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Loss of Certified Maize (*Zea mays* L.) and Cowpea (*Vigna unguiculata* (L.) Walp.) Seed Viability during Storage in a Sub-Saharan Region: Analysis of Environmental Factors

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Abstract

The objective of this study was to characterize environment factors involved in loss of seed viability during storage in open granaries. The temperature and relative humidity of the granary as well as the equilibrium moisture content of seeds were determined monthly. Their effects on the loss of viability of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* (L.) Walp.) seeds were examined. The results showed that relative humidity levels > 65% associated with temperatures > 25˚C (conditions in the open granary) do not guarantee safe storage of maize lots for a period of 9 to 12 months. Based on these data and the results of seed viability analysis, local environmental conditions in Gandajika (DR-Congo) and seed genetic background are the main factors for the rapid deterioration of seeds during storage. The germination rate correlated negatively with storage duration (−0.94) and temperature (−0.57) while it correlates positively with the relative humidity (0.58) for both lots of maize analyzed. The same trend was observed with the two-cowpea varieties studied (IT82D-889 and Diamant). Similar work using more varieties in other granaries is required to validate key factors involved in seed viability during storage in targeted regions.

Keywords

Seed Viability, Storage, Maize (*Zea mays* L.), Cowpea (*Vigna unguiculata*): DR-Congo, Modeling Approach

1. Introduction

The intrinsic quality of the seed is one of the essential factors for the success of a crop and agricultural productivity. Access to seeds of good quality also facilitates the diversification of food resources and the prevention of genetic erosion in agriculture. It has been established that seed lots subject to the certification process lose rapidly their germinability during storage. This is a source of concerns among the stakeholders in the DR-Congo seed sector, especially since current legislation does not provide specific information on the expiry date of certified seed lots. To address this problem, it is necessary to carry out studies on the environmental factors likely to influence the loss of viability during storage in granaries most frequently used in the DR-Congo, as well as to determine the appropriate storage period to prevent significant losses. Seed viability during storage has been a concern for nearly a century. A number of studies have been conducted to predict loss of seed germination and to determine factors influencing seed viability of some in-storage species such as wheat, barley, oats and soybeans [1]-[7]. In addition to the time factor, seed aging is influenced by three fundamental factors, water, temperature, and oxygen [8] [9] [10] [11]. Temperature and relative humidity during storage are the most important determinants of the lifespan of stored seeds [2]. Seeds attain a rather specific moisture content when subjected to given levels of atmospheric humidifies [12] [13] [14] [15] [16]. The deterioration of the quality of stored seed is the net result of the interactions within the complex ecological system in a seed store. In fact, moisture content is considered the most influential factor in seed deterioration followed by seed temperature [2].

Quantitative models have been developed to predict seed viability during storage [17] [18] [19]. These models are based on statistical analysis (probit analysis, multiple regression, etc.) of cumulative germination, storage environment, and seed moisture content. Qualitative models on the other hand, are based on the relative effect of seed initial quality and environmental conditions on seed longevity [20]. Although they provide practical recommendations for favorable combinations of water content and temperature for seed storage, they have limited use in the planning and management of seed storage systems [1] [8] [17] [18]. Modeling equations for predicting seed viability in a limited range of environmental conditions have been developed and widely used [20]. These equations were improved by Ellis and Roberts [17] to adapt them to prediction of seed lot viability for different types of storage environments, taking into account genetic differences within the same species.

They also predict the effect of the environment on seed longevity, ranging from the rapid loss of viability that can occur during air-drying of wet seeds to the slow loss occurring during storage. Between these two extreme situations, these equations can also accurately predict the percentage of viability expected after a given period, regardless of temperature and moisture content, under medium-term storage conditions [1] [8] [17] [18]. Modifications to these modeling equations have been proposed for certain species and storage conditions [2].

The objective of this study was to characterize environment factors involved in loss of seed viability during storage in open granaries. These seed lots were subject to certification and were also used for the conservation of genetic resources.

2. Materials and Methods

2.1. Experimental Site

The experiment was carried out under the natural conditions of seed storage in an open granary at the agronomic research station (INERA) in Gandajika in Eastern Kasaï (Democratic Republic of Congo) located at 6˚45' south latitude and 23˚57' east longitude, and at altitude of 792 m. The region falls within the Aw4 climate type according to Köppen classification characterized with three months of dry season (from mid-May to august) coupled with eight months of rainy season, sometimes interrupted by a short dry season in January/February [21] [22]. Daily temperature averages 24˚C and the average annual rainfall is 1400 mm over nine months and the relative humidity is highest in November and December (81% and 82%) with a minimum in June and July (55% and 52%) [22].

2.2. Data Collection

The open granary has an area of 115 m^2 (23 m × 5 m) with a corrugated aluminum sheet roof of 0.9 mm thick. The walls were bare baked bricks, 228 mm thick, covered with a brilliant color. Aeration was natural and the orientation was East-West. Four lots of seeds from the CTB-INERA described were used including two maize lots from the same variety (Salongo 1) and two cowpea lots (one from IT82D-889 and the second from Diamant varieties). The lot 1 of Salongo (MS1) was harvested in January and put in storage three months later while the lot 2 (MS2) was harvested later and put in the granary a month after harvest. The cowpea varieties IT82D-889 was produced four months before the Diamant var. The two cultivars were placed in storage a month after harvest.

Indoor and outdoor temperatures and relative humidity were measured for 15 days per months using a Testo 625 thermo hygrometer. Measurements were recorded daily in the morning (9 - 10 am), midday (12 pm) and evening (4 pm).

At the beginning of each month, a standard germination test was performed and the water content was measured from seed samples taken from the four lots, following sampling techniques developed by the International Seed Testing Association (https://www.seedtest.org/en/international-rules-for-seed-testing-_content---1--1083.html).

Sampling of small quantities of seeds was carried out using a seed probe in a given number of bags to form the overall sample representative of the batch. The latter was homogenized and reduced to 1000 g of seeds for analysis. Seed sampling in a granary is described in **Figure 1**.

The test was performed in wet sand using tap water. The design consisted in 200 seeds in four replicates of 50 seeds each. The germination was recorded for seven days for maize and eight days for cowpea. The evaluation of normal seedling germination was based on the International Seed Testing Association Guidelines (https://www.seedtest.org/en/international-rules-for-seed-testing-_content---1--1083.html). Seedlings with good development of essential parts (roots, stems and leaves) were considered normal and were used to express the percentage of germinated seeds (see **Figure 2**). Abnormal seedlings, fresh, hard and dead seeds were considered agronomically dead seeds.

Figure 1. Seed sampling in a granary in Gandajika (DR-Congo).

Figure 2. Normal maize seedlings seven days after sowing.

The water content was measured using a Dickey John brand moisture rapid tester that operates on the dielectric principle. The electrodes (+ and −), brought into contact under the weight of a suitable quantity of seeds, give information on the conductivity of electricity in terms of the quantity of water contained in the seed. Three measurements were performed each time to estimate an average value of the water content.

2.3. Data Processing

The germination data at the start of the experiment was used to describe the initial lot quality and to calculate the length of storage under the granary conditions. Data analyses were performed on logit-transformed germinability, that is, the logarithm of the ratio of the number of germinated seeds to the number of dead seeds.

The equation of the model [Equation (1)] is thus:

$$ylogit = \log\left(\frac{PG}{1-PG}\right) = \beta_0 + \beta_1 \text{ Days} \quad [17]$$

where, $\log\left(\frac{PG}{1-PG}\right)$ corresponds to ν which is the percentage of viability at logit scale; β_0 corresponds to K_i representing the percentage of viability at logit scale at the beginning of storage; β_1 corresponds to $1/\sigma$, the slope of the curve or the inverse of the standard deviation of the frequency of dead seeds; and "days" represent the unit of the period of loss of seed viability during storage [17].

The percentage of germination (PG) was then estimated using the following equation [17]:

$$PG = \frac{e^{\beta_0 + \beta_1 \text{ Days}}}{1 + e^{\beta_0 + \beta_1 \text{ Days}}}$$

It is shown that the half-viability period is given by $\frac{\beta_0}{\beta_1}$ days. The parameters β_1 and β_0 were estimated using the Generalized Linear Model, which relates the transformed germination rate in logit with the time. This is the generalization of linear regression on data that is not distributed in a normal distribution [17]. The R 2.9.0 software was used for data analyses.

3. Results

3.1. Characterization of the Microclimate of the Granary

Table 1 shows the monthly mean values of the temperatures (outdoor and indoor) and relative humidity measured during the experimental period. Analysis of these values showed that outdoor temperatures vary between 25.2˚C and 33˚C, a difference of 7.8˚C while inside the granary, they vary between 28.9˚C and 26.2˚C, a difference of 2.7˚C. The largest differences between the minimum and maximum outdoor values were 20.2˚C and the smallest 10.7˚C. The temperature differences inside the granary hardly exceed 8.4˚C during the test. Average relative humidity measures vary slightly (65.2% to 68.5%), although the differences between the minimum and maximum values were quite high (20.8% to 33.8%).

