Storage behaviour of two contrasting upland rice genotypes

R. K. BAM, T. D. HONG, R. H. ELLIS, F. K. KUMAGA, K. OFORI & E. A. ASIEDU
(R. K. B. & E. A. A.: CSIR-Crops Research Institute, P. O. Box 3785, Kumasi, Ghana; F. K. K. & K.O.: Department of Crop Science, University of Ghana, Legon, Ghana; T. D. H. & R. H. E.: Department of Agriculture, The University of Reading, P. O. Box 237, Earley Gate, Reading RG6 6AR, UK)

ABSTRACT

This study investigated complaints by upland rice farmers in Ghana that their local rice cultivar "Kawomo" (*Oryza glaberrima)* stored better than an improved upland rice cultivar, IDSA 85 (*Oryza sativa* subsp. *japonica*), tested and selected in a Participatory Varietal Selection programme. One seed lot of "Kawomo" and two seed lots of IDSA 85, differing in initial quality, were stored hermetically at 50 °C with five (18, 15, 12, 10 and 8%) moisture contents. In the second investigation, seed of "Kawomo" was stored hermetically at the above moisture contents, but at 30 °C. Both investigations were carried out at the Seed Science Laboratory, Department of Agriculture, The University of Reading, UK. In the third investigation, 122 samples of farmer-saved seed were stored hermetically at moisture contents between 12 and 16 per cent under ambient temperature in Ghana for 6 months. Seed moisture content had a significant (P <0.001) effect on the rate of seed deterioration. Although the negative logarithmic relation between longevity and moisture content did not differ significantly (P >0.10) among the two species, glaberrima rice showed marginally greater longevity than japonica rice. The viability equation also accurately predicted germination of farmer-saved seed stored under ambient (fluctuating) temperature in Ghana.

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RÉSUMÉ

BAM, R. K., HONG, T. D., ELLIS, R. H., KUMAGA, F. K., OFORI, K. & ASIEDU, E. A.: *Les comportements contrastés de deux génotypes du riz des hautes terres pendant le stockage.* Les plaintes par les riziculteurs des hautes terres au Ghana que leur cultivar de riz local "Kawomo" (*Oryza glaberrima*) se conserve mieux qu'un cultivar du riz des hautes terres, IDSA 85 (*Oryza sativa* subsp. *japonica*) qui a été testé et sélectionné dans un Programme Participatif de Sélection Variétale, était vérifié. Un lot de graines de "Kawomo" et deux lots de graines de IDSA 85 qui se diffèrent en qualité initiale étaient conservées hermétiquement à 50 °C avec cinq (18,15,12,10 et 8%) teneurs en humidité. Dans la deuxième étude, les graines de "Kawomo" étaient conservées hermétiquement à 30 °C mais avec les teneurs en humidité comme ci-dessus. Les deux études étaient entreprises au Laboratoire de la Science de Graine, Département d'Agriculture, Université de la Lecture, Royaume-Uni. Dans la troisième étude, 122 échantillons des graines mises à côté par le riziculteur étaient conservées hermétiquement avec les teneurs en humidité entre 12 et 16% sous la température ambiante au Ghana pour six mois. La teneur en humidité de graine à eu un effet considérable (P < 0.001) sur le taux de détérioration de graine. Bien que la relation négative logarithmique entre la longévité et la teneur en humidité n'a pas différé considérablement (P > 0.10) parmi les deux espèces, le riz *glaberrima* montrait une longévité qui est légèrement plus grande que celle du riz *japonica*. L'équation de la viabilité aussi a prédit avec justesse la germination de graine mise à côté par les riziculteurs, conservée sous la température ambiante (fluctuante) au Ghana.

Introduction

Rice is an important staple in Ghana and ranks next to maize in importance (Bam *et al*., 1998). About half of the rice area in Ghana is found in upland/hydromorphic ecosystem. However, one of the main constraints facing rice farmers is the lack of improved cultivars adapted to this ecology (Dogbe *et al*., 2002). Most upland rice farmers, therefore, continue to grow low-yielding, traditional *Oryza glaberrima* cultivars or old *O. sativa* or landraces secured from informal sources. A Participatory Rice Varietal Selection (PVS) programme was implemented in the Hohoe District of the Volta Region, Ghana (DfID, 2000,

2004) to offer upland rice farmers the opportunity to identify acceptable new rice cultivars and, thereby, overcome the constraint of growing obsolete cultivars. Farmers identified IDSA 85, an improved upland japonica from the PVS, as a high-yielding medium-duration cultivar, easy to thresh and important cash crop because of its high grain quality and market price (Dogbe *et al*., 2002). This is confirmed by the remarkable spread of the cultivar 3 years after an initial injection of seed for on-farm testing (DfID, 2004).

However, the main source of seed to rice farmers is farmer-saved seed from previous harvests (Marfo *et al*., 2000) because a formal system of rice seed production and distribution is lacking in the country. Farmer-saved seed is stored at high moisture content (between 12.8 and 18.0%) and at high relative humidity and temperatures (Bam *et al*., 2007).

A recent study on farmers' seed production and storage practices in Hohoe, Ghana, indicated that seed of the two most popular and widely grown low-yielding, traditional glaberrimas, "Kawomo" and "Viono", were perceived to store better than IDSA 85 and other PVS varieties (DfID, 2004; Bam *et al.*, 2007). However, IDSA 85 has been officially proposed by the CSIR-Crops Research Institute (CRI) for release. Thus, the major problem to address now is how to manage IDSA 85 and other PVS varieties in storage, given that this trait was among the highest scored for importance, and that the cultivar is so popular among farmers (DfID, 2004). Future adoption and popularity of this variety and other PVS varieties depend on how well seed viability is maintained in storage.

However, seed deterioration or viability loss depends on understanding the quantitative relationships between seed longevity and initial seed quality, seed moisture content and storage temperature. Factors such as genotype, pre-harvest seed production environment, and post-harvest practice have all been reported to affect seed longevity in storage (Ellis & Roberts, 1981; Ellis, Hong & Roberts, 1992; Rao & Jackson, 1996).

The improved seed viability equation developed by Ellis & Roberts (1980) has been widely used to estimate seed longevity in storage:

$$v = K_i - p/10^{K_E - C_W \log_{10} m - C_H t - C_Q t^2} \quad (1)$$

where v is probit percentage viability, p is the storage period in days, m is the moisture content (%, fresh weight basis f.wt), t is the temperature (°C), K_i is the seed lot constant estimated in probits, and K_E, C_W, C_H and C_Q are species constants. The viability equation has two components:

$$v = K_i - p/\sigma \quad (2)$$

and

$$\log_{10} \sigma = K_E - C_W \log_{10} m - C_H t - C_Q t^2 \quad (3)$$

This equation incorporates a negative logarithmic relation between seed moisture content and longevity. At one temperature, this component relation can be written as

$$\log_{10} \sigma = K - C_W \log_{10} m \quad (4)$$

where σ is the standard deviation of the frequency distribution of seed deaths in time (days), and

$$K = K_E - C_H t - C_Q t^2 \quad (5)$$

The objectives of this study were to : (i) investigate whether IDSA 85 and "Kawomo" deteriorated at different rates during storage in identical environments as reported by farmers, (ii) investigate whether the storage characteristics of "Kawomo" are superior in longevity to IDSA 85, and (iii) use results recorded in (i) to predict changes in germination of farmer-saved seed stored under fluctuating temperature and relative humidity. Predicting changes in seed germination under changing environmental conditions would be useful to seed growers in managing their cultivars during storage.

Materials and methods

Two seed lots of japonica rice (*Oryza sativa* L. subsp. *japonica*) cv. IDSA 85 produced in 2003 (lot A) and 2004 (lot B) cropping seasons, and one lot of glaberrima landrace (*Oryza glaberrima* Steud.) cv. Kawomo (lot C) produced in 2004 were received from the CRI, Ghana. At Reading, seeds were re-cleaned using a seed-cleaning equipment, and viability and moisture content were then determined (Table 1).

For each lot, seeds were adjusted to five moisture contents (8, 10, 12, 15 and 18%) either by further drying using silica gel, or by humidification at 20 °C above water. Seeds were then sealed in laminated aluminium foil packets and stored at 4 °C for 1 week for seed moisture content to equilibrate. Seed moisture content was determined on 2 × 5-g milled samples at 130 °C for 2 h (ISTA, 2005). Seed equilibrium relative humidity was also determined at 20 °C using AquaLab CX-2 (Decagon Devices Inc., Pullman, Washington, USA).

In Experiment 1, 10 200-seed subsamples of each seed lot at each moisture content were then sealed in laminated aluminium foil packets (8 cm × 8 cm) and stored in an incubator maintained at 50 ± 1°C. This high storage temperature was chosen to ensure complete seed survival curves at all moisture contents within a comparatively short period (6 months). Temperature was recorded daily at the packet positions using C*hecktemp1* electronic thermometers. The packets were removed at regular intervals ranging from 6 h to 23 days (depending on seed moisture content) for periods up to 153 days for viability determination.

In Experiment 2, seed lot C already conditioned to 8, 10, 12, 15 and 18 per cent moisture contents, were each further divided into five subsamples of 200 seeds sealed in laminated aluminium foil packets and stored in an incubator maintained at 30 ± 1 °C. The packets were removed at 30-day intervals for germination assay.

TABLE 1

Information on Rice Seed Lots Investigated

Species	*Cultivar name*	*Lot*	*Year produced*	*Moisture content (%, f.wt) at receipt*	*1000-grain weight (g)*	*Viability (%) at Reading**	*Type of previous storage*
O. sativa .	IDSA 85	A	2003	13.8	32.7	75	Cold storage
subsp. *japonica*	IDSA 85	B	2004	12.7	32.2	96	Ambient
O. glaberrima	Kawomo	C	2004	12.4	26.9	88	Ambient

* Viability tested at 34 °C/11 °C (16 h/8 h) for 28 d

All samples, together with controls (not stored at 50 or 30 °C) for each moisture content, were then tested for germination between moist rolled paper towels at 34/11 °C (16 h/8 h) for 28 days (Ellis, Hong & Roberts, 1983). The criterion for normal germination was normal seedling development (ISTA, 2005).

Seed survival curves were fitted to the germination test results in accordance with Equation (2), using probit analysis. The probit procedure provided slopes (1/σ) and intercepts (K_i) for each survival curve. The GENSTAT (Genstat, 1997) was used for subsequent regression analyses.

In the third investigation, a survey was used in Ghana between 29 January 2003 and 1 February 2003 to determine the moisture contents at which farmers stored their seed. Seed samples of local and improved cultivars were collected from farmers' stored seed stocks, cleaned and moisture content determined at 105 °C for 24 h on 2 × 2-g subsample of each sample. The samples were stored in airtight plastic containers under ambient conditions at the Seed Science Laboratory at the CRI, Kumasi, Ghana. Temperature and relative humidity were logged throughout the day for the storage period, using Tinytag (Gemini data logger, UK). Mean daily minimum and maximum temperature and relative humidity for the 6-month storage period were recorded. Effective storage temperature was estimated using equations developed by Hung, Hong & Ellis (2001).

A one-time sample was drawn in July (6 months after storage) for germination assay to determine the viability of the seed samples. Samples were taken in July because it was the peak sowing period in the district. Standard germination tests were applied to four replicates of 50 seeds drawn from each sample. The data collected were subjected to regression analyses (Genstat, 1997). Viability at various moisture contents was predicted using the constants K_E and C_W derived from the results of the Experiment 1 (Table 2); C_H and C_Q are species constants with values 0.0329 and 0.000478, respectively, from Dickie *et al*. (1990); and K_i was assumed to be 1.645 (i.e. 95% initial germination) for all samples.

Results and discussion

The relation between the moisture content and the equilibrium relative humidity of three seed lots was sigmoidal (Fig. 1).

Fig. 2 presents the survival data of five survival curves for each seed lot. In accordance with Equation (2), the five survival curves were fitted as negative cumulative normal distribution. Constraining all five survival curves fitted by probit analysis to a common origin within each seed lot provided no significant increase in residual deviance ($P > 0.25$). The values of K_i were 0.677 (s.e.= 0.025), 2.233 (s.e.= 0.041), and 1.862 (s.e.= 0.034), equal to 75.1, 98.7, and 96.9 per cent initial germination for seed lots A, B, and C, respectively.

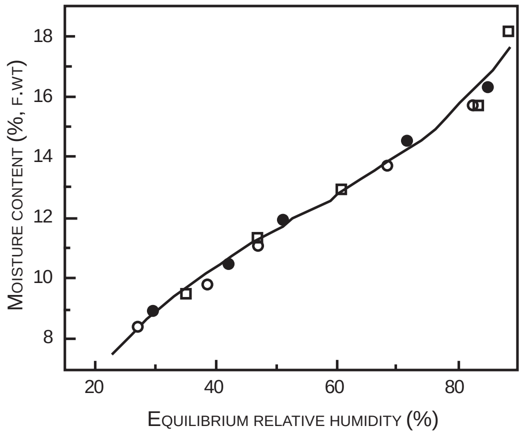

Fig. 1. Relation between moisture content (%, f.wt) and the equilibrium relative humidity (%) at 20 °C of seeds of *Oryza sativa* subsp. *japonica* cv IDSA 85 produced in 2003 (o), or 2004 (•), and *Oryza glaberrima* cv Kawomo (□). The isotherm is described by a cubic model.

Fig. 3 shows the estimates of σ for storage at each moisture content provided by probit analysis. Both axes have logarithmic scales. In accordance with Equation (4), there was a negative logarithmic relation between longevity and moisture content (P< 0.005, 0.01, and 0.05 for lots A, B, and C, respectively) in each seed lot (quantified in Table 2).

Comparison of regressions among the three seed lots showed no significant effect of seed lot on the values of C_w of Equation (4) ($P > 0.10$). Accordingly, the fitted lines drawn have a common slope (Fig. 3). Similarly, within each seed lot of the japonica, there was no significant effect of seed lot on the values of K (P >0.25). A common line was fitted for the japonica (solid line in Fig. 3). Table 2 provides the parameters of the viability equation for the two species.

The results of Experiment 2 showed that viability of glaberrima rice seeds (lot C) stored hermetically at 30 °C was lost completely within

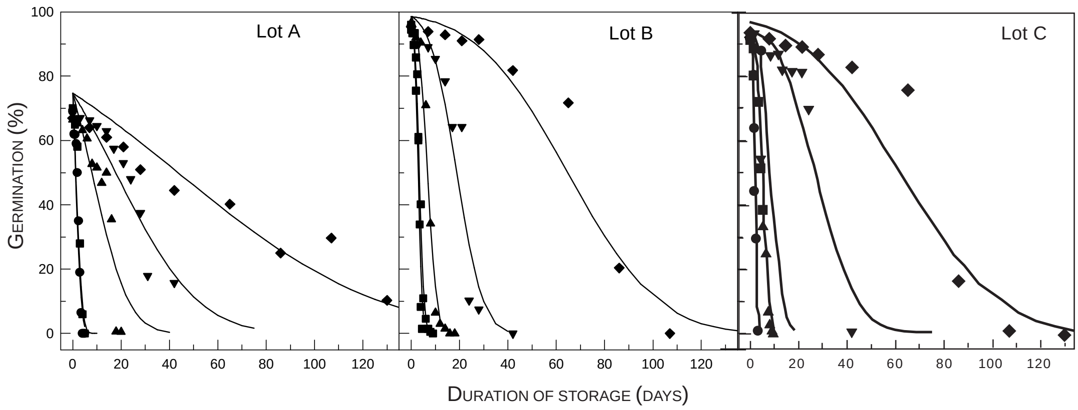

Fig. 2. Survival curves of rice seed lots stored at 50 °C in sealed laminated aluminium foil packets with about 18 (●), 15 (■), 12 (▲), 10 (▼), or 8 % (◆) moisture content (f.wt). Precise moisture content values are shown in Fig. 3. The fitted curves shown are negative cumulative normal distributions fitted to observations by probit analysis in accordance with Equation (2), where the values of K_i are 0.677, 2.2329, and 1.8617 for seed lots A, B, and C, respectively; and the values of ó are shown in Fig. 3.

TABLE 2

Viability Constant Values for Three Seed Lots from Two Contrasting Rice Species

Species	*Lot*	*K (s.e.)*	C_w *(s.e.)*
Oryza sativa	A	6.716 (0.495)	5.51 (0.462)
subsp. *japonica*	B	6.575 (0.462)	5.51 (0.462)
	Common for japonica	6.628 (0.529)	5.51 (0.462)
O. glaberrima	C	6.871 (0.114)	5.51 (0.462)

1 month with 18.2 per cent moisture content, and 5 months with 15.7 per cent moisture content; while 80 and 86 per cent of seeds germinated after 5 months with seeds at 12.9 and 9.5 per cent moisture content, respectively (Fig. 4).

Seeds collected from farmers that were stored hermetically at ambient fluctuating temperatures (Fig. 5) lost viability rapidly or slowly, depending on their moisture contents. Viability was lost rapidly at 16 per cent moisture content, and slowly at lower moisture contents; 60-80 per cent germinated after 6 months' storage at 12.8 per cent moisture content. Except for japonica rice cv. Wab126, glaberrima (cvs "Kawomo", "Viono" and "Wuwulili") survived better in storage than japonica rice (Fig. 6). The seed viability equation of Ellis & Roberts (1980) accurately predicted viability of glaberrima and japonica rice from farmers' stores and stored under ambient temperature for 6 months (Fig. 6).

The isotherms for the three seed lots were similar (Fig. 1). These isotherms suggested that cvs "Kawomo" of *O. glaberrima* and IDSA 85 of *O. japonica* had similar seed composition. This finding is similar to that for the three sub-species *indica*, *japonica* and *javanica* of *Oryza sativa* (Ellis *et al*., 1992).

The results of this investigation confirmed that seeds of glaberrima "Kawomo" were superior to those of japonica IDSA 85 in storage as claimed by farmers. Fig. 6 shows this trend, except for cv. Wab126. Varietal differences in seed longevity have been reported in rice by Ellis *et al*. (1992, 1993) and Rao & Jackson (1996). *Japonica* rice

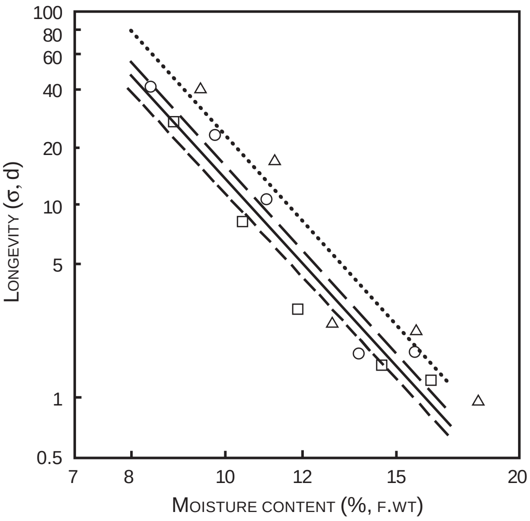

Fig. 3. Relations between seed moisture content (%, f.wt, logarithmic scale) and longevity (*ó*, logarithmic scale) for *japonica* cv. IDSA 85 produced in 2003 (lot A) (——O——), or 2004 (lot B) (——□——), and *glaberrima* (lot C) (···Δ···). The solid line is the fitted relation describing the common relation for two seed lots of IDSA 85 (P>0.25).

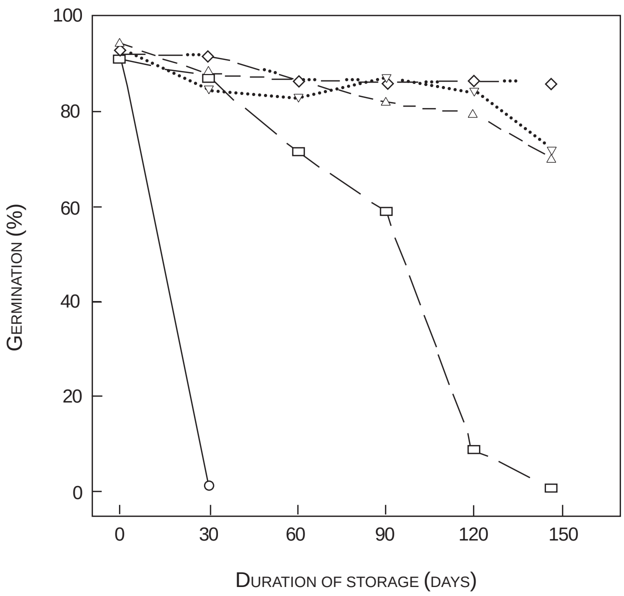

Fig. 4. Changes of viability of *glaberrima* (lot C) during hermetic storage at 30 °C with 18.2 (O), 15.7 (□), 12.9 (Δ), 11.3 (∇), and 9.5% (✧) moisture content.

cultivars have been reported to have poorer longevity characteristics than *indica* or *javanica* cultivars (Ellis *et al*., 1992, 1993). Rao & Jackson (1996) have also reported intrinsically poorