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Full Length Research Paper

Physiological quality of hybrid maize seeds during containerized-dry storage with silica gel

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Seed storage operations in the tropics would benefit from low input techniques that can maintain seed physiological quality for considerably long periods without investments in cooling. A study was conducted to evaluate seed vigour and estimate seed longevity in maize during dry storage with commercial desiccant (silica gel) at various levels of gel/seed ratios in air-tight containers under ambient tropical temperature. Seed moisture content (MC) was lowest indicating effective drying at 1:1 gel/seed (100 g of seed stored over 100 g of gel) and 1:2.5 gel/seed ratio (100 g of seed stored over 80 g of gel) during 2 trials set up in 2005 and 2006. After 4 months of storage, laboratory seed germination capacity and vigour variables were consistently higher (*p<0.05*) in seed lots stored at 1:1 and 1:2.5 gel/seed ratios than seed lots stored at 1:20, 1:10 and 0:1 gel/seed ratios in the 2 trials. Probit analysis of seed survival data from controlled deterioration (CD) tests showed that estimates of potential longevity were optimal at 1:2.5 gel/seed ratios in the two experiments. The results indicated the possibility of maintaining seed physiological quality in containerized-dry storage under ambient humid tropical storage conditions. Moreover, the storage system experimented in the study simulated a condition that eliminates labour involved in regenerating or drying silica gel, since silica gel was not changed throughout the storage period. Gel/seed ratios between 1:1 and 1:2.5 are recommended for direct application or in developing technology and equipment for containerized-dry seed storage in the humid tropics.

Key words: Maize, low input storage, silica gel, seed quality, potential longevity.

INTRODUCTION

Medium to long-term seed conservation in gene banks as well as the delivery of high quality commercial seed lots under the humid tropical climates are practically impossible without cooling facilities, because seed deteriorates rapidly under the prevailing conditions of high temperature and relative humidity (RH) that causes high equilibrium seed moisture content (MC) (Daniel and Ajala, 2004). But investment in cooling facilities and energy is too cost intensive for economical operation of seed gene banks and for operating sustainable commercial seed industry in the humid tropics. The problem is further exacerexacerbated by epileptic power supplies in many of the humid tropical countries with developing economies and infant seed industries like Nigeria where these studies were conducted. Low-input storage techniques that can minimize operational costs and technological sophistication associated with cooling will benefit seed storage operations in the humid tropics if workable procedures are investigated and standardized. Thus, considerable research efforts are currently focused on dry storage for low-input seed conservation under ambient humid tropical conditions (Achigan et al., 2004; Somado et al., 2006; Daniel, 2007). But there is paucity of information on statistical evaluation of potential seed longevity in low input seed storage systems at ambient humid tropical conditions (FAO/IPGRI, 2004).

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Dry and ultra-dry storage at high temperature conditions are recommended technologies for low-input seed storage for several seed types in these climates (FAO/IPGRI, 1994; Ellis, 1998; Hong et al., 2005) and specifically for maize (Asiedu et al., 1999). This is because it is cheaper to reduce storage atmospheric RH around the seed (and consequently the equilibrium seed MC) in closed containers than to reduce temperature with cooling facilities. The containerized silica gel storage method should achieve this objective. This study was designed to evaluate the potentials of desiccant aided dry-storage in closed containers (containerized-dry-storage) for preservation of seed physiological quality as well as for seed longevity enhancement.

MATERIALS AND METHODS

These trials were conducted from September to December 2005 and May to September 2006 in the seed store and laboratory facilities of the University of Agriculture, Abeokuta, Nigeria (~5°3'N, 3°10'E). The daytime conditions in the store and in the containers were monitored weekly with a digital thermo-hygrometer, the mean temperature in the main store was ~31°C and the average RH was ~71% throughout the storage period. The seed materials used were 5 Nigerian commercial hybrid maize varieties sourced from the Institute of Agricultural Research and Training (IAR and T), Ibadan and Premier Seeds (Nigeria) Ltd. (Table 1).