3.2. Loss of Viability of Seeds over Time

Seed germination and water content are described in Table 2. Apart from the cowpea diamant (N_2) where a drop of 14% of germination rate was observed, variations of this parameter were minimal (4% to 7%). In all cases, it must be considered that, the seed lots had, as the case may be, a duration of about three months of storage prior to our study.

The MS_1 maize lot lost viability reaching < 90% standard during pre-storage prior to the start of the experiment. This lead to less than 165 days after storage

Table 1. Monthly average of temperature and relative humidity in Gandajika (DR. Congo) during seed storage trial.

Observation period	Values	T (˚C)		RH (%)
		Outside granary	Inside granary	
November Year 1	Means	29.3	26.4	65.8
	Min-Max	24.5 - 39.2	24.5 - 32.9	47.9 - 81.7
	difference	14.7	8.4	33.8
December Year 1	Means	33.0	27.5	68.5
	Min-Max	24.5 - 44.7	23.2 - 30.2	59.4 - 82.4
	Difference	20.2	7.0	23.0
January Year 2	Means	32.1	26.2	66.4
	Min-Max	26.3 - 38.2	25.3 - 31.5	56.8 - 77.6
	Difference	11.9	6.2	20.8
February Year 2	Means	25.2	28.9	65.2
	Min-Max	23.3 - 34.0	26.2 - 33.5	51.4 - 84.2
	Difference	10.7	7.3	32.8

Table 2. Mean values of germination rate and seed water content for maize and cowpea seed lots tested in Gandajika (DR-Congo).

N˚	Lot	November Year 1		December Year 1		January Year 2		February Year 2		March Year 2	
		WC (%)	GR (%)	WC (%)	GR (%)	WC (%)	GR (%)	WC (%)	GR (%)	WC (%)	GR (%)
1	MS_1	14.2	83	15.2	83	15.2	79	14.9	79	14.2	77
2	MS_2	14.7	96	14.9	94	13.6	93	15.5	92	13	92
3	N_1	12.1	94	11.1	92	11.1	88	17.6	87	10.9	86
4	N_2	10.9	65	11.1	61	11.2	60	18.4	59	8.9	51

WR: water content; GR: germination rate; MS1: Maize var Salongo 1 (lot 1); MS2: maize var Salongo (Lot 2); N1: cowpea (Var IT82D-889, and N2: cowpea (Var. Diamant).

and the lot MS_2 maize kept its viability until the end of the experiment, more than 210 days after the start of storage.

Like the MS_1 maize, the Cowpea Diamont seed had also lost viability before the 70% standard less than 120 days after storage while cowpea batch IT82D-889 maintained viability until the end of the experiment, more than 240 days after storage. The moisture content oscillated with peaks at different periods.

3.3. Prediction of Loss of Viability of Two Lots of Maize over Time

Table 2 describes data on moisture content and germination rate of maize seeds as well as changes in the relative humidity in the granary during storage. The p-values, the small standard deviations in relation to the estimated values of the parameters showed that this model can be used to predict the viability loss of these two seed lots over time (Table 3).

The equation of the model is therefore:

$$ylogit = \log\left(\frac{PG}{1-PG}\right) = 3.899849 - 0.09210\ \text{Days}$$

$$PG = \frac{e^{3.899849-0.09210\ \text{Days}}}{1+e^{3.899849-0.09210\ \text{Days}}}$$

The number of days corresponding to the loss of viability of 50% is therefore

$$PG50 = \frac{3.899849}{0.009210} = 423\ \text{days}$$

Considering the peremption standard for maize foundation seeds set at 90%

Table 3. (a) Model prediction parameters for maize seed viability during storage in granary in Gandajika (DR-Congo). (b) Model prediction parameters for cowpea (IT82D-889) seed viability during storage in granary in Gandajika (DR-Congo). (c) Model prediction parameters for cowpea (Cv Diamant) seed viability during storage in granary in Gandajika (DR-Congo).

