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Effect of storage conditions on soybean seed quality produced by smallholder farmers within two districts of Gauteng, South Africa

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Abstract

Seed quality comprises of physical, physiological, and health attributes. Moreover, significant aspects of seed quality include seed viability and vigour. Maintaining good seed quality under sub-optimal storage conditions is one of the major challenges smallholder soybean farmers face. Hence, this study aimed to determine the effect of on-farm storage conditions on the seed quality of soybeans from smallholder farmers within the Gauteng Province, South Africa. The objectives of this study were to i) evaluate and compare the viability and vigour of farm-saved soybean seeds, and ii) evaluate the effect of seed moisture and simulated storage period on the rate of deterioration of the seeds. Farm-saved seed samples collected from the twenty-two smallholder farmers from two districts within the Gauteng Province showed significant variations in terms of seed moisture, viability, vigour [accelerated aging (Aa) and conductivity], and in the rate of deterioration. The seed moisture content ranged from 7.8-30.8 %. The majority of the farm-saved seed samples had a germination percentage significantly higher than 75 %, irrespective of the storage conditions. On the other hand, seeds subjected to Aa and to the controlled deterioration test resulted in less vigourous seedlings. Seeds that were subjected to 24 hr Aa had a significantly ($p < 0.05$) higher germination than those subjected to 72 hr Aa. The 72 hr Aa results verified the reduction of seed vigour as the storage period increased. A similar declining germination trend was observed on seeds subjected to deterioration tests under high moisture content levels. The study gives an indication of how the sub-optimal storage facilities used by smallholder soybean farmers affect seed quality. Based on the vigour tests, it can be assumed that storing seeds with high SMC under high relative humidity coupled together with high temperatures for prolonged periods tends to deteriorate the seeds rapidly and thus reduce seed vigour.

Keywords: deterioration, germination, on-farm, seed moisture, storage period, vigour

1 Introduction

Soybean (*Glycine max* (L.) Merrill) is one of the most important sources of protein and vegetable oil worldwide (FAOSTAT, 2019). In South Africa, this crop plays a significant role in aquaculture, animal feed, and the human diet (Dlamini *et al*, 2014). Soybean production has the potential to enhance food security, lessen poverty in developing countries, and improve income through increased yield (Dlamini *et al*, 2014). The soybean production for the 2021/2022 season in South Africa was predicted to amount to nearly 1.89 million metric tons, which is much lower than the demand (Statista, 2022). This shortage is covered by imports of soybean products from countries such as Malawi, Zambia, Mozambique, Brazil, and the United States (Murithi *et al*, 2016). The area under soybean production has expanded as there have been emerging smallholder soybean farmers or producers in various parts of South Africa in recent years (Department of Agriculture Forestry and Fisheries [DAFF], 2019).

Soybean production in developing countries is mainly by smallholder farmers primarily in rural areas, and farmers are reported to use farm-saved seeds (Tibaingana *et al*, 2018). On-farm seed storage plays a crucial role in providing seeds between seasons. The farmers still use traditional, unregulated storage practices and facilities to produce and store seeds in preparation for the next planting season (Kandil *et al*, 2013; Mbofung *et al*, 2013; Muga *et al*, 2019). Storage

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facilities used by these farmers include but are not limited to maize meal sacks, metallic silos, and plastic buckets (Mbofung *et al*, 2013; Chawla *et al*, 2017; Tibaingana *et al*, 2018). These practices are often not optimal and can lead to high post-harvest or storage losses. One common and effective practice amongst smallholder farmers is the use of woven polypropylene bags to store their seeds. The use of polypropylene bags is reported to maintain high seed viability over a period of time (Kandil *et al*, 2013). Additionally, polypropylene bags are known to minimise fluctuations in moisture content, resulting in highly vigourous seedlings as reported in a study in Egypt (Kandil *et al*, 2013; Muga *et al*, 2019). However, due to their porosity, polypropylene bags allow easy access to air as they do not provide a sufficient barrier, which favors the development and survival of insects that feed on the seeds, ultimately reducing seed quality (Baributsa & Baoua, 2022).

Soybean seeds are regarded as short-lived since they tend to deteriorate rapidly when stored for more than a year as compared to other crops (Wen *et al*, 2014; Isaac *et al*, 2016). The short life span of soybean seeds is due to factors such as high moisture and oil content (Isaac *et al*, 2016). According to Ali *et al* (2017), depending on the type of seeds stored, the seed moisture content in storage ranges from 6-16 %, while the relative humidity in storage should not exceed 65 %. High relative humidity and temperatures ranging from 25 °C to 34 °C promote the development and infestation of storage insects and fungi, which also affects seed quality (Mbofung *et al*, 2013). Storage insects tend to feed on the stored seeds and thus cause mechanical damage to the seed coat membrane. Storage fungi may affect the germination of the seeds by causing pre-damping off. Regardless of the initial seed quality, harsh storage environmental conditions such as fluctuating temperatures and relative humidity in storage accelerate the rate of seed deterioration, thus, seed viability, and vigour, and longevity are highly impacted or reduced (Govender *et al*, 2008; Ali *et al*, 2017).

The multidimensional interaction of the various biotic and abiotic factors within the seed storage ecosystem is crucial (Al-Shikli *et al*, 2017). Seeds must be stored in regulated storage facilities to maintain the initial seed quality until the seeds are used for sowing. If this is not done, the quality of the seeds can deteriorate to a level that may result in poor quality seeds that are unacceptable for sowing. Maintaining storage conditions such as relative humidity and temperature at optimal levels will help to maintain the initial quality of the seeds and, ensure the ideal physiological potential of the stored seeds to be reused for planting in the next growing season. Thus, the aim of this study was to determine the impact of on-farm storage practices and facilities on soybean seed quality from smallholder soybean farmers within the Gauteng Province of South Africa. The specific objectives of this study were to i) evaluate and compare the viability and vigour of farm-saved soybean seeds, and ii) evaluate the effect of seed moisture content and simulated storage period on the rate of deterioration of the different soybean seed samples.

2 Materials and methods

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2.1 Study area and seed sourcing

The current study was conducted in collaboration with the Gauteng Department of Agriculture, Rural Development and Environment (GDARDE). Most of the agricultural production in Gauteng is done in the Sedibeng and West Rand districts, as well as in the City of Tshwane Metropolitan. Based on the availability and willingness of the smallholder farmers to take part in the study, twenty-two soybean farmers were identified and selected from the City of Tshwane Metropolitan (N = 7) and Sedibeng District (Lesedi and Emfuleni Local Municipality) (N = 15) with the help from agricultural advisors from GDARDE. Farm-saved soybean seed samples were sourced from the twenty-two smallholder soybean farmers. Information regarding seed type, storage material, storage conditions, i.e., storage temperature and relative humidity as well as the geographic location were recorded during seed collection (Table 1). The samples were then grouped into the following main groups: i) seeds stored under ambient conditions (control); ii) seeds stored under low temp and high RH (T < 20 °C; RH > 50 %; iii) seeds stored under high temp and RH (T > 20 C; RH > 50 %); iv) seeds stored under high temp and low RH (T > 20 °C; RH < 50 %). The soybean seed samples were collected after four to six months of storage. Approximately 5 kg of seeds per sample was randomly drawn rom the stored seed samples. Seed samples were placed in plastic bags and then labelled with a unique sample code (FS1- FS22). Upon collection, the seed samples were stored under ambient laboratory conditions until all the standardised seed quality tests, according to the International Seed Testing Association (ISTA, 2020) were conducted. For comparison purposes, three certified commercial soybean seed samples (C1- C3) were used as controls.

2.2 Viability tests

2.2.1 Moisture content test

To determine the seed moisture content (SMC), the low constant oven temperature method was used. Approximately

Table 1: *Storage materials and conditions of soybean smallholder farmers around the City of Tshwane Metropolitan and Sedibeng District of the Gauteng Province, South Africa.*

Sample		*Storage*		*Storage conditions*		
code	*District*	*material*	*period (months)*	*Temperature (°C)*	*Relative humidity (%)*	*range*
C1-C3	-	Polypropylene	-	4	54.1	Ambient
FS1	Sedibeng	Polypropylene	4	17.3	59.3	T < 20 °C; RH > 50 %
FS3	Sedibeng	Polypropylene	5	21.5	80.4	T > 20 °C; RH > 50 %
FS4	Sedibeng	Polypropylene	4	21.2	61.1	
FS5	Sedibeng	Polypropylene	4	21.9	57.1	
FS6	Sedibeng	Polypropylene	6	22.4	52.9	
FS2	Sedibeng	Polypropylene	4	20.2	48.5	T > 20 °C; RH < 50 %
FS7	Sedibeng	Polypropylene	4	24.3	45.1	
FS8	Sedibeng	Polypropylene	4	33.6	33.8	
FS9	Sedibeng	Polypropylene	4	28.2	35.4	
FS10	Sedibeng	Polypropylene	6	27.7	34.5	
FS11	Sedibeng	None	4	26.0	45.2	
FS12	Sedibeng	Polypropylene	5	28.5	38.1	
FS13	Tshwane	Polypropylene	4	32.1	33.3	
FS14	Tshwane	Polypropylene	4	30.8	32.4	
FS15	Tshwane	Polypropylene	4	31.0	33.5	
FS16	Tshwane	Polypropylene	5	30.6	34.2	
FS17	Tshwane	Polypropylene	4	34.2	29.1	
FS18	Tshwane	Polypropylene	4	30.4	29.5	
FS19	Tshwane	Polypropylene	6	32.0	29.8	
FS20	Sedibeng	Polypropylene	5	32.3	37.2	
FS21	Sedibeng	Polypropylene	5	33.3	30.9	
FS22	Sedibeng	Polypropylene	5	33.3	30.9	

15 g of soybean seeds were randomly taken from each seed sample (N = 25). The seeds were then ground to a coarse powder using a coffee grinder [Sunbeam, Model SCG-2012, Nu World Industry (Pty) Ltd, Johannesburg]. Empty closed glass Petri dishes were weighed (M1) and then the closed glass Petri dishes containing the resultant seed powder were also weighed (M2). The Petri dishes were then placed in an oven at 103 °C for 17 hr (± 1 hr) and thereafter placed in a desiccator for 10 min for cooling. The samples were then reweighed (M3). The percentage moisture (MC) content was calculated using the formula specified by ISTA (ISTA, 2020).

$$\text{MC}\ (\%) = \frac{\text{M2 - M3}}{\text{M2 - M1}}\ x\ 100 \tag{1}$$

2.2.2 *Standard germination test (SGT)*

For the germination test, the between-paper (BP) method was used. For this test, 400 soybean seeds (four replicates of 100) were randomly counted from each seed sample (N = 25). Thereafter, fifty seeds were placed uniformly on three moistened germination papers and covered with a fourth moistened germination paper. The germination papers were rolled up and placed individually in plastic bags, sealed with elastic bands, and then incubated in an upright position at 25 ± 1 °C in a growth chamber for ten days. Germination percentage and seedling evaluation (normal and abnormal seedlings) were determined after the fourth and tenth day of incubation, respectively. Anormal seedlings are defined as those seedlings that have abnormally spiralled hypocotyl, negative geotropism, poor or no primary roots, very tiny hypocotyl, more than 50 % of the cotyledon is damaged, have primary fungal infections, etc (ISTA, 2020). The germination percentage (GP) of normal seedlings was calculated using the formula:

$$\text{GP}\ (\%)\ =\ \frac{\text{Number of germinated normal seeds}}{\text{Total number of seeds plated}}\ x\ 100 \tag{2}$$

2.3 *Vigour tests*

2.3.1 *Seed characteristics: Thousand-seed weight (TSW)*

For the thousand-seed weight (TSW), eight hundred (eight replicates of 100) pure seeds (seeds without any damage) were randomly counted from each seed sample (N = 25) and

weighed. The TSW was calculated as the average of eight replicates of 100 seeds multiplied by 1000.

2.3.2 Electrical conductivity tes

The electrical conductivity test was used to determine the membrane integrity (any mechanical damage and storage deterioration causing seed leachate) of the stored seed (Delouche, 1980). To determine the electrical conductivity (EC) of seed leachates, 200 seeds (four replicates of 50) were randomly counted from each seedsample (N = 25). The seeds were then weighed and soaked individually in ice-cube tray wells filled with 9 mL sterile distilled water. In each ice-cube tray, two wells were filled with sterile distilled water only to serve as controls for background readings. The ice-cube trays were then wrapped with aluminium foil and incubated for 24 hr at 20 ± 2 °C in a growth chamber. At the end of the incubation period, the electrical conductivity leachate of the solution was read on an E215 conductivity meter (Jenway, Model 4510, Bibby Scientific Ltd Stone, Staffs, United Kingdom. The actual conductivity leachate values of the seeds were calculated using the formula stipulated by ISTA (2020) and expressed in $\mu S\,cm^{-1}\,g^{-1}$:

$$EC = \frac{\text{conductivity reading - background reading}}{\text{weight of the seeds}} \quad (3)$$

2.3.3 Accelerated aging (Aa) test

To assess the vigour of the farm-saved soybean seeds, 400 seeds (four replicates of 100) from each sample were randomly counted (N = 25). The seeds were placed uniformly on a sterile metal sieve, which was placed into plastic accelerated aging (Aa) boxes filled with 45 mL of sterile distilled water. Sealed Aa boxes were placed in an oven with 100 % relative humidity and incubated for 24, 48, and 72 hr at a temperature of 45 ± 1 °C to age the seeds. The above-mentioned storage period simulated three-, six- and nine months of storage, respectively. Following the Aa of the seeds, the seeds were subjected to the standard germination test (ISTA, 2020) as previously described.

2.3.4 Controlled deterioration test (CDT)

The seed moisture content (SMC) of the 25 seed samples was adjusted to five SMC levels according to ISTA (2020). The adjustment of SMC was performed by measuring the initial moisture content of the seeds by the low constant temperature oven method as previously described. To adjust the SMC, a fraction of pure seeds was thoroughly hand-mixed. Approximately 400 seeds per sample (four replicates of 100) were randomly counted from the fraction of pure seeds and weighed (W1). Thereafter, the weight of the seeds for the desired moisture content value (W2) due to CDT treatment: 12 %, 14 %, 16 %, 18 %, and 20 % was calculated based on the ISTA (2020) formula:

$$W_2 = W_1 \times \frac{100 - A}{100 - B} \quad (4)$$

Where: A = initial seed moisture content (%); B = desired seed moisture content (%); W_1=initial weight of the seeds (g); W_2=final weight of the seeds with desired moisture content (g)

The SMC was adjusted by placing the weighed seeds on moist germination paper and put inside a container to allow imbibition. The container was sealed with aluminium foil and equilibrated at 4 °C overnight to ensure an even distribution of moisture. The seeds were then weighed periodically until the desired weight corresponding to the desired adjusted moisture was reached. Thereafter, the seeds were aged following the procedure of the Aa test (0, 24, 48, and 72 hr). Following this period, seeds were subjected to a standard germination test.

2.4 Statistical design and analysis

The Shapiro-Wilk test was used to assess the normality of the data. The data was analysed using the Statistical Analysis Software (SAS) version 9.3 as well as the GraphPad Prism version 9.4.1. To compare the means of each experiment, analysis of variance by the t-test ($p \leq 0.05$) as well as the separation of means using Fisher's Least Significant Difference test at $p \leq 0.05$ was conducted.

3 Results

3.1 Seed germination

There were significant differences ($p \leq 0.05$) in the germination of the seed samples stored under varying storage conditions (Fig. 1). The germination percentage ranged from 69.7-80.5 %. The germination percentage of seed samples that were stored under high temperatures and low RH (T > 20 °C; RH < 50 %) was significantly lower ($p \leq 0.05$) than that of the seed samples that were stored under ambient conditions (4 °C) and the other storage condition treatments. In addition, the germination percentage of the former was below the minimum standard germination percentage (dotted line). The germination percentage of seed samples that were stored under lower temp and high RH (T < 20 °C; RH > 50 %) was similar to that of the seed samples stored high temp and high RH (T < 20 °C; RH > 50 %).

3.2 Seed moisture content and seed vigour

The results of seed moisture content (SMC), thousand-seed weight (TSW), and seed electrical conductivity (EC)

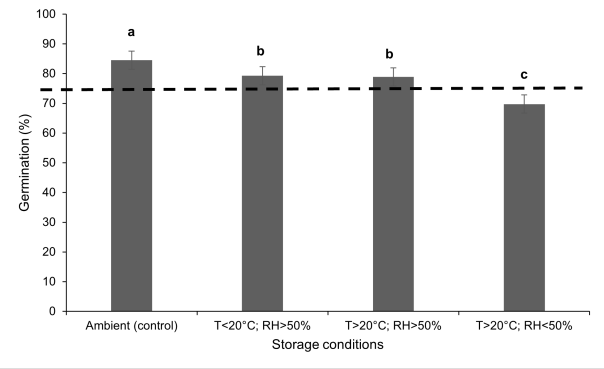

Fig. 1: *Seed germination of farm-saved soybean seed samples collected from smallholder farmers in the City of Tshwane Metropolitan and Sedibeng District of the Gauteng Province. Bars followed with the same letters (a-b) do not differ significantly according to the Fishers' LSD test (2.58) (p≤ 0.05). The dotted line represents a minimum germination percentage of good quality seed.*

are summarised in Table 2. The SMC showed variation (7.8 - 30.8 %) amongst all the seed samples. The MC of seed samples that were stored under higher temperatures and RH was significantly higher (p≤ 0.05) than that of the control samples and the seed samples that were stored at lower temperatures and high RH. On the other hand, the SMC of the remaining seed sample (high temp and low RH) was similar with that of the control samples.

In terms of the TSW, seeds stored under higher temperatures and RH or high temp and low RH storage conditions had a significantly lower (p≤ 0.05) seed weight when compared to seed samples that were stored under ambient conditions. Findings on EC also showed a highly significant (p ≤ 0.05) variation in the seed membrane integrity of the seed samples. Significantly higher (p ≤ 0.05) EC values (above 70 μS.g^{-1}.cm^{-1}) were observed on seed samples that were stored under humid storage conditions (RH > 50 %). In contrast, significantly lower EC values (lower than 30 μS.g^{-1}.cm^{-1}) were recorded on seed samples that were stored under ambient conditions and those under high temp and low RH.

3.3 Accelerated aging

A general decreasing trend was observed in the performance of the seed samples following the Aa test (Fig. 2). The results indicate that there were significant (p≤ 0.05) differences in the germination percentage among the seed samples from the various districts stored under varying storage conditions. In general, seed samples that were stressed for 24 hr had significantly (p≤ 0.05) higher germination relative to those stressed for 48 - and 72 hr in all the varying storage conditions. Overall, the results showed that the seed

Table 2: *Seed moisture content (SMC), thousand-seed weight (TSW), and electrical conductivity (EC) of farm-saved soybean seed samples as influenced by storage practices and facilities used by smallholder farmers.*

Storage conditions	*SMC (%)*	*TSW (g)*	*Conductivity ($\mu S\ g^{-1}\ cm^{-1}$)*
Ambient (control)	13.4^{b}	178.7^{a}	27.8^{b}
T > 20 °C; RH > 50 %	7.8^{b}	175.8^{a}	101.6^{a}
T > 20 °C; RH > 50 %	30.8^{a}	151.6^{b}	82.7^{a}
T > 20 °C; RH < 50 %	18.0^{b}	149.6^{b}	24.2^{b}
LSD^{ab}	10.2	10.0	20.4
CV (%)	15.4	10.7	22.4

*Mean values within each column (a-b) with the same letters do not differ significantly according to the Fishers' LSD test (p≤0.05), LSD= Least Significant Difference, CV= Coefficient variation, T= Temperature, RH= Relative humidity

vigour/germination decreased with an increasing stressing period. This was more severe for seed samples that were aged for 72 hr since they had zero germination (Fig 2.ii and Fig 2.iii).