In 2005, 100 g of the hybrid maize seeds were packed in net bags and placed in 2 litre capacity screw-caped containers with different weights of a commercial desiccant (silica gel) to achieve 4 different gel/seed ratios by weight namely: a) 100 g silica gel (1:1 gel/seed ratio), b) 40 g silica gel (1:2.5 gel/seed ratio), c) 5 g silica gel (1:20 gel/seed ratio), and d) 0 g silica gel (0:1 gel/seed ratio). In 2006, 200 g of seeds were packed in net bags and placed in each container containing different weights of silica gel to achieve 5 different gel/seed ratios: a) 200 g silica gel (1:1 seed/gel ratio), b) 80 g silica gel (1:2.5 gel/seed ratio), c) 40 g silica gel (1:5 gel/seed ratio), d) 10 g silica gel (1:20 gel/seed ratio), and e) 0 g silica gel (0:1 gel/seed ratio). In the two experiments, control treatment seed lots were stored in opened containers without silica gel. Once closed, containers were not opened and silica gel was not replaced throughout the storage period, until after the 4th month to enable evaluation of a dry storage system that eliminates labour and costs involved in frequent replacing or drying silica gel. In both trials, seeds were stored under ambient temperature of the seed store.

Seed viability and vigour evaluation

After 4 months of storage, the seeds were evaluated for MC and viability. Seed MC was determined gravimetrically by drying 5 g of seeds at 130°C for >3 h and expressed on a fresh weight basis. Seed germination tests were carried out in sand trays on 3 replicates of 10 seeds drawn from each of the storage treatments. Germination counts were taken at 3, 5 and 7 days after culture.

To evaluate seed vigour, the germination data were used to estimate rates of germination (GR) as the reciprocal of time taken for seeds to reach maximum germination within 7 days of incubation (Daniel, 1997):

$$GR = 1/t_n.(\Sigma G_n)$$

Where t is time taken for seeds to reach maximum or cumulative germination G. Seed vigour was also evaluated by seedling assessment. Seedling length was measured after 3 days and 7 days of culture. Weight of 3 and 7 days old seedlings was also measured after drying in envelops (dry weight) at 100°C for 24 h. Seedling growth rate was estimated using the formula:

$$\text{Seedling growth} = (dw2 - dw1) / \Delta t$$

Where $dw2$ = seedling dry weight after 7 days of culture, $dw1$ = seedling dry weight after 3 days of culture, Δt is the time difference. A seedling vigour index (VI) was estimated for one-week old seedlings as the product of percentage germination and seedling length:

VI = Seedling length x percentage germination

Controlled deterioration (CD) tests and determination of potential seed longevity

After storage in the containers, the remaining seeds of each seed lot were subjected to CD tests in an oven at 45°C and 90% RH for 72 h. During the aging course, 3 replicates of 10 seeds of each treatment were removed from the aging chamber for germination tests at 3, 6, 24, 27, 48, 51 and 72 h. The serial germination data of aging seeds were subjected to probit analysis to estimate potential seed longevity under each containerized-dry storage treatment. Potential seed longevity parameters determined for each seed lot were values of Ki (intercept on the y axis), σ (standard deviation of individual life spans of seeds), and $p50$ (half-life values or time to 50% viability) (Ellis and Roberts, 1980). The slope of the seed survival data from probit modelling is the reciprocal of σ, and it represents the rate of seed deterioration.

All data were subjected to Analysis of Variance (ANOVA) using a PROC GLM statement of SAS™. The percentage germination data were normalised by arc-sin transformation. Post-hoc tests for comparison of means of various seed vigour and longevity variables were done with the Least Significant Differences (LSD) ($p=0.05$). Estimates of potential seed longevity parameters were also compared for statistical differences among treatments.

RESULTS AND DISCUSSION

There were marked differences in initial quality of seed lots of the different varieties with respect to seed viability and MC between the 2 experiments (Table 1), due to variations in production environments and years of the different lots. Table 2 shows the microclimate and equilibrium seed MC within each container in response to the various gel/seed ratio treatments. Disparities in temperature inside containers between the 2005 and 2006 trials reflected differences in seasonal temperature variation; the time of the trial in 2005 was the hot and dry season while the time in 2006 was the cool and wet season. Highest %RH values were in open containers and there was gradual decrease in %RH values along the gradient of increasing gel/seed ratios such that lowest %RH values were containers with 1:1 gel/seed ratio treatments in both experiments. Seed drying indicated by variations in seed MC of seed lots of indivi-

Table 1. Initial quality of seed lots of maize varieties.

Variety	2005		2006	
	% Germination	% MC	% Germination	% MC
ART (Oloyin) (AR)	95	11.3	75	11.4
DMR-ESR-Y (DM)	83	10.9	63	10.5
Oba Super (Premier seeds) (OB)	100	8.2	72	9.9
Swan 1 (SU)	97	9.6	80	11.2
TZm (TZ)	97	10.0	58	12.0
Mean± s. e.	94.4±6.61	10.2±1.21	69.6±8.96	11.0±0.86

Table 2. Equilibrium seed moisture content of various Nigerian commercial maize seed lots stored at different containerized dry storage regimes for 4 months (~120 days).

Treatment (gel/seed ratios)	Temperature* (℃)	% RH	% MC*** (varieties)					Mean ± s.e
			DM	SU	OB	TZ	AR	
2005								
Open	30.3	73	10.7	12.5	10.5	10.7	10.5	11.04±0.83
0:1	30.2	70	14.5	15.2	9.7	8.3	13.4	12.08±2.99
1:20	30.3	67	14.4	12.5	8.6	9.2	12.5	11.26±2.66
1:2.5	30.2	64	11.8	12.4	7.7	8.4	11.9	10.44±2.20
1:1	30.2	50	10.0	10.4	6.6	8.2	9.4	7.12±3.45
2006								
Open	-**	-	10.2	11.3	10.5	7.1	7.9	10.10±1.65
0:1	29.3	70	11.6	14.62	10.0	12.2	21.6	9.64±0.85
1:20	29.3	69	10.9	12.1	9.6	13.2	20.9	9.32±0.67
1:5	29.2	64	9.6	11.7	8.4	13.5	18.6	8.86±0.72
1:2.5	29.3	62	8.6	11.2	8.3	11.4	13.9	8.40±0.67
1:1	29.3	54	9.1	11.4	9.2	10.6	11.7	8.12±0.90

*Temperature and %RH are average values recorded inside containers from hygrometer data.
**Hygrometer data not available.
***MC data taken after ~120 days of silica gel storage treatments.

dual varieties did not follow a regular pattern under the different treatments in the 2 experiments (Table 2). However, storage over 1:1 and 1:2.5 gel/seed ratios consistently resulted in the lowest mean seed MC (Table 2). Several seed drying studies demonstrated effectiveness of silica-gel method when high gel/seed ratios were used (Kong and Zhang, 1998; Achigan et al., 2004). Though Zhang and Tao (1989) used 1:2 gel/seed ratio to dry bean seeds to 5% MC, the recommended standard for long-term seed conservation (FAO/IPGRI, 1994) from 14% MC within 34 days, none of the gel/seed ratio treatments in the current trials sufficiently dried seeds to 5% MC or less. The differences observed between other reports and results of the current study could be attributed to frequency of silica gel replacement which was greater in the former than the latter. With more frequent changes of silica gel, it should be possible to achieve standardized seed MC for maize germplasm conservation using containerized storage. Another explanation for the disparity in seed MC under high silica gel ratios is the size of the seeds involved; for instance bean seeds are smaller than maize seeds. Achigan et al. (2004) indicated that while seeds of cowpea and maize reached constant weight with 1:1 gel/seed ratio treatment in 5 days, larger sized bambara groundnut seeds took up to 30 days. The effect of different seed sizes on seed drying rates during desiccant storage would be of further research interest.

Some authors argued that the use of desiccants, especially silica gel is not practicable as a low-input seed storage procedure in the humid tropics because of labour involved in the daily regeneration of silica gel

Table 3. Effect of containerized dry storage treatments on seed germination and seedling vigour traits (2005).

Treatment (gel/seed ratio)	Germination (%)	Seedling length (cm)	Germination rate (% d^{-1})	Seedling growth rate (g d^{-1})	Seedling vigour index
Control	57.78±0.066	4.66±0.236	5.98±1.031	0.084±0.080	259.76±23.187
0:1	45.00±0.075	5.00±0.833	6.86±2.087	0.097±0.024	240.25±56.064
1:20	55.56±0.074	5.22±0.547	7.59±2.207	0.106±0.031	303.33±54.416
1:2.5	72.22±0.106	5.11±0.200	9.42±2.364	0.079±0.027	318.89±56.235
1:1	77.78±0.035	4.56±0.626	12.12±3.400	0.091±0.050	365.56±54.902

Values are mean ± standard error of means* of 3 varieties and 3 replicates.
*SE, N = 9.

Table 4. Effect of containerized dry storage treatments on seed germination and seedling vigour traits (2006).

Treatment (gel/seed ratio)	Germination (%)	Seedling length (cm)	Germination rate (% d^{-1}))	Seedling growth rate (g d^{-1})	Seedling vigour index
Control	24.12 ±0.029	1.98 ±0.274	4.13 ±0.337	0.029 ±0.015	56.00 ±34.293
0:1	39.56 ±0.066	3.47 ±0.698	1.90 ±0.569	0.043 ±0.006	122.22 ±22.492
1:20	50.51 ±0.054	4.52 ±0.581	4.38 ±0.704	0.062 ±0.009	192.67 ±29.887
1:5	50.40 ±0.055	4.56 ±0.504	4.66 ±0.690	0.061 ±0.006	241.56 ±32.158
1:2.5	57.58 ±0.042	4.90 ±0.456	6.10 ±0.744	0.058 ±0.006	265.33 ±44.399
1:1	57.67 ±0.064	4.74 ±0.576	5.71 ±0.946	0.052 ±0.009	233.33 ±57.426

Values are mean ± standard error of means* of 5 varieties and 3 replicates.
*SE, N = 15.

(Hong and Ellis, 1996; Kong and Zhang, 1998). Results from this trial however showed that low seed MC can be maintained with containerized storage without regular regeneration of silica gel especially with high gel/seed ratios. Moreover, in situations where the supply of electricity is a problem as in many West African countries including Nigeria where these experiments were conducted, silica gel storage with less frequent regeneration is a feasible option. Furthermore, Somado et al. (2006) demonstrated that sun-drying seeds could also be as effective as and probably cheaper than silica gel drying for seed storage in the humid tropics which will be applicable to farm-saved seeds. However, high value seeds like commercial hybrids and gene bank seed collections face risks of losses of genetic and physiological integrity by regular sun drying. Moreover, taking seeds out for sun sun-drying is labour intensive. A compromise approach proposed from these trials is occasional drying of silica gel by low input means like sun or fire-wood dryers. Furthermore, the use of other cheap desiccants in place of silica gel like toasted rice (Sadik and White, 1982) or salt (FAO/IPGRI, 2004) are potentially practicable low-input seed storage containerized methods in the humid tropics.

From the 2005 trial, the effects of containerized storage treatments were significant on germination, germination rate ($P< 0.01$) and seedling vigour index ($P< 0.05$), but insignificant on seedling length and seedling growth rate ($P> 0.05$) (Table 3). A similar trend was observed in the 2006 trial, only that there were significant differences in seedling growth rates of seed lots containerized over silica gel, open seed lots and seed lots containerized without silica gel (Table 4). Achigan et al. (2004) also reported insignificant effect of drying treatments on seedling length and dry weight. However, it was observed that seed germination, seed germination rate and seedling vigour index of the seed lots that were stored at 1:1 and 1:2.5 gel/seed ratios were highest in the 2 experiments (Tables 3 and 4). In the 2005 trial, seed germination rate and seedling vigour index increased with increasing gel/seed ratios. Germination and all vigour characteristics were not significantly different between openly stored seeds and seeds containerized at 1:20 and 0 gel/seed ratios. In the 2006 trial, all seed lots stored in containers with silica gel had significantly higher values of viability and vigour variables than control seed lots, but seed lots containerized at 1:1 and 1:2.5 consistently had highest vigour values.

The results agreed with enhanced seed germination associated with slow drying in silica gel drying systems (Hong and Ellis, 1997) but it also supports reports that the ability of slow drying treatments to improve seed physiological quality under high temperature storage has optimal limits (Walters et al., 1998; Ellis and Hong, 2006; Daniel, 2007). Thus more data on optimization of gel/seed ratios for different storage environments and seed

Table 5. Effect of containerized dry storage treatments on estimates of parameters of potential seed longevity (2005).

Treatment (gel/seed ratio)	*Ki***	*1/σ*	*σ*	*p50*
Control	5.22±0.173	2.36±0.213	13.71±2.970	8.37±2.155
0	4.39±0.480	1.89±0.559	10.18±5.251	1.56±0.769
1:20	5.14±0.217	0.14±0.083	25.45±6.832	7.69±2.100
1:2.5	6.02±0.447	0.03±0.003	36.20±3.598	23.13±6.000
1:1	5.99±0.274	0.04±0.016	32.40±6.699	22.55±4.715

*SE, N = 9.
**Initial germination of probit survival data was below 50% for some of the treatments, thus the value of 5 was added to probit equivalent of initial percentage germination values of all seed lots to avoid negative *Ki* values.

Table 6. Effect of containerized dry storage treatments on estimates of parameters of potential seed longevity (2006).

Treatment (gel/seed ratio)	*Ki***	*1/σ*	*σ*	*p50*
Control	4.91±0.040	0.19±0.021	7.18±1.375	0.99±0.251
0	5.15±0.078	0.08±0.021	20.61±2.735	7.18±2.059
1:20	5.46±0.102	0.11±0.032	24.69±4.295	14.70±2.996
1:5	5.68±0.105	0.08±0.025	23.57±3.616	18.88±3.904
1:2.5	5.62±0.813	0.03±0.002	32.95±2.024	19.48±2.355
1:1	5.62±0.125	0.04±0.003	24.79±1.470	16.74±3.472

*SE, N = 15.
**Initial germination of probit survival data was below 50% for some of the treatments, thus the value of 5 was added to probit equivalent of initial percentage germination values of all seed lots to avoid negative *Ki* values.

types would be necessary for implementation of the results.

The CD test provides data that can be subjected to probit analysis for estimating seed longevity parameters (Daniel et al., 1999; Davies and Probert, 2004) as well as for making conclusions on seed physiological quality (Kruse, 1999; Powell et al., 2000; Torres and Marcos, 2003). In the 2005 trial, probit analysis of CD data showed that *Ki* estimate was highest in seed lots that were containerized at 1:1 and 1:2.5 gel/seed ratios and least in seeds containerized at 1:20 and 0 gel/seed ratios (Table 5). In the 2006 experiments, *Ki* values were significantly greater in all seed lots containerized with silica gel at 1:1, 1:2.5 and 1:5 gel/seed ratios than open and seed lots without silica gel (Table 6). The estimates of slope (*1/σ*) of the survival data by probit modelling was significantly higher in control seed lot and seed lots containerized without silica gel, indicating higher rate of seed deterioration in control seed lots. Also, estimates of *σ* and seed half-life (*p50*) were highest in seeds containerized at higher gel/seed ratios than seeds containerised without silica gel and control seed lots in the 2 experiments (Tables 5 and 6). Overall, silica gel containerized seed lots exhibited significantly higher potential longevity than the control seed lots, supporting previous report of significant longevity extension through dry storage under ambient temperature in the humid tropics (Daniel, 2007). The results provide evidence estimates that containerized storage at 1:1 and 1:2.5 gel/seed ratios maximised storage life extension of maize seeds and elucidates the potential application of containerized-dry storage for low input seed preservation at high ambient tropical temperature without cooling.

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