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RESEARCH ARTICLE

Influence of storage conditions on viability and vigour of Sunflower (*Helianthus annuus* L.) seeds

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ABSTRACT

The storage experiment examined the effects of storage temperatures, seed moisture contents (SMC), and storage durations (SD) on the viability and vigour of sunflower seeds. Certified sunflower seeds were evaluated for germination, seedling vigour, and fungal infection. A 3x3x6 factorial experiment in CRD was set out in four replicates. The three factors were temperature (5, 20, 35 ºC), SMC (6,8,10%), and SD (15, 30, 45, 60, 75, 90 Days After Storage, DAS). Before storage (0 DAS), the initial germination percentage (GP=94%), Germination index (GI=322), Seedling vigour index (SVI=2118), and fungal infection incidence (FII=52%) were determined and used as control. The lowest GP of 73.83% and 75.5%, GI (276.08 and 283.2), SVI (1485 and 1530), and greatest FII (73.0 and 72.67%), were found in seeds stored at a temperature of 35 ºC and SMC of 10% respectively at 90DAS. Upon the interaction effect of temperature and storage duration, the temperature of 5 ºC followed by the temperature of 20 ºC at 90 DAS recorded the greatest GP of 84.67and 83.83%, GI of 299.0 and 293.0; SVI of 1804 and 1779 and fewer fungi incidence (%) of 64.5 and 65.83 respectively. While the greatest GP of 83.83 and 83.00%, GI of 292.8 and 292.17; SVI of 1792 and 1747 and fewer fungi incidence (%) of 64.83 and 65.83 was recorded in seeds stored with SMC of 6% followed by 8% respectively at 90 DAS. Results indicate optimal storage settings (5-20ºC, SMC 6-8%) for maintaining sunflower seed viability and vigor during 90 DAS.

Keywords: germination percentage, sunflower, seed viability, storage conditions, vigour index

INTRODUCTION

Seeds take a crucial part in crop production and productivity. Well stored seeds have high viability, vigour and its purity are maintained. This kind of seed gives good performance when grown in the field (Aqil, 2020). Htwe et al. (2018), found that physiological weakening of seeds at the storage-time is one of the main aspects hindering seeds from normal germination and energetic growth. In order to increase their germination capability, the seeds should be instantly available or well-preserved under right conditions for the forthcoming generation (Genes and Nyomora, 2018).

It is important therefore, sunflower producers have accessible and available, high-quality seeds for establishing of large sunflower farms, aiding at fast development of plants, a critical condition for gaining crops with high harvests (Catão et al., 2016). Low temperature, low seed moisture content and fungal infestation-free storage conditions are necessary for orthodox seed storage (Aqil, 2020). Soybean seeds, for instance, had better germination rates when stored between 15°C and 20°C than when stored at ambient temperature, according to Mbofung et al. (2013). Additionally, (Aqil, 2020) found that cereal seeds are kept at a storage temperature of less than 20°C and a moisture content of roughly 10–11%.

Currently in Tanzania small-holder farmers store their sunflower seeds at uncontrolled storage conditions. Since, the seed are hygroscopic in nature, that is, they absorb or release water from the surroundings at the storage-time, so controlling the seed storage conditions is vital, this is according to Suleiman, (2013). This is in order to maintain viability and vigour Mettananda at el., 2001 testified that seed vigour declines with rise in seed moisture content particularly in areas with unrestrained temperature and air-humidity. Commonly, seeds can therefore be kept for a long time when quality, moisture content, and temperature control are taken into account for long-term storage. Additionally, Surki (2012) stated that adverse seed preserving conditions, mainly air temperature and air-humidity, can hasten the demise of seeds while being stored. Together, Engels and Visser (2003) and Rao et al., (2006) indicated that seeds can also be kept for a significant amount of period relying on the initial quality of the seed, their water content and the seed kept at a controlled temperature for a significant amount of time.

Seeds with a high initial moisture content, such as those with an 18% moisture content, are typically attacked by mould and insect pests and can suffer mechanical damage. If the crop—be it a grain, an oil seed, or a legume—contains a living organism, it will continuously respire, releasing heat and moisture that, if present in excess, can foster the development of numerous harmful species. These in other way, will result in a damage of the seeds' quantity and quality, which will reduce their viability and vigour while being stored.

Successful storage is therefore of utmost importance to the seed industry. This suggests that storing sunflower seeds properly is crucial for the growth of sunflower crops. Additionally, because the relative humidity, temperature, and initial seed water content are the primary factors influencing seed viability and vigour during storage, seed health evaluation is also inevitable as likewise revealed by Hasan et al., (2017). Nevertheless, research work concerning the effects of storage temperatures, duration and moisture levels on the seed viability and vigour of the sunflower seeds are limited in Tanzania.

Consequently, this experimental study was conducted in order to investigate the effect of moisture content of the seed, storage temperature and storage duration. It further find-out the effect of their interactions, the optimal moisture content, storage temperature and the ideal storage duration on seed viability and vigour of sunflower seeds.

MATERIALS AND METHODS

Assembling and Preparing of Seed Material

Certified OPV of sunflower seed collected from Agricultural Seed Agency (ASA) was used for this study. The Seeds were produced by ASA during the growing season of 2022/2023. The moisture contents of the received seeds were determined using a high-temperature oven method and found to be 10.00%; This was the first level of seed moisture content. Two-thirds of the seeds were then taken from the seed with a moisture content of 10.00% and dried under natural air-drying conditions for 24 hours on three consecutive days (8 hours each day) while on each day, a portion of the sample was taken for moisture content determination using the same method as above. On the third day of seed drying, the moisture content was 8.00% and recorded as the second moisture content level.

After the first 24 hours of seed drying, one-third of the seeds (with a moisture content of 8.00%) were taken and further dried for another 3 days (8 hours of natural air-drying condition per day). The moisture content was then determined and found to be 6.06% on the third day and recorded as the third moisture content level.