(a)

Parameters	Estimated values	Standart deviation	Z-value	P-value
β_0	3.899849	0.332753	11.72	<2e − 16 ***
β_1	−0.009210	0.001453	−6.34	2.29e − 10 ***

(b)

Parameters	Estimated values	Standart deviation	Z-value	P-value
β_0	4.108299	0.658848	6.236	4.5e − 10 ***
β_1	−0.005937	0.001965	−3.022	0.00251 **

(c)

Parameters	Estimated values	Standart deviation	Z-value	P-value
β_0	2.31215	0.26950	8.580	2e − 16 ***

β_1	−0.01034	0.00148	−6.988	2.79e − 12 ***

for the germination rate (GR) by the DR-Congo Ministry of Agriculture, data of this study showed that this value would be reached after 198 days. Based on the 85% GR used by Ellis and Robert [8], the lot would lose viability after 234 days. On the other hand, for certified seeds for which the standard germination rate is set at 80%, the expiry period would occur after 270 days.

The MS_1 maize lot actually lost viability earlier than expected, at less than 165 days, considering the above three normative criteria while the MS_2 lot still meets the criteria of 90% viability more than 210 days in storage.

3.4. Prediction of Loss of Viability of Cowpea cv IT82D-889 over Time

The result of the Generalized Linear Model of the cowpea lot cv IT82D-889 is shown in Table 3.

The equation of the model is therefore:

$$ylogit = \log\left(\frac{PG}{1-PG}\right) = 4.108299 - 0.005937\ \text{Days}$$

$$PG = \frac{e^{4.108299-0.005937\ \text{Days}}}{1+e^{4.108299-0.005937\ \text{Days}}}$$

The number of days corresponding to the loss of viability of 50% is derived from:

$$PG50 = \frac{4.108299}{0.005937} = 692\ \text{Days}$$

Considering that the standard expiry date for a lot of the foundation and certified seeds is set at 70% of germination rate, this lot would lose its viability after 572 days. If we consider the harmonized standard for the SADC region (SSSN, 2008) which sets at 75% the minimum germination rate for the certification of cowpeas, the expiry would occur after a storage for 518 days.

However, this lot maintained its viability until the end of the experiment, *i.e.* 240 days after storage, with a score of 86% which is significantly above the standard of 70%. germinability. The question is whether this 16% margin is sufficient to maintain viability in accordance with the standard for the additional 332 days predicted by the model.

3.5. Prediction of Loss of Viability of Cowpea Diamond

The result of the Generalized Linear Model of cowpea lot cv Diamant is shown in Table 3. The equation of the model is therefore:

$$ylogit = \log\left(\frac{PG}{1-PG}\right) = 2.31215 - 0.01034\ \text{Days}$$

$$PG = \frac{e^{2.31215-0.01034\ \text{Days}}}{1+e^{2.31215-0.01034\ \text{Days}}}$$

The number of days corresponding to the loss of viability of 50% is derived by:

$$PG50 = \frac{2.31215}{0.01034} = 224 \text{ Days}$$

At the standard of 70% germinability, this lot would lose its viability after 154 days. When considering the harmonized standard for the Southern African Development Community

(SADC) region set at 75% of the minimum germination rate, the expiry time would occur after a storage period of 118 days.

It was evident that this lot had lost its viability considerably even before the start of the experiment, *i.e.* less than 90 days after storage. The question that remains to be known is when the expiry is precisely occurred and why this important difference (more than 64 days) with the prediction.

3.6. Effect of Seed Lots on Loss of Viability

The two maize seed lots stored in the same environment exhibited similar trend in terms of loss of viability. However, lot MS_1 lost viability at a faster rate than batch MS_2 (**Figure 3**). On the other hand, the two lots of cowpea showed an opposite trend. In fact, cowpea cv Diamant produced and placed in storage after cowpea cv IT82D-889 lost viability before the latter. Its curve (**Figure 4**) is downhill whereas that of cowpea lot cv IT82D-889 (**Figure 5**) is in the upper plateau phase.