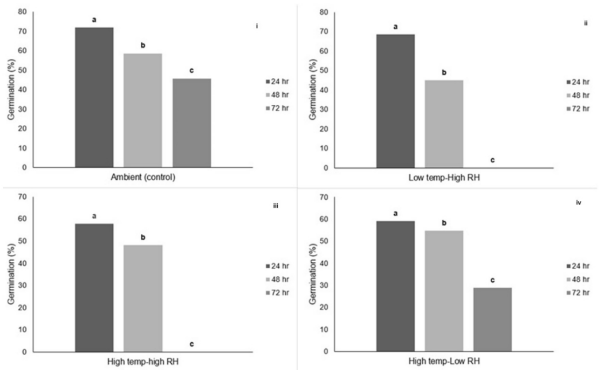

Fig. 2: *The impact of the different aging periods on seed vigour (germination) of farm-saved soybean seeds. *Bars with the same letters (a-c) do not significantly differ according to the Fisher's LSD test at p≤ 0.05. *The aging periods simulate the following storage periods: 24 hr=3 months; 48 hr=6 months; 72 hr= 9 months storage. * i) Control ; ii) T < 20 °C; RH > 50 %; iii) T > 20 °C; RH > 50 % ; iv) T > 20 °C; RH < 50 %.*

3.4 Seed deterioration

The results of seed deterioration are summarised in Supplementary Tables S1-S5. Based on the analysis of the effect of storage period and SMC on the rate of seed deterioration, a decreasing trend was observed in seed germination as the SMC and simulated storage period (stress period) increased. A decline in seed vigour was noted as the simulated storage period increased. A slight decline of the seed vigour was seen between the 0 hr and 24 hr as well as the 24 hr and 48 hr simulated storage period. However, a rapid decline was

noted between the 24 hr and 72 hr storage periods. The deterioration rate at an SMC value of 14 % (Table S2) showed a similar decreasing pattern in the farm-saved seed samples stored under high temp and low RH as in the seeds stored under ambient conditions. Their germination decreased significantly ($p \leq 0.05$) between 24 hr and 48 hr storage period. The seed deterioration rate at an SMC value of 16 % (Table S3) showed a similar trend as at 12 % SMC. The germination of seed samples was significantly affected by high SMC (18 and 20 % SMC) (Table S4 and S5). On average, the majority of the seed samples had a germination rate equal to or below 65 % at an SMC value of 18 % and 20 %.

4 Discussion

Soybean production is a critical component of many smallholder cropping systems in sub-Saharan Africa, with a significant potential for improving food security and economic development (Hlatshwayo *et al*, 2021). However, smallholder farmers, particularly those involved in crop production through the propagation of seeds, face various challenges. One of the most significant challenges faced by smallholder farmers is producing good-quality seeds (Hlatshwayo *et al*, 2021). The latter is a consequence of using unregulated storage facilities and practices (Hlatshwayo *et al*, 2021). In seed production, physiological attributes, particularly seed vigour, viability and longevity are important.

The seed quality of farm-saved soybean seeds collected from the various smallholder farmers has showed a highly significant variation in the moisture content, germination rate, electrical conductivity, accelerated aging, and controlled deterioration tests. Seed moisture content of the majority of the samples was within the acceptable 16 % level for legumes [Food and Agricultural Organisation (FAO), 2009]. However, seed samples stored in storage conditions characterised by high temp and RH ($T > 20$ °C; $RH > 50$ %) had SMC above 30 %. Theoretically, when SMC is above the acceptable storage MC levels, the seeds are prone to excess water injury, which may lead to decreased germination (Wen *et al*, 2014). These seeds tend to deteriorate rapidly as a result of accelerated physiological damage (Delouche, 1980; Baributsa & Baoua, 2022). This implies that SMC is a critical storage factor and should be monitored. However, in the current study, the initial MC had a limited impact on the initial viability of the seed samples that had extremely high MC. It was noted that seed samples that had an initial MC above 20 % showed a germination rate of 75 % and above. In terms of the seed germination, seed samples that were stored under high temp and low RH ($T > 20$ °C; $RH < 50$ %), had a germination percentage significantly lower than 75 %. These seed samples were characterised by SMC above the recommended storage MC (> 16 %), low TSW, and low EC. In this case, the high storage temperature together with high SMC might have influenced their germination percentage.

