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Longevity of maize (*Zea mays* L.) seeds during low input storage under ambient conditions of southwestern Nigeria

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Abstract

Seed longevity of two commercial hybrid maize (*Zea mays* L.) varieties ('Oba-Super' and 'Suwan-1') were evaluated under simulated low-input seed storage systems typical of the tropics. Saturated salt solutions of $ZnCl_2$, $CaCl_2$, $Ca(NO_3)_2$, NaBr, NH_4NO_3, NH_4Cl, and KCl in air-tight containers at 31±4°C provided relative humidity (RH) levels of 15.6, 28.7, 52.5, 56, 60, 75.4, and 80.5% respectively for storage. Monthly germination data for a 12-month storage period were analyzed using the Probit model. Survival curves confirmed a normal distribution pattern for most RH treatments. Seed longevity estimates (*p50* or seed half-viability period and σ or distribution of seed mortality in time) were significantly different among the RH treatments. The two seed kinds equilibrating at 15.6±0.95 and 28.7±1.51% RH had *p50* values of ~600 days representing a 10-fold increase in the estimates of seed longevity compared to seeds stored at >60% RH and 31±4°C (corresponds to the ambient microenvironmental conditions in southwestern Nigeria). Implicit in this are potential gains in seed longevity for dry and ultra-dry seed storage under tropical temperature regimes.

Keywords: Probit analysis, Seed conservation, Tropical seed storage.

Introduction

Implementing standardized seed storage for genebank or for commercial seed operations faces considerable limitations in southwestern Nigeria. The poor infrastructure (e.g., power outages) particularly hampers medium and long-term preservation of seeds under cold storages. There are also environmental challenges to seed production and conservation in southwestern Nigeria (Adebisi et al., 2004). In general the climate is characterized by high temperature (~33°C in day-time and ~27°C at night) and high relative humidity (>65% RH) round the year. As a result, seeds stored under ambient conditions deteriorate rapidly.

Nevertheless, in the traditional agricultural systems of the tropics, commercial seeds have been preserved under ambient conditions employing the principle of low-cost drying (Engelmann and Engels, 2002). Examples include the popular maize cribs of West Africa, coated seed baskets of Eastern and Southern Africa (IPGRI, 2004), and the dry-sealed storage in polyethylene bags for elite commercial seeds (Zheng et al., 1998). Although research efforts are currently underway on dry storage under ambient conditions (Somado et al., 2006), statistical quantification of seed longevity useful for decision-making on seed processing and storage and predicting seed viability during storage and gene bank management are generally scarce. The present study was aimed to quantify and model the longevity parameters of maize seeds stored at various RH levels under ambient temperature as such information would be of practical relevance to the seed producers and traders alike. This paper also reports survival data on two locally important maize seed kinds, facilitating greater precision in their quality labeling.

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Materials and Methods

Seedlots of two major registered commercial hybrid maize cultivars of southwestern Nigeria namely 'Oba Super' produced by Premier Seeds (Nigeria) Ltd. and 'Suwan-1' harvested in 2004 at the seed farm of the Institute of Agricultural Research and Training, Ibadan were used. No previous warehouse storage was done for the seed lots before acquisition.

The seeds were stored in 2 L capacity, air-tight plastic containers conditioned to eight different RH levels (range 10 to 80%; Table 1) inside an incubator set at 33°C with mean inside container temperature of 31±4°C (upper limit 35°C and lower limit 27°C during night and during power outages). The specified RH level in each container was achieved by equilibrating saturated solutions of different salts namely $ZnCl_2$, $CaCl_2$, $Ca(NO_3)_2$, NaBr, NH_4NO_3, NH_4Cl, and KCl. The salts were added to 10 ml of distilled water in glass petri-plates till saturation, i.e., when no more salt grains dissolved. The plates containing the salt slurries were placed at the bottom of each container. Half inch wire gauze (~7.5 cm above the salt slurries) separated the salt and seed compartments. Two replicates of ~500 g each seed lots packed in polyethylene net bags (1-ply thickness) were placed in the seed compartment of each container. A digital thermo-hygrometer (Tfa™ Germany) placed in the seed compartment of each container monitored temperature and RH. Storage lasted for 12 months. Triplicate samples of 100 seeds were drawn from each storage treatment for germination testing in sand culture; and for seed moisture determination by oven-drying (5 g seeds at 130°C for >3 h) at monthly intervals. Initial germination was 100% for 'Oba Super' and 97% for 'Suwan-1' seedlots. Pre-storage seed moisture content of the two seedlots were 8.2 and 10.6% respectively and details on the equilibrium seed moisture content of the two seedlots are presented in Table 1.