3.7. Correlations among Temperature, Relative Humidity, Seed Moisture Content and Loss of Viability

Table 4 and **Table 5** showing the pairwise correlations among parameters allowed

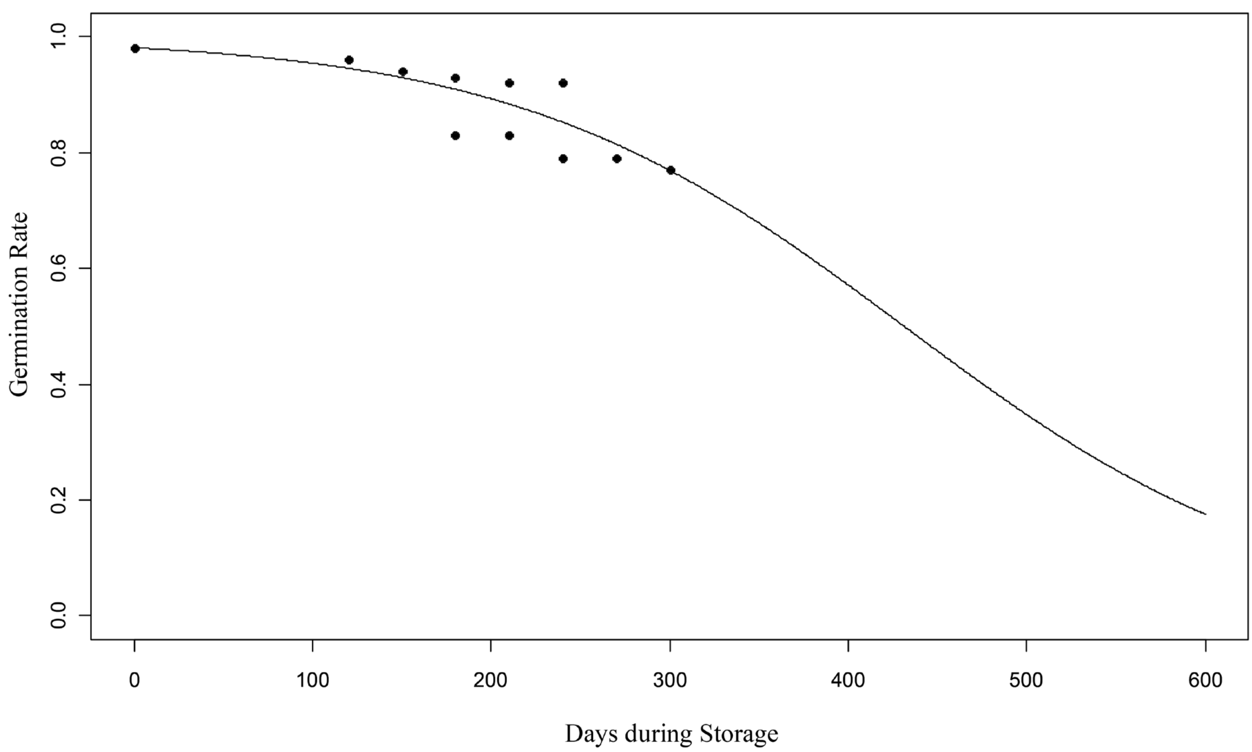

Figure 3. Prediction of seed viability loss for maïs (Salongo 1: lots 1 and 2) during storage in a granary (Gandajika, DR-Congo).