The electrical conductivity test also helps in determining the seed vigour. As reported in a study conducted by Alencar *et al* (2010), a direct link exists between seed germination and electrical conductivity. Damaged seeds have high EC values and tend to lose essential electrolytes needed for germination, thus, resulting in low germination. Therefore,the seeds are regarded to be less vigourous (Ali *et al*, 2017). However, this trend was not seen distinctly in all samples in the current study. Low EC values coupled with high germination percentages as well as low EC values with low germination were noted on some seed samples. Based on these observations, it is difficult to come to conclusions regarding the relationship outlined by Alencar *et al* (2010).

Seed deterioration is influenced by the initial seed quality at the time of storage, SMC, as well as the temperature and relative humidity of the storage environment (Shelar *et al*, 2008; Baributsa & Baoua, 2022). In the current study, the effect of different levels (12-, 14-, 16-, 18- and 20 %) of SMC, initial storage conditions (temperature and relative humidity), as well as the storage period: no storage, three, six and nine months of storage represented by 0-, 24-, 48- and 72 hr, respectively, were evaluated. The results revealed that the rate of seed deterioration was not rapid for seeds with an SMC of 12- and 14 %, irrespective of the storage period. In contrast, the rate of seed deterioration was more rapid on seeds with an SMC value of 16-, 18-, and 20 %. Their germination was significantly poorer with increasing storage time. One of the factors that may have influenced the rapid deterioration of the seeds was the initial temperature and relative humidity of the storage facilities under which the seeds were stored. According to the literature, elevated temperatures and relative humidity cause seed catabolic alterations (Shelar *et al*, 2008). The findings of the Aa test also showed a similar trend as the seed deterioration test. The 24 hr Aa test showed that seeds aged relatively slower than the 48 hr Aa, however, the 72 hr Aa showed that seeds aged more rapidly than in the 24- and 48 hr Aa treatments. This applies to the poor germination of seed samples that were stored under humid storage environments with either low ($T < 20$ °C) or high ($T > 20$ °C) temperatures. Storage of seeds under sub-optimum conditions tends to accelerate the aging process, compromising membrane integrity and resulting in loss of seed viability (Kandil *et al*, 2013).

Variations in the seed quality particularly the seed vigour linked to the storage conditions were clearly demonstrated by both the Aa test and the deterioration test. The latter

showed that there was a relationship between the SMC, relative humidity, elevated temperature, and storage time. Similar results were observed in studies done by Ali *et al*, (2017) and Baributsa & Baoua (2022). The results of the current study indicated that the majority of the farm-saved seed samples from the smallholder farmers were less vigourous as their germination percentage was less than 60 % for seeds that were subjected to the Aa and deterioration tests. The results imply that seed vigour declines very rapidly after six months of storage. This also supports the idea that soybean seeds are orthodox seeds and are relatively short-lived oil crops (Ali *et al*, 2017). Therefore, it is not ideal for farmers to store soybean seeds for more than one planting season.

5 Conclusion

The results of the current study showed that the longer the seed storage period the more likely it is that seed deterioration will occur, and as a result, seed viability will decrease and seed vigour may be affected. Prolonged storage of farm-saved soybean seeds for prolonged periods under sub-optimum conditions (hot and unventilated conditions) should be avoided, as these seeds are regarded as orthodox seeds and require short-term storage under optimal conditions. As much as it is financially savvy for smallholder farmers to practice seed saving, it is also important for smallholder farmers to have regulated storage facilities. Emphasis should be placed on the use of storage facilities that maintain constant low temperatures and relative humidity. The use of the latter will ensure that the initial seed quality is maintained, minimising the rate of seed deterioration and thus ensuring that the seeds remain vigourous and viable until the next planting season.

Supplement

The supplement related to this article is available online on the same landing page at: https://doi.org/10.17170/kobra-202403129758 .

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Conflict of interest

The authors declare that they have no conflict of interest.

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