Data analysis

The serial seed germination data were analyzed with PROBIT procedure of SAS (2001) to estimate the longevity parameters from the seed viability equation given below.

$$V = Ki - p\ (1/\sigma) \qquad (1)$$

Where V is the probit germination percentage after p days of storage, Ki is a constant equivalent to the probit value

Table 1. Relative humidity attained under different saturated salt solutions in closed containers at 31±4°C and the equilibrium moisture content of maize seeds after 12 months of storage.

Salt	% RH (± S.E.) [1]	Seed kinds	Equilibrium seed moisture % (± S.E.)
Zinc chloride [$ZnCl_2$]	15.6 ± 0.95	'Oba Super'	4.05 ± 0.33
		'Suwan-1'	4.53 ± 0.23
Calcium chloride [$CaCl_2$]	28.7 ± 1.51	'Oba Super'	4.62 ± 0.30
		'Suwan-1'	4.63 ± 0.31
Calcium nitrate [$Ca(NO_3)_2$]	52.5 ± 0.78	'Oba Super'	6.64 ± 0.37
		'Suwan-1'	5.95 ± 0 31
Sodium bromide [NaBr]	56 ± 0.43	'Oba Super'	7.38 ± 0.38
		'Suwan-1'	7.23 ± 0.43
Open	56.5 ± 1.18	'Oba Super'	6.16 ± 0.15
		'Suwan-1'	7.49 ± 1.43
Ammonium nitrate [NH_4NO_3]	60.0 ± 0.72	'Oba Super'	7.5 ± 0.24
		'Suwan-1'	8.46 ± 0.43
Ammonium chloride[NH_4Cl]	75.4 ± 0.62	'Oba Super'	7.50 ± 0.22
		'Suwan-1'	8.84 ± 0.69
Potassium chloride [KCl]	80.5 ± 1.19	'Oba Super'	8.16 ± 0.37
		'Suwan-1'	9.58 ± 0.67

[1]Average of RH (%) from seven hygrometer readings; SE= standard error.

of seed viability before storage, and σ is the standard deviation of the frequency of seed mortality in time (Ellis and Roberts, 1980). The reciprocal of σ (*1/*σ) is the slope of a seed survival curve and an estimate of seed deterioration during storage. The μ of tolerance distribution is equivalent to 0.5 probability or half the viability period (*p50*). Values of *1/*σ, σ, and *p50* were derived for each seed kind under varying RH treatments. Probit analysis also provided goodness-of-fit for survival data under various RH treatments. General Linear Model (GLM) procedure of SAS was used to determine statistically significant differences and optimal seed longevity under simulated tropical temperatures.

Results and Discussion

Both seeds kinds when stored at RH levels below 28% retained germination above 70% (probit 0.52), whereas storage above 60% RH resulted in less than 50% germinability (0 on probit scale) after 12 months (Fig. 1). Linear fits of survival data of the two seed lots to the probit model gave negative slopes under all RH treatments signifying seed deterioration. Under most of the storage treatments, large and significant χ^2 values were obtained for the goodness of fit tests, but the estimates of heterogeneity factor were low *(H<10)* (Table 2). Although significant χ^2 values of the fitted seed survival curves suggest deviations from normal distribution, the low *H* values (<*10*) under various RH conditions signify that such deviations were due to random errors and do not depict a systematic deviation from the model. Tang et al. (1999) confirmed the negative cumulative normal distribution for survival curves for 11 corn seed lots under various constant storage environments based on *H* values.