Seed Storage

The laboratory experiment was conducted at the Sokoine University of Agriculture, Department of Crop Science and Horticulture, in the African Seed Health Lab from December 2022 to March 2023. Five hundred grams of each treatment-certified seeds with a seed moisture content of 6%, 8%, and 10% were packed separately in polypropylene bags labelled 5, 20, and 35 ^{0}C replicated four times. The packaged sunflower seeds were kept in three different storage temperature environments using ovens and refrigerators in December 2022.

Experimental Design

The experiment was set in 3 x 3 x 6 factorial using completely randomized design (CRD) in four replications. The three factors were three temperature levels (5, 20, 35 ^{0}C) with three different moisture content levels (6, 8 and 10%). The preserved seed samples were drawn at 15-day intervals at 15, 30,45,60,75, and 90 days, constituting six storage durations. The drawn samples were evaluated for germination test, seedling vigour, fungal infestation, and infection.

Standard Germination Test

In four replicates, 200 seeds from each treatment were drawn and sown in sterile sand bowls. Watering was performed as necessary to maintain ideal soil moisture. Germination was monitored every day from the day of sowing for 10 days. Germination tests were done according to ISTA rules (ISTA, 2022).

Germination percentages of normal seedlings were calculated according to Ashokkumar et al. (2023) as follows: Germination % = Number germinated seeds/ Total number of seeds sown X 100.

Seedling Vigour Index

This test was executed concurrently with the germination experiment. At the final count (10 days), seedlings with perfect morphological regions with no defects were chosen as vigorous. An average length of 20 seedlings was taken to determine the seedling vigour index using the equation suggested by Abdul-Baki and Anderson (1973).

Seedling vigour index = Germination (%) × (Root length (cm) + Shoot length (cm)

Germination Index

The germination index was determined by using the equation: Germination Index = (10 x n1) + (9 x n2) + (8 xn3) +…+ (1 x n10), Where n1, n2, n3…n10 = Number of seeds germinating on the first, second, third, and the subsequent days until the 10th day. 10, 9, 8...and 1 are weights given to the seeds germinated on the first day, second, third, and subsequent days, respectively.

Seed Health Test

200 seeds from each sample were plated using blotter papers in Petri dishes at a rate of 10 seeds per dish and incubated for 7 days, undergoing a 24-hour cycle of light and darkness at room temperature in order to detect fungal infestation and infection of the stored sunflower seeds. Before plating, sunflower seeds were cleaned with a 2% sodium hypochlorite solution for five minutes and rinsed thrice in sterile distilled water.

After 7 days, a stereomicroscope was used to examine the presence or absence of fungal growth. The fungal conidia and conidiomata were observed through a compound microscope using slides. Species were then identified, according to Mathur and Kongsdal (2003). Fungal infection incidence was calculated using the formula (Ghiasian et al., 2004), Infection incidence (%) = No. of seeds infected by a fungus/ Total number of seeds X 100.

Data Analysis

The data collected were subjected to Analysis of Variance (ANOVA). Means separation was done using Tukey's at P≤0.05. The Analysis was performed using the GenStat Discovery Statistical Package of the 16th version.

RESULTS

Influence of temperature, moisture content, and storage duration on Germination percentage, germination index, seedling vigour index, and fungal incidence of stored sunflower seeds

The influence of temperature was highly significant (p<0.001) on germination percentage, germination index, seedling vigour index, and fungal infection incidence on stored sunflower seeds. The seeds stored at 5 ^{0}C recorded the highest germination percentage of 90.83%, germination index of 312.3, seedling vigour index of 1995, and less fungal infection incidence (%) of 57.73; the results for germination percentage and fungal infection incidence were not significantly different with the germination percentage of 90.45% and fungal infection incidence of 57.85% shown by seeds stored at 20⁰C. The results on seeds stored at 35⁰C, germination value (85.26%), germination index of 298.5, and seedling vigour index (1802) were found to be the smallest recorded values among the temperature levels with high fungal infection incidence (61.62%), (**Table 1**).

The results further revealed that germination percentage, germination index, and seedling vigour index of sunflower seeds were also highly significantly influenced by seed moisture content ($p<0.001$), whereby the seeds stored with a moisture content of 6% recorded the greatest values of germination percentage (90.1%), germination index of 310.9 and seedling vigour index (1970) which was not significantly different with that recorded from seeds stored with a moisture content of 8% on germination percentage (89.74%), (**Table 1**).

Table 1. Effects of temperature and moisture content on germination percentage, germination index, seedling vigour index, and fungal infection incidence during storage of sunflower seeds.

Treatment	Germination percentage	Germination index	Seedling vigour index	Fungal incidence (%)
TP (ºC)				
T1	90.83[a]	312.3[a]	1995[a]	57.73[a]
T2	90.45[a]	309.3[b]	1971[b]	57.85[a]
T3	85.26[b]	298.5[c]	1802[c]	61.62[b]
Mean	*88.85*	*306.71*	*1922.4*	*59.065*
SE	0.253	0.579	5.33	0.1167
CV%	2.6	1.7	2.5	1.8
p-value	<0.001	<0.001	<0.001	<0.001
SMC (%)				
M.C1	90.1[a]	310.9[a]	1970[a]	57.7[a]
M.C2	89.74[a]	307.8[b]	1947[b]	58.57[b]
M.C3	86.71[b]	301.5[c]	1850[c]	60.92[c]
Mean	*88.85*	*306.79*	*1922.4*	*59.065*
SE	0.253	0.579	5.33	0.1167
CV%	2.6	1.7	2.5	1.8
p-value	<0.001	<0.001	<0.001	<0.001

SE=Standard errors of means; SMC=Seed moisture content i.e MC1=6%, MC2=8%, MC3=10%; TP=Storage temperature i.e T1=5 ºC, T2=20 ºC and T3=35 ºC. The means with similar letter(s) in the same columns are not significantly different at $p \leq 0.05$ as per Tukey's 95% confidence intervals.

On the other hand, the moisture content of 10% appeared to be the worst of all moisture content levels as it recorded the smallest values of germination percentage (86.71%), germination index (301.5), seedling vigour index (1850) and high fungal infection incidence (60.92%), (**Table 1**). The analysis of variance (ANOVA) showed that the effect of storage duration was highly significant ($P<0.001$) on seed germination percentage, germination index, and seedling vigour index. Increasing storage duration from 0, 15, 30, 45,60,75 and 90DAS resulted in a decline in germination percentage with respective values of 94.0, 93.39, 92.39, 90.44, 87.33, 83.61 and 80.78%, germination index of 322.0, 317.7, 312.9, 307.4, 304, 293.7 and 289.4 and seedling vigour index of 2118.0, 2060.0, 2019.0, 1945.0, 1857.0, 1769.0 and 1690.0 (**Figure 1A-C**).

Interaction effect of storage temperature and moisture content on germination percentage, germination index and seedling vigour index of sunflower seeds

The interaction effect of storage temperature and moisture content (TP x MC) on seedling vigour index, seed germination percentage and fungal infection incidence was highly significant (p=0.001), (p=0.023), and (p=0.002) respectively and not significant (p=0.329 on germination index (**Table 3.2**). Treatments differed significantly in the germination percentage and Seedling vigour index due to interaction of storage temperature and moisture content. It was noted that significant difference was observed on the results obtained on the seeds stored at a temperature of 50C with moisture content of 6% with that stored at a temperature of 50C with moisture content of 10%, temperature of 200C with moisture content of 10% and that stored at 350C, 6%; 350C,8% and 350C,10% where 350C,10% recorded the smallest value (82.14%), the effect of interaction of temperature 50C and moisture content 6% recorded the highest germination percentage(91.79) which was not statistically different with that recorded in interaction of 50C and 8%(91.43) and that of 200C and of 6% (91.43%) on germination percentage **(Table 2)**.

On the other hand, the results shown significant different on seedling vigour index on the seeds stored at a temperature of 5^0C with moisture content of 6% with that stored at a temperature of 5^0C with moisture content of 10%, temperature of 20^0C with moisture content of 10% and that stored at 35^0C, 6%; and 35^0C, 10% where 35^0C,10% recorded the smallest value (1704) of seedling vigour index **(Table 2).** The greatest seedling vigour index value (2040) was found at the interaction of temperature 5^0C and moisture content of 6% followed by the interaction of 5^0C x 8% (2005) and that of 20^0C x 6% (2010).

Furthermore, the interaction of 5 ^{0}C and 6% resulted into the smallest fungal infection percentage (56.43) followed by the interaction of 20 ^{0}C and 6% with infection percentage of 56.61%. On the other hand, the interaction of 35 ^{0}C and 10% gave the highest fungal infection percentage (64%), **Table 2.**

The effect of seed moisture content on fungal infection incidence and effect of storage temperature on fungal infection incidence on stored sunflower seeds revealed a significant difference in individual fungal infection incidence. Eight (8) different fungal species namely *Aspergillus flavus, A. niger, Alternaria padwickii, A. zinniae, Botrytis cinerea, Curvularia lunata*, *Fusarium moniliforme* and *Rhizopus* species were found in the sunflower seeds stored in different storage temperatures with different moisture contents (**Figure 5C -D**).

Interaction of temperature and storage duration on germination percentage, germination index and seedling vigour index of stored sunflower seeds

The effects of interaction of temperature and storage duration on germination percentage, germination index and seedling vigour index of stored sunflower seeds was highly significant (p<0.001) **(Figure 2A-C).** It was noted that, the effects of storage temperatures on tested seed quality attributes depended significantly due to storage duration. The germination percentage, germination index and seedling vigour index from their initial seed test results (control) of 94%, 322 and 2118 respectively decreased significantly due to storage duration **(Figure 2A-C).** It was found that seeds stored at a temperature of 5^0C and 20^0C maintained high seed germination percentage (86.67 and 86.33), germination index (303.08 and 295.67) and seedling vigour index (1877 and 1846) respectively at all stages of storage duration even up to 75DAS.

Until the end of 75 days of storage duration, the values for germination percentage were still above the minimum certification standards of germination percentage (85%) set out by seed regulatory authorities (Tanzania Official Seed Certification Institute, TOSCI) in Tanzania for sunflower seeds.

By the end of the storage duration (90DAS), the maximum values of germination percentage (84.67%), germination index (299), and seedling vigour index (1804) were noted in seeds stored at a temperature of 5^0C followed by germination percentage of 83.83%, germination index of 293 and seedling vigour index of 1779 of the seeds stored at a temperature of 20^0C while the minimum values of germination percentage of 73.83%, germination index (276.08) and seedling vigour index (1485) was found in seeds stored at 35^0C **(Figure 2A-C).**

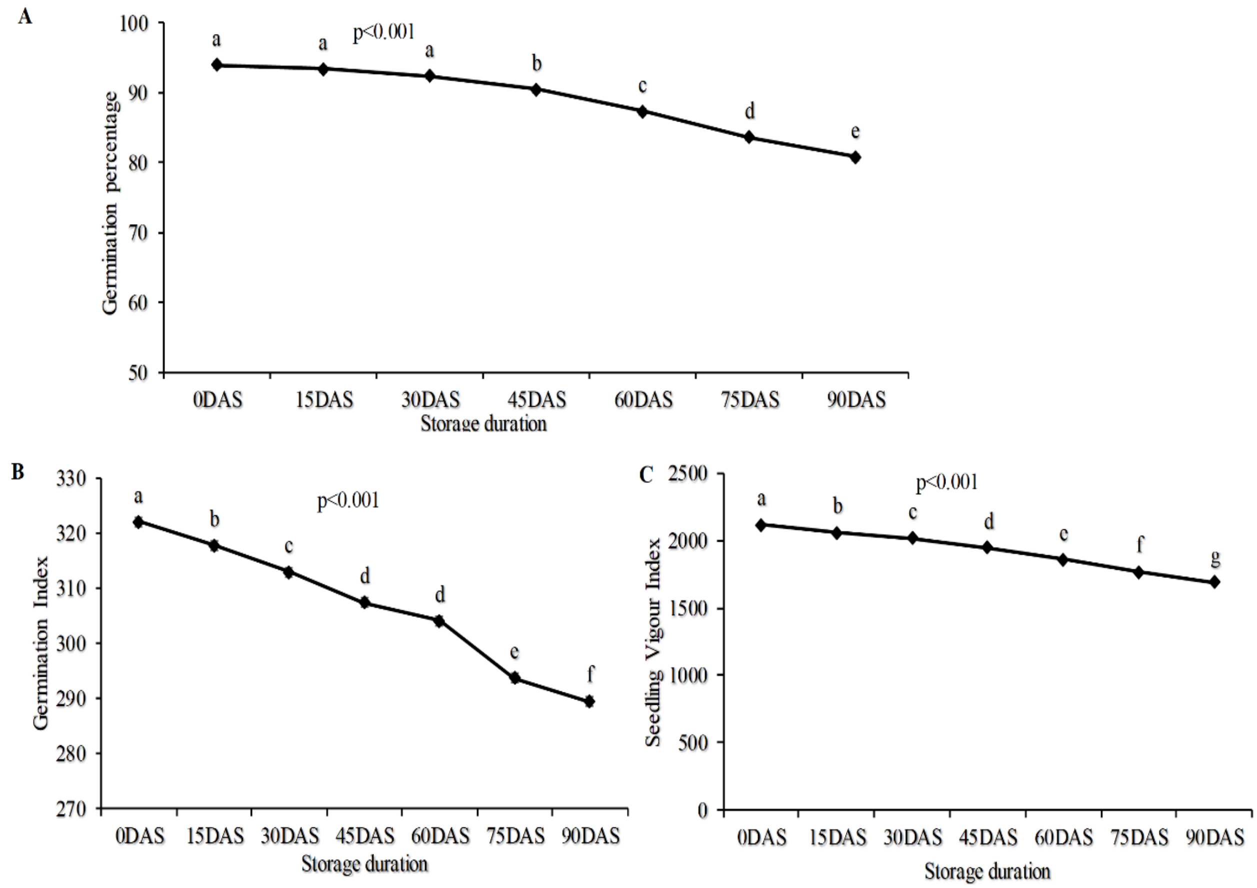

Figure 1. Effects of storage duration on germination percentage (A), Germination index (B) and Seedling vigour index (C) on stored sunflower seeds.

Table 2. Interaction effects of storage temperature and moisture content on germination percentage and Seedling vigour index on stored sunflower seeds

TP (°C) X SMC (%)	Germination (%)	Germination index	Seedling Vigour Index
T1x MC1	91.79[a]	316.6[a]	2040[a]
T1x MC2	91.43[a]	313[ab]	2005[ab]
T1x MC3	89.29[bc]	307.2[cd]	1940[c]
T2x MC1	91.43[a]	313.8[a]	2010[ab]
T2x MC2	91.21[ab]	309.4[bc]	1995[b]
T2x MC3	88.71[cd]	304.8[de]	1907[c]
T3x MC1	87.07[de]	302.1[e]	1861[d]
T3x MC2	86.57[e]	300.9[e]	1840[d]
T3x MC3	82.14[f]	292.4[f]	1704[e]

Mean	88.85	306.71	1922.4
SE	0.438	1.003	14.11
CV%	2.6	1.7	2.5
p-value	0.023	0.329	0.001

Where SE=Standard errors of means; TP=Storage temperature i.e T1=5 °C, T2=20^{0}C and T3=35 °C; SMC= Seed moisture content i.e MC1=6%, MC2=8%, MC3=10%. The means with similar letter(s) in the same columns are not significantly different at p ≤ 0.05 as per Tukey's 95% confidence intervals.

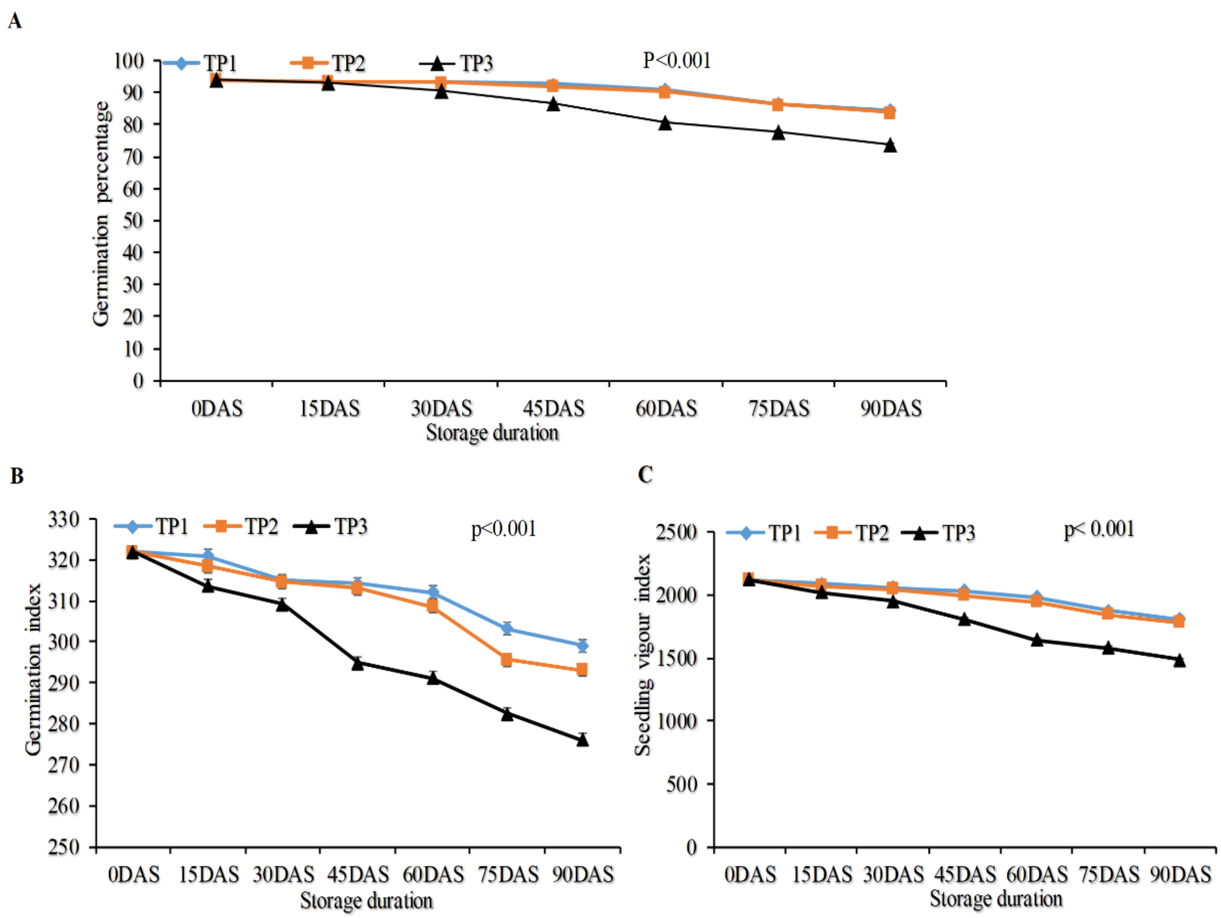

Figure 2. Interaction effects of temperature and storage duration on Germination percentage (A), Germination index (B), and Seedling vigour index (C) on stored sunflower seeds. TP1-TP3=Storage temperatures (TP1=5 ºC, TP2=20 ºC and TP3=35 ºC)

Interaction effect of moisture content and storage duration on germination percentage, germination index, and seedling vigour index during storage of sunflower seeds

The interaction effect of seed moisture content on seed germination percentage, germination index (p=0.001) and seedling vigour index (p<0.001), were significantly dependent on the storage duration. It was observed that the germination percentage, germination index and seedling vigour index of sunflower seeds varied due to storage duration. This implied that, although the highest germination percentage, germination index, and seedling vigour index was found at 0DAS with respective values of 94%, 322, and 2118 there was a decrease in the tested parameters with the increase in storage duration from 0DAS to 90DAS **(Figure 3A-C)**.

By the end of this storage duration (90DAS), the maximum values of germination percentage (83.83), germination index (292.75), and seedling vigour index (1792) were recorded in seeds stored with the initial moisture content of 6%. This was not significantly different with the germination percentage (83), germination index (292.17) and seedling vigour index (1747) of the seeds stored with the initial moisture content of 8% **(Figure 3A-C)**.

These findings further indicate that sunflower seeds can retain viability values of 86% and 85.67% until 75DAS when stored with the initial moisture content of 6% and 8%, respectively, which is also above the minimum certification standards of germination percent of the sunflower seeds in Tanzania **(Figure 3A)**.

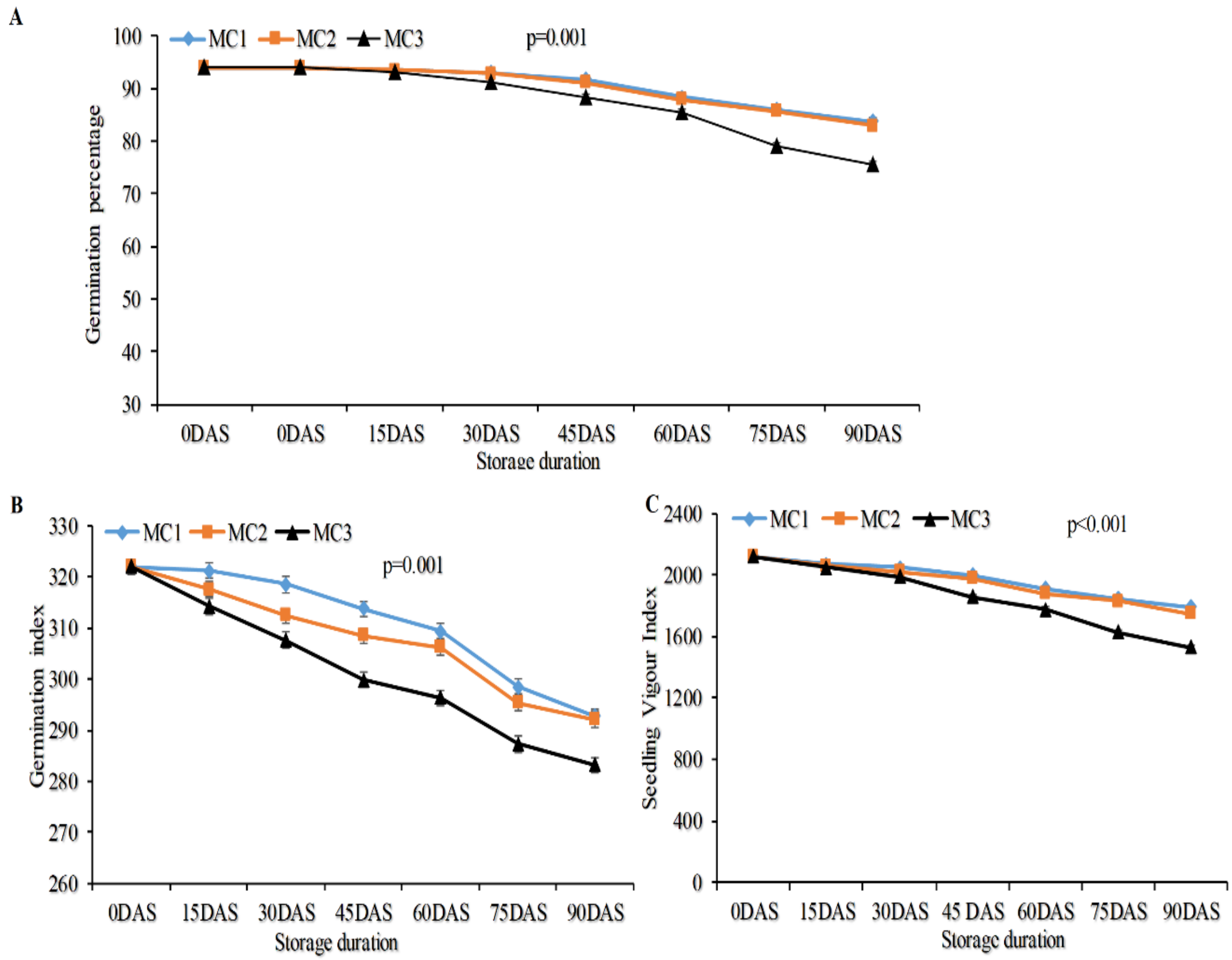

Figure 3. Interaction effects of moisture content and storage duration on: Germination percentage (A), Germination index (B) and Seedling vigour index (C) on stored sunflower seeds. MC1-MC3= Seed moisture content (MC1=6%, MC2=8%, MC3=10%).

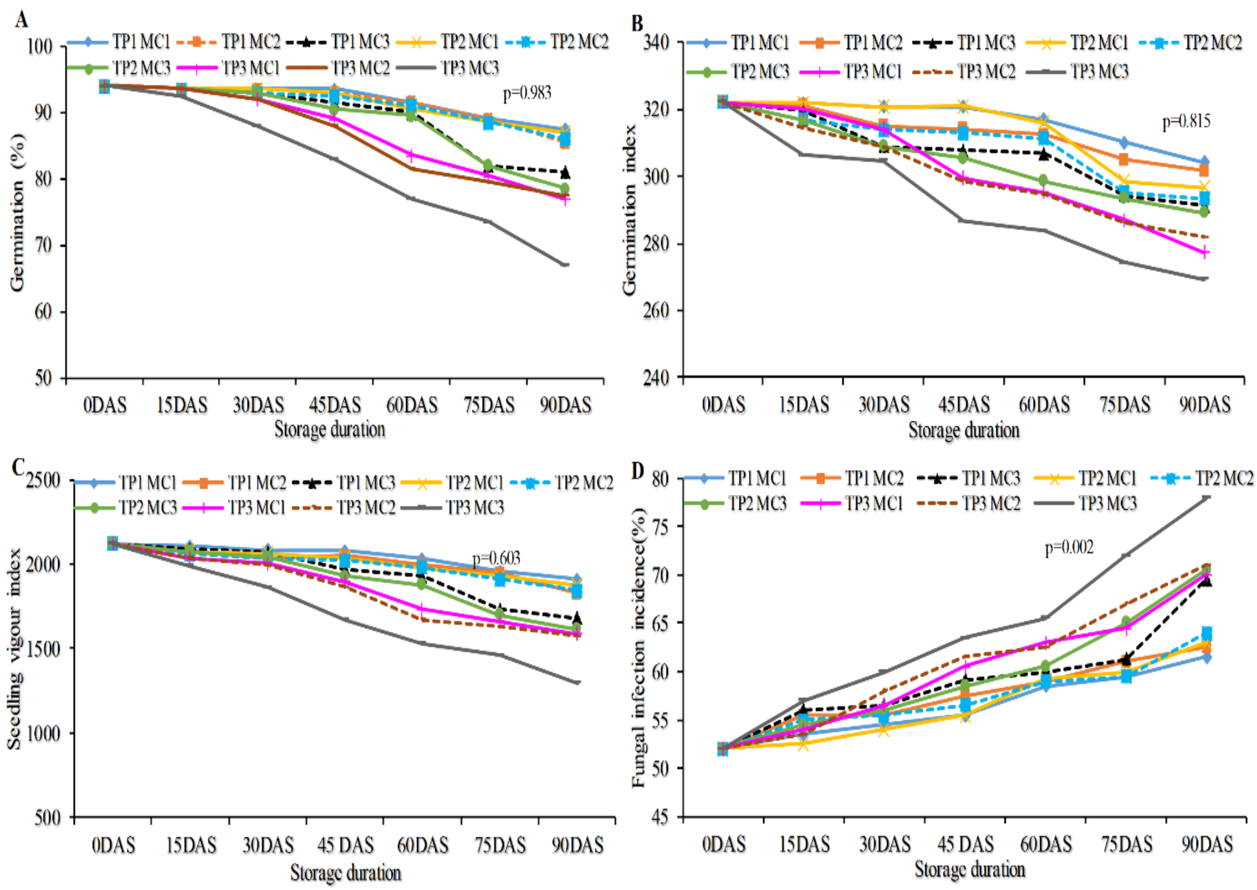

Figure 4. Interaction effects of storage temperature, moisture content and storage duration on: Germination percentage (A), Germination index (B)Seedling vigour index (C) and fungal infection incidence on stored sunflower seeds. TP1-TP3=Storage temperatures (TP1=5 ºC, TP2=20 ºC and TP3=35 ºC); MC1-MC3= Seed moisture content (MC1=6%, MC2=8%, MC3=10%)

Interaction effect of temperature, moisture content, and storage duration on germination percentage, germination index, seedling vigour index and Fungal infection incidence (%) during storage of sunflower seeds

From the ANOVA results, the interaction effect of temperature, moisture content and storage duration (TP × MC ×SD) was not significant on germination percentage (p=0.983) germination index (p=0.815) and Seedling vigour index (p=0.603) on stored sunflower seeds **(Figure 4A-C)**.

The interaction effect on fungal infection incidence was however significantly different (p=0.002) in stored sunflower seeds **(Figure 4D)**. Less fungal infection incidence of 61.5% was recorded at 5 ºC and moisture content of 6% followed by 62.5 found at 5 ºC with the moisture content of 8%. At the end of storage duration (90DAS), the highest fungi incidence of 78% was recorded at a temperature of 35 ºC in seeds preserved with moisture content of 10% **(Figure 4D)**.

DISCUSSION

Low storage temperatures and low air humidity typically prevent rapid increase in seed moisture content and, consequently, the rate at which the seeds breathe during storage, which can extend the shelf life of the stored seeds. Likewise, drying of the seeds to small moisture contents leads to low fungal infection incidences in the storage (**Figure 5B**). The storage of seeds at temperatures of (5^0C and 20^0C) and low moisture content (6% and 8%) shown relatively higher performances on seed germination and vigour, this could occur due to the fact that when seeds are stored at low temperatures the possibility of deterioration is smaller **(Table 2)**. During germination and the early stages of seedling development, the impacts of drying and storing on seeds are most obviously seen as physiological changes.

These findings also concurred with that of some other previous researchers who studied on other seed crop types. Hasan et al. (2017), described that Lentil seeds stored at a low seed moisture level of 8.8% experienced the highest germination rates and vigour index. Mbofung at al. (2013) stated that soybean seeds that were stored at low temperatures had greatest viability and vigour compared to soybean seeds that were not preserved at low temperatures and air humidity. Germination percentage, Germination index, and Seedling vigour index values diminished with an increase in initial seed moisture content, storage temperature, and storage period. The larger the period seeds need to be stored, the lower the storage temperature and seed moisture content (Aqil, 2020).

On the other hand, storage of seeds at a large temperature value (35 °C) and seed moisture content led to low seed germination and vigour. This could be because high temperatures accelerate the respiration of the seeds speedily, so the quicker the decline in food material reserved in the seeds causes the disintegration of the membrane system of the seeds during storage; this might alter the lipids' chemical instability, exacerbating the seeds' performance decline and reducing their viability and vigour. Earlier researchers in other crop species reported similar results. Htwe (2018), working in green gram, found that the quality of seeds lessened with the rise in moisture content of seeds under storage; Syeda (2000) in mash bean, Bhandari et al. (2017) and Angelovič et al. (2015) in maize.

The variation in germination percentage, germination index and seedling vigour index was found with increase in storage duration. This could be due to the variability in fungal infection percentage as the storage duration prolonged **(Figure 5A)**. This can further be revealed through the increase in the percentages of abnormal seedlings observed during germination tests as the storage duration increased **(Figure 6A-B)**. Similar findings also were reported by Patharkar *et al*. (2013) who concluded that, as the storage duration extended the fungal infection raised resulting into decrease in seed germination.

The findings also agreed with what earlier authors did on different seed crops. Vange et al. (2016) and Kandil et al. (2013) concluded that germination parameters decreased over time as storage time increased, indicating an inverse relationship between storage time and germination percentage and seedling vigour index in soybean seeds. Islam et al. (2017) concluded that the rate of rise in germination capacity and seedling vigour indices was reduced with the progression of storage periods in mung-bean seeds.

Additionally, Tame et al. (2011) identified that germination percentage and seedling vigour decreased with progression in storage duration in onion seeds, so did Tatipata et al. (2009) in soybean seeds and MR et al. (2013) in chickpea seeds.

Still, the occurance of different fungal species could also be an important reason as to why there is decrease in seed viability and vigour of the stored sunflower seeds.

The highly affected seeds are those stored at 35 ºC with an initial moisture content of 10 ºC in a storage duration of 90 DAS. Some researchers reported on the negative effects of the fungal species on the germinability and vigour of the seedlings and the growth of the sunflower crop as a whole. It was shown by Rukhsana et al., (2010) that fungal inversion decreased the germination of sunflower seeds by 10–20% and raised seedling mortality by 10-12%.

Soomro et al. (2020) reported that Alternaria species lowered seed germination, with seed rot, scratches on seedlings, and a weaker root-shoot system being the key symptoms. Patharkar et al. (2013) found that microorganisms ascending from seed preserved, like *Aspergillus* species, they also cause root-collar rot and also damping-off of the seedlings. Caldeira et al. (2015) reported that *Alternaria* species affect germination by damaging the seedlings.

Confirming the undesirable effect of the incidence of microorganisms, accompanied by higher storage temperatures and higher moisture content, the number of suspected fungal-damaged seedlings was larger in seeds stored at higher temperatures (35 ºC) and higher moisture content (10%). From the infection of pathogenic and saprophytic fungi found in the stored sunflower seeds **(Figure 5C and D)**, a large percentage of infection by fungi of *Aspergillus species* and *Alternaria species* was detected. The mentioned species impair the quality of the sunflower as they can enter and damage tissues inside the seed embryo, releasing toxins that lower the germination rate and cause the seeds to discolour, rot, and heat up. This favours a faster rate of seed degradation. The same findings were also reported by Caldeira et al. (2015) and Singh & Prasad, (1977).

Also, Fusarium species like Fusarium moniliforme in sunflower seeds causes spread of numerous diseases in fields including fusarium wilting as revealed by Vijayalakshmi and Rao (1986) and Jasnić &

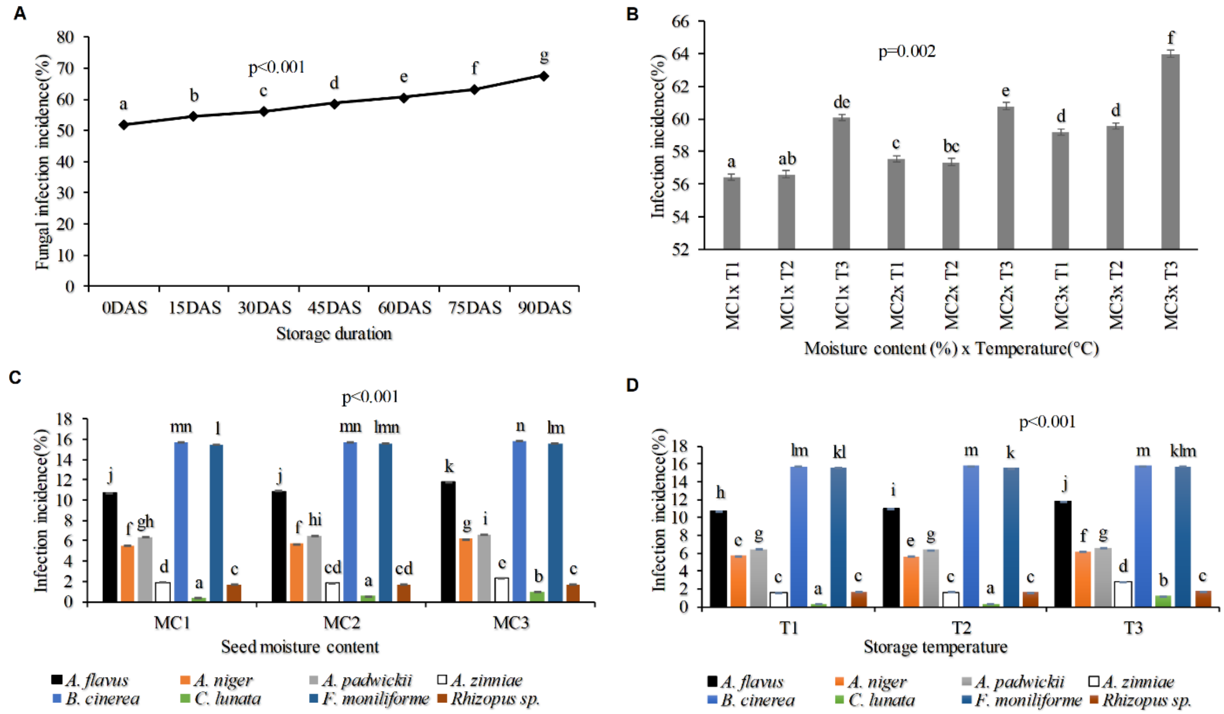

Figure 5. Effects of storage duration on fungal infection incidence (A); Interaction effects of temperature and moisture content on fungal infection incidence (B); Effects of moisture content on individual fungal infection incidence (C); Effects of temperature on individual fungal infection incidence (D) on stored sunflower seeds. T1-T3=Storage temperatures (T1=5 ºC, T2=20 ºC and T3=35 ºC); MC1-MC3= Seed moisture content (MC1=6%, MC2=8%, MC3=10%).

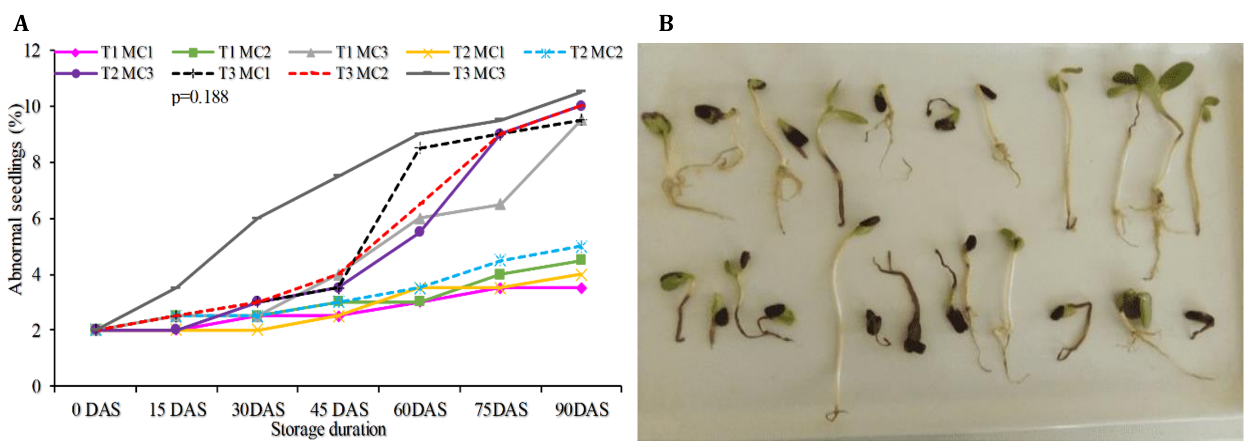

Figure 6. Interaction effect of storage temperature, seed moisture content and storage duration on abnormal seedlings (%) (A), Some abnormal infected seedlings observed during storage(B); T1-T3=Storage temperatures (T1=5 ºC, T2=20 ºC and T3=35 ºC); MC1-MC3= Seed moisture content (MC1=6%, MC2=8%, MC3=10%).

Masirevic, (2006) while Glinushkin et al. (2021) and Gulya et al. (2016) found foot-rot, blight in seedlings and plant stunting, plant-wilting and hypertrophy in sunflower.

Sunflower seeds are vulnerable to different fungal diseases while being stored. As found by Ramesh and Avitha, (2005) and Rukhsana et al. (2010), this may cause a variety of harms, such as dropping in the quantity and quality of sunflower seed yield, and a drop in seed viability and seedling vigour, mycotoxin generation, and complete decay.

CONCLUSION

It is therefore clear from the results that among the three temperature levels under the study, the best storage temperature is 5 ºC followed by 20 ºC with moisture contents of 6% followed by 8%, the temperature of 35 ºC was the unsuitable storage temperature across all factor-levels of moisture contents for sunflower seeds. On the interaction of more than one factors we recommend to store the sunflower seeds at 5 ºC x 6% followed by 20 ºC x 6% or at 5 ºC x 8% followed by 20 ºC x 8%. This will maintain high seed germination and seedling vigour during storage even up to 90 days after storage.

Lastly, our study discovered that the best and ideal storage conditions—temperatures of 5 and 20 ºC, seed moisture contents of 6 and 8%, have the greatest advantage in preserving the viability and vigour of sunflower seeds throughout the storage duration.

DISCLOSURE STATEMENT

The author declares no competing interests.

AUTHORS' CONTRIBUTIONS

Siwajali Selemani performed the experiment, collected the experimental data, processed the data, performed the data analysis, and conscripted the manuscript. Both Richard Madege and Yasinta Nzogela supervised the whole implementation process of the research study.

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