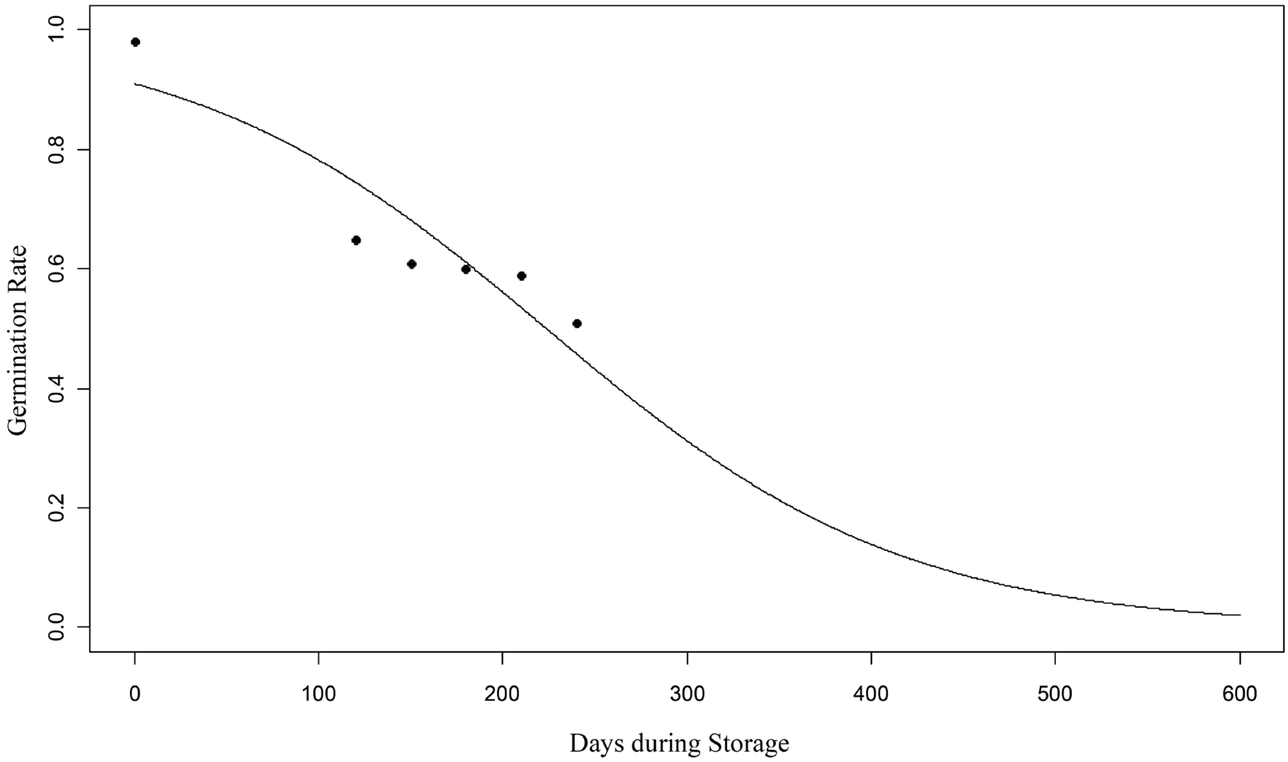

Figure 4. Prediction of seed viability loss for cowpea cv Diamant during storage in a granary (Gandajika, DR-Congo).

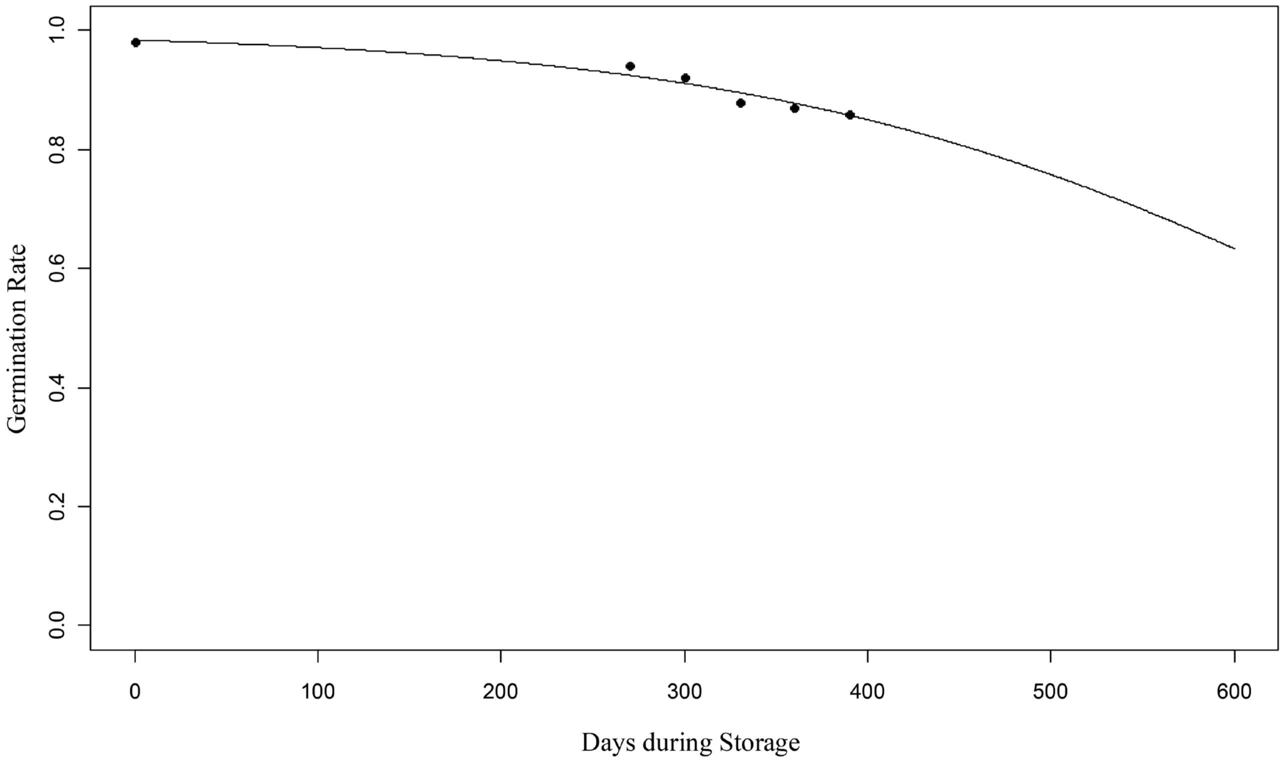

Figure 5. Prediction of seed viability loss for cowpea cv IT82D-889 during storage in a granary (Gandajika, DR-Congo).

Table 4. Correlation coefficients among environmental factors in the granary during maize seed.

	GR MS_1	Days	WC-MS1	Tm	RH
GR MS_1	1.000000	−0.942809042	−0.005992646	0.569197451	0.583016325
Days	−0.942090	1.0000000	−0.2542464	0.4417500	−0.4355900
WC MS_1	−0.005992646	−0.254246418	1.000000000	−0.176706365	−0.048649659
Tm	−0.5691975	0.4417500	−0.1767064	1.0000000	−0.9327880
RH	0.58301632	−0.43558997	−0.04864966	−0.93278803	1.00000000
	GR MS_2	**Days**	**WC-MS_2**	**Tm**	**RH**
GR MS_2	1.000000000	−0.942809042	−0.005992646	−0.569197451	0.583016325
Days	−0.9428090	1.0000000	−0.2542464	0.4417500	−0.4355900
WC MS_2	−0.005992646	−0.254246418	1.000000000	−0.176706365	−0.048649659
Tm	−0.5691975	0.4417500	−0.1767064	1.0000000	−0.9327880
RH	0.58301632	−0.43558997	−0.04864966	−0.93278803	1.00000000

MS1: Maize Vr Salongo 1 (lot 1); MS2: Maize Var-Salongo 1 (Lot 2). GR: germination rate; Days: days in storage; WC: water content: Tm: temperature; RH: relative humidity.

Table 5. Correlation coefficients among environmental factors in the granary at INERA Gandajika during cowpea seed storage.

	Days	GR N_1	Tm	WC N_1	RH
Days	1.0000000	−0.9534626	0.4417500	0.2269666	−0.2542464
GR N_1	−0.95346259	1.00000000	−0.32291398	−0.29425692	−0.03636217
Tm	0.4417500	−0.3229140	1.0000000	−0.5851092	−0.1767064
WC N_1	0.22696663	−0.29425692	−0.58510924	1.00000000	−0.01717089
RH	−0.25424642	−0.03636217	−0.17670636	−0.01717089	1.00000000
	Tps	**PG N_2**	**Tm**	**WC N_2**	**RH**
Days	1.0000000	−0.9112580	0.4417500	0.1431000	−0.2542464
GR N_2	−0.9112580	1.0000000	−0.6772818	0.2498182	0.4311680
Tm	0.4417500	−0.6772818	1.0000000	−0.7234543	−0.1767064
WC N_2	0.1431000	0.2498182	−0.7234543	1.0000000	0.1339544
RH	−0.2542464	0.4311680	−0.1767064	0.1339544	1.0000000

N1: Cowpea var. IT 82D-889; N2: Cowpea var. Diamant; GR: germination rate; Days: days in storage; WC: water content: Tm: temperature; RH: relative humidity.

the probing of the role of various factors on the loss of viability of the maize and cowpea seeds. It appears that the germination rate shows a negative correlation with storage duration (−0.94) and temperature (−0.57) while it correlates positively with the relative humidity (0.58) for both lots. The water content has a negative correlation of almost zero with the germination rate (0.5) (**Table 4**)

The correlation between the germination rate and the storage duration for the two cowpea varieties is significant and negative (−0.95 and −0.91). It correlated negatively with temperature for IT 82D-889 (−0.32) and Diamant (−0.67). Seed moisture content and relative humidity were negatively correlated with germination for the IT82D-889 variety (−0.29 and −0.036) although the correlation was null to little; whereas for the Diamant variety, they weakly correlated positively with the germination rate (0. 25 and 0.43) (**Table 5**).

4. Discussions

4.1. Microclimate in the Granaries and Drop in Germination

The mean temperature and relative humidity values inside the granary were respectively above 25˚C and 65% for the entire experimental period while the average water content varies between 12.1% to 14.7%. However, the theoretical model of Delouche *et al.* [20] indicated that for short-term storage (9 months), the conditions should be 30˚C of temperature and 50% relative humidity in the granary while the seed should be dried between 12% and 8% of water content. Alternatively, at 60% of the relative humidity, the temperature in the granary should be 20˚C and the seed moisture content between 13% and 9.5% of moisture content. It is therefore evident that the conditions prevailing in the INERA granary in Gandajika, are not likely to promote safe storage of seeds beyond one year. Strelec *et al.* [11] reported significant influence of storage conditions on moisture content, germination and vigour changes during storage of wheat seeds, as well as varietal dependence of seed. Suma *et al.* [12] also showed that *Brassica spp.* seed viability and seedling vigour parameters were considerably reduced in all accessions at high relative humidity irrespective of the species. Storage at intermediate relative humidities caused minimal decline in viability. All the accessions performed better at relative humidity level of 32% maintaining seed moisture content of 3%. Rate of seed deterioration is accelerated with increased initial seed moisture content, temperature, and relative humidity of the storage environment [10] [13].

Ellis and Robert [8] showed that at a temperature of 35˚C and a water content of 8.5% or 25˚C temperature and 10.7% water content, it takes 234 days for maize seed viability to drop below 85%. The results of this study are consistent with previous studies since based on the international standard; the predicted loss of viability over time is 240 days.

However, a close analysis revealed a difference between the two lots of maize, the MS_1 having lost viability earlier than expected. This more rapid deterioration of the germination capacity of the MS_1 lot would be due to pre-storage factors in the ambient conditions according to the findings of Probert *et al.* [23]. In fact, this lot has been pre-stored for nearly four months under uncontrolled conditions. It is reasonable to assume that the prevalence of elevated temperature and relative humidity conditions during the pre-storage period of MS1 throughout the season B, would be the cause of the faster loss of viability compared to MS_2 produced in season B and placed in storage within a reasonable period of time. The harvest after the B season takes place during the dry season under more favorable conditions for seed viability. A comparative study of yearlong loss of viability based on production and storage seasons could elucidate this issue and determine the best period of production and storage of maize seed in the region. Gandajika.

For cowpea, the model of loss of viability predicts 572 days for the IT 82D-889 cultivar and 154 days for the Diamant cv. This prediction seems realistic for IT 82D-889 which still had a margin of 16% above the norm of 70% of germinability at the end of the experiment. But for Diamant which lost viability a few days before the start of the experiment, judging by the score of the first germination test (65%), the 154 days viability period is abnormal. The differences in the response of the two cowpea varieties stored in the same environment are likely attributed to a genetic difference between the two varieties [14].

4.2. Correlation of Factors and Loss of Viability

Analysis of correlations data showed that the loss of viability was essentially due to storage period, while showing correlations > −0.50 with temperature (−0.68 for cowpea Diamant and −0.57 for both lots of maize). The correlation between germination rate and relative humidity was −0.58 for both maize lots. This could be due to the storage conditions rather than to a real biochemical phenomenon [20].

As much as 50% - 60% cereal grains can be lost during the storage stage due only to the lack of technical inefficiency [4]. Use of scientific storage methods can reduce these losses to as low as 1% - 2%. Mathematical modelling is an inexpensive tool of managing seed in storages. Xanthopoulos [2] demonstrated that it could be used for optimization of the stored seed ecosystem to improve the aeration management strategies in favor of the quality of the final product minimizing postharvest losses. This will help in minimization of the use of preservation chemicals during seed storage.

In the present study, discrepancies in the loss of viability of the maize Mus 1 and cowpea vat Diamant suggest that additional research is needed with more granaries and varieties to accurately determine the role of environmental and genetic factors in the loss of viability of seed during storage in DR-Congo.

5. Conclusion

The objective of this study was to characterize environment factors involved in loss of viability of the seeds during storage in open granaries. The temperature and relative humidity of the granary as well as the equilibrium moisture content of the seeds were determined monthly and their effects on the loss of viability of four seed lots were examined. Relative humidity above 65% associated with temperatures > 25˚C, the conditions prevailing in the open granary were not appropriate for a short-term storage (9 months) of maize and cowpea seeds. Based on the data and the results of seed viability analysis, local environmental conditions in Gandajika and genetic background are the main factors for the rapid deterioration of seeds during storage, given the rapid decline in germination capacity of MS1 maize seedlings and cowpea cv Diamant. It is important to carry out similar work using more varieties in other granaries to validate key factors involved in seed viability during storage in targeted regions.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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