P., Burman, R. R., Hajong, D., Dastagiri, M. B., & Sumanthkumar, V. (2015). Factors affecting accessibility, use and performance of quality seeds in Andhra Pradesh and Bihar: Farmers' experiences. *Journal of Community Mobilization and Sustainable Development, 10*(1), 130-145.
Mašková, T., & Herben, T. (2018). Root: shoot ratio in developing seedlings: How seedlings change their allocation in response to seed mass and ambient nutrient supply. *Ecology and Evolution*, *8*(14), 7143–7150.
https://doi.org/10.1002/ece3.4238
Mwamahonje, A., Eleblu, J. S. Y., Ofori, K., Deshpande, S., Feyissa, T., & Bakuza, W. E. (2021). Sorghum Production Constraints, Trait Preferences, and Strategies to Combat Drought in Tanzania. *Sustainability*, *13*, 12942.
https://doi.org/10.3390/su132312942
Naing, A. A., One, K. T., Myint, T. S., Man, E. H., & Win, K. K. (2019). Grain and seed quality of manawthukha rice (Oryza sativa L.) as affected by different storage containers and storage durations. *Journal of Agricultural Research*, *6*, 79-88.
Prasad, S. R. (2023). Testing Seed for Quality. Malavika Dadlani, p299.
Rahmawati, & Aqil, M. (2020). The effect of temperature and humidity of storage on maize seed quality. *IOP Conference Series: Earth and Environmental Science*, *484*, 012116. https://doi.org/10.1088/1755-1315/484/1/012116
Rajabi Dehnavi, A., Zahedi, M., Ludwiczak, A., Cardenas Perez, S., & Piernik, A. (2020). Effect of Salinity on Seed Germination and Seedling Development of Sorghum (*Sorghum bicolor* (L.) Moench) Genotypes. *Agronomy*, *10*(6), 859. https://doi.org/10.3390/agronomy10060859
Reed, R.C., Bradford, K.J. & Khanday, I. (2022). Seed germination and vigor: ensuring crop sustainability in a changing climate. *Heredity 128,* 450–459.
https://doi.org/10.1038/s41437-022-00497-2
Roy, T., Prashant Kumar Rai, and Shivam Kumar Rai (2023). Standardization of pre-sowing seed treatment with selected bio fertilizers and different packaging materials on seedling parameters of sorghum (*Sorghum bicolor* L.) during storage. *Annals of Agricultural Research*, *44*(4), 480–487.
Saida Naik, D., & Chetti, M. B. (2018). Influence of packaging and storage conditions on different seed quality parameters in paddy. *International. Journal of Pure and Applied. Bioscience, 6*(1), 159-166. http://dx.doi.org/10.18782/2320-7051.4004
Sharma, P., Roy, M., Roy, B., & Deka, S. D. (2023). Post-Harvest Management Strategies and Storage Approaches for Quality Seed Production. *Emerging Issues in Agricultural Sciences*, *2*, 110-129.
Stanisavljevic, R., Poštić, D., Štrbanović, R., Tabaković, M., Jovanović, S., Milenković, J., & Terzić, D. (2020). Effect of seed storage on seed

germination and seedling quality of Festulolium in comparison with related forage grasses. *Tropical Grasslands-Forrajes Tropical*, *8*(2), 125-132.

Tandoh, P., Banful, B., Gaveh, E. and Amponsah, J. (2017). Effects of packaging materials and storage periods on seed quality and longevity dynamics of Pericopsis elata seeds. *Environment, Earth, and Ecology*, *1*(2), 27–38. https://doi.org/10.24051/eee/76919

Wang, J., Hu, Z., Upadhyaya, H. D., & Morris, G. P. (2020). Genomic signatures of seed mass adaptation to global precipitation gradients in sorghum. *Heredity*, *124*(1), 108-121. https://doi.org/10.1038/s41437-019-0249-4

Venothini, S., Sujith, A. S., Riya, E., Soji, S. A., Vinodha, K., & Ashokkumar, K. (2024). Effect of halo priming on germination and growth parameters of finger millet, little millet, and barnyard millet under osmotic stress. *Journal of Current Opinion in Crop Science*, *5*(2), 62-69. https://doi.org/10.62773/jcocs.v5i2.246