Estimates of the negative slope of survival data fits (*1/*σ*)*, which correspond to the seed deterioration rates, were significantly high in the seeds equilibrated at 80.5% RH (equilibrium seed MC > 7.5% in Oba and > 8% in Suwan-1). Least estimates of *1/*σ were observed in the seeds stored at 15.6% and 28.7% RH with equilibrium MC below 5% for both seed kinds (Tables 1 and 3). Also, seeds of both lots stored at 15.6 and 28.7% RH had the highest estimates of longevity (σ and *p50*) which were statistically different in comparison to the seeds stored at other RH treatments. Under these drying treatments, estimates of *p50* of 'Oba Super' seedlots were over 600 days and 'Suwan-1' seedlots were over 500 days, which is approximately 10 times greater than the *p50* values of seeds stored at >60 %RH. The absolute seed longevity (*p50x2*) values derived for the seeds stored at 15% RH and ~4% equilibrium MC were 1,084 days for 'Oba Super' and 1,149 days for 'Suwan-1'.

Significant differences in longevity estimates of the two seed kinds with lower RH and equilibrium seed moisture content are consistent with the concept of 'drier-the-better' that underlies ultra-dry seed storage under high temperature conditions (Zheng et al., 1998). The

Table 2. Goodness of fit test statistics for maize seed survival data fits to the probit model (*Eqn. 1*) during storage under various equilibrium relative humidity conditions at 31±4°C in South Western Nigeria.

RH%)	Seed kinds					
	'Oba Super'			'Swan-1'		
	χ^2	$P(\chi^2)$	*H*	χ^2	$P(\chi^2)$	*H*
15.6	40.31	<0.0001	8.06	38.82	<0.0001	7.66
28.7	16.38	<0.011	5.38	38.32	<0.0001	7.66
52.5	25.12	<0.0001	5.02	39.67	<0.0001	7.93
56	18.42	0.0025	3.68	35.67	<0.0001	5.94
56.5	23.88	0.0001	5.97	54.40	<0.0001	7.73
60	28.55	<0.0001	9.51	36.52	<0.0001	7.31
75.4	17.23	0.0006	5.0	29.46	<0.0001	7.37
80.5	31.84	0.0001	31.84	6.29	0.981ns	-

χ^2 = Pearson chi-square estimates, *P* = probability of significant χ^2 at 0.05%, and *H* = heterogeneity factor.

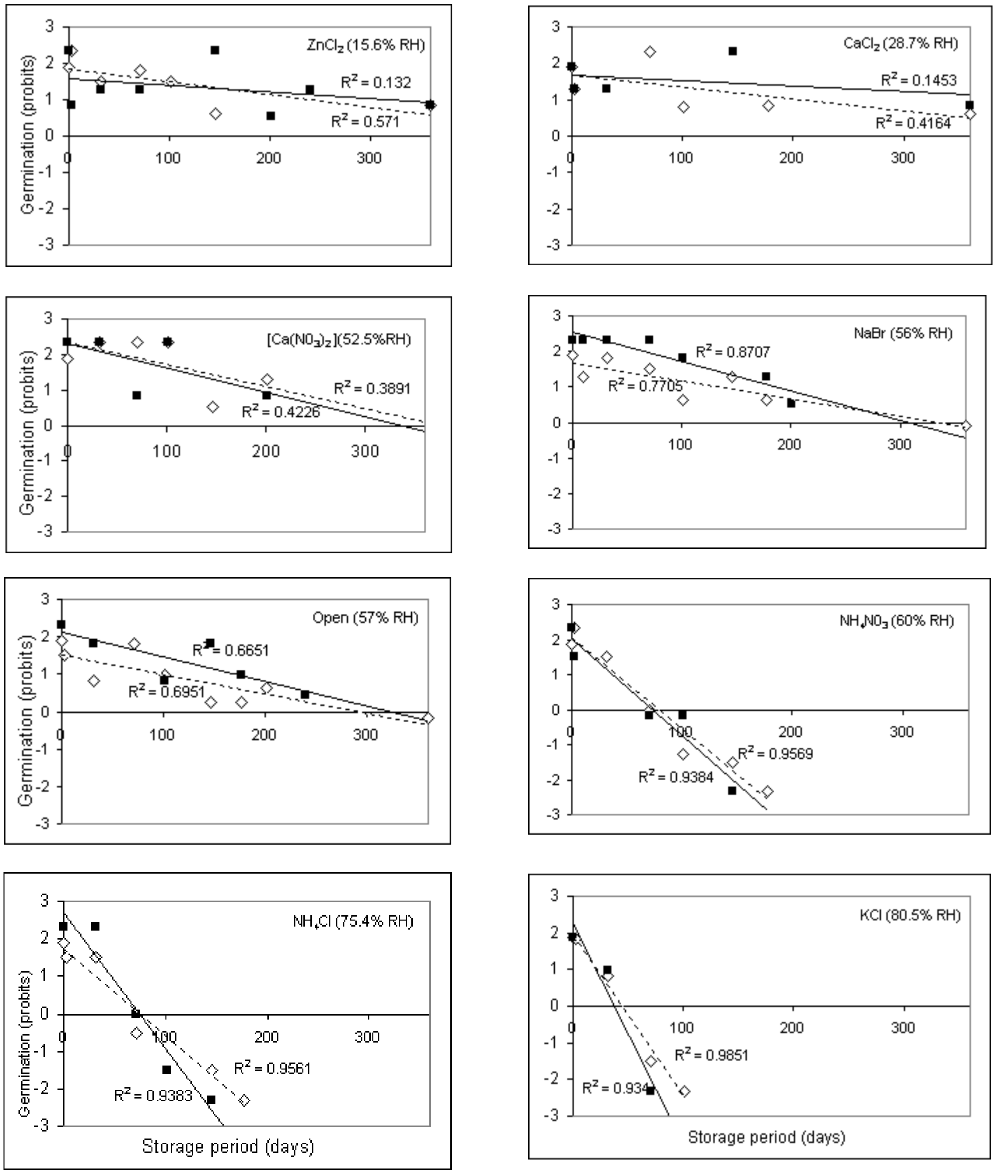

Figure 1. Line fits to scatter plots of germination (probit scale) against time under the various RH treatments at 31±4°C in Southwestern Nigeria; 'Oba Super' (bold lines with solid squares); 'Suwan-1' (dotted lines with hollow squares).

common explanation for enhanced seed longevity of dry seeds at high temperature is the low chemical potential of water in dry seeds that reduces seed damage at higher temperatures compared to seeds with high moisture content where weakly bound water is present (Ellis and Hong, 2006). Vertucci and Roos (1990) reasoned that drying can induce thermo-tolerance and enhance longevity by preventing thermal denaturation of seeds. The higher longevity of drier seeds under ambient tropical temperatures has implications for term defined seed storage in genebank operations. Maximum absolute longevity of ~4 years estimated for dry maize seeds is consistent with the farmers' claims of prolonged seed longevity under low input storage systems (IPGRI, 2004). Although there was significant improvement in seed longevity for dry storage at 15% and 28% RH at ambient

Table 3. Estimates of seed longevity (means of three replicates) parameters based on *Eqn. 1* during storage of two maize seed lots under various relative humidity conditions at 31±4°C in South Western Nigeria.

RH%)	Seed kinds					
	'Oba Super'			'Swan-1'		
	1/σ[1]	σ[2]	*P50*[3] (days)	*1/σ*	σ	*P50* (days)
15.6	0.002	544.17	661.31	0.003	337.85	573.74
28.7	0.0034	361.32	595.83	0.003	301.74	531.16
52.5	0.007	149.05	348.02	0.004	239.9	398.82
56	0.009	116.51	308.84	0.005	218.17	340.31
56.5	0.006	177.82	339.94	0.005	213.58	296.57
60	0.029	37.36	76.58	0.031	33.3	73.09
75.4	0.034	37.14	66.33	0.038	32.95	65.78
80.5	0.066	15.11	42.10	0.056	18.31	43.53
LSD (*0.05 df = 14*)	0.013	205.571	299.1	0.014	65.13	5.38

[1]Slope of probit model and estimate of rate of seed deterioration (1/σ) probit viability loss per day;
[2]Standard deviation of seed death in time representing estimate of time taken to lose 1 probit viability;
[3]Estimate of *μ* of probit model representing time taken to lose 50% viability or the half viability period.

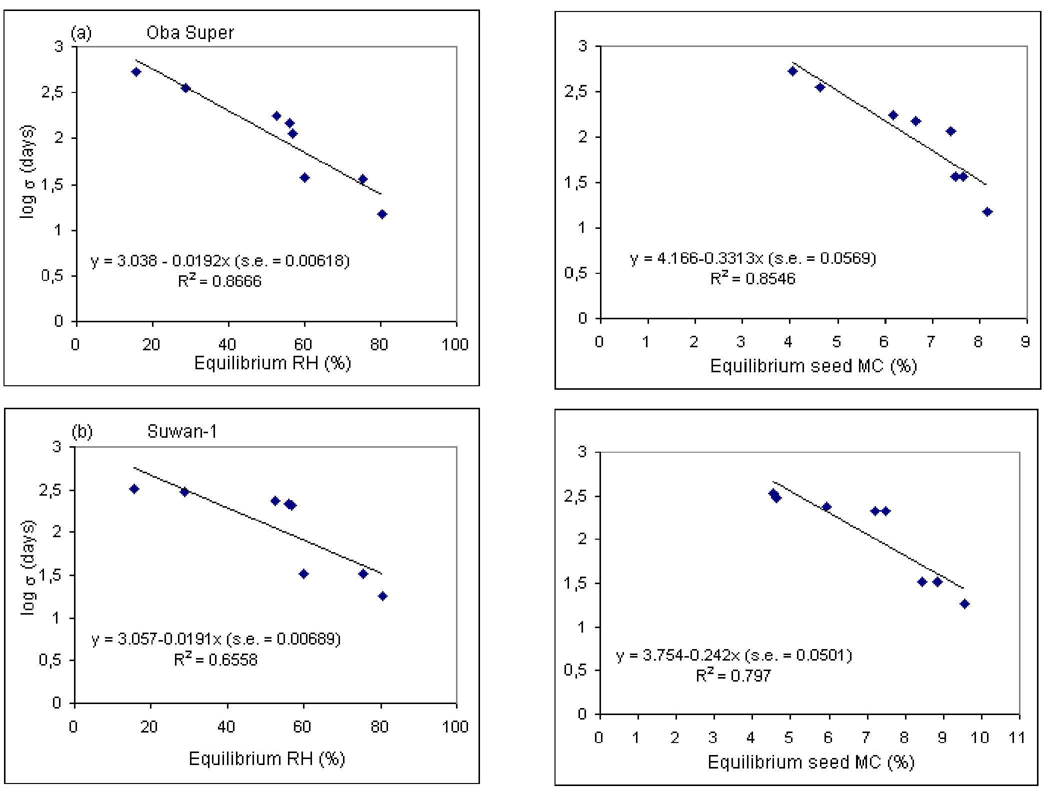

Figure 2. Plots of equilibrium relative humidity (RH) and seed moisture content (MC) against *Ã* (logarithmic scale) for (a) 'Oba Super' seed lot and (b) 'Suwan-1' seed lot at 31±4°C in South Western Nigeria. Estimates of slopes of linear fit to the plots for equilibrium RH and seed MC were insignificantly different between the 2 seed lots showing that, for both seed lots seed equilibration pattern and survival responses to equilibrium RH were similar.

temperatures (~4.5% seed moisture content), it may be suitable only for maintaining seeds over short- to medium-terms by genebank standards (FAO/IPGRI, 1994). The question, therefore, is whether further reduction in RH and equilibrium moisture content of seeds will improve longevity under long-term storage. Critical equilibrium RH and moisture content were apparent from the longevity response data (Table 3; Fig. 2). Longevity of both seedlots significantly increased in response to a reduction in equilibrium RH from 60% to 56%, indicating a critical RH region at which dry storage at ambient temperature began to significantly improve seed longevity (Fig. 2). Also, non-significant differences in longevity estimates of seeds stored under 15% RH and 28% RH indicate that seed longevity increments with dry storage were optimal at 28% RH. Moreover, both seedlots equilibrated to within 4.0 and 4.6% moisture content at 15 and 28% RH levels respectively. This critical low moisture content is the threshold for significant seed life extension, which is temperature-dependent and specific to individual seed types (Ellis and Hong, 2006). Results of this study also indicate an equilibrium moisture content of 4.6% (28% RH at 31±4 °C) as the limit over which maize seed longevity no longer improves significantly with dry storage.

Overall, maize seed survival data at RH ranging from 15 to 80% (31±4°C) fitted well to the probit seed viability model and seed longevity optimized between 15 and 28% equilibrium RH extending the storage life of maize seeds 10 times more than storage at ambient RH. From this trial, 28.7% RH and equilibrium moisture content limits of ~4.6% emerged as optima for extending longevity of maize seeds at 31±4 °C. The results showed potential application of dry storage under the tropical ambient temperatures for maintaining seed longevity up to 4 years in low-input seed storage systems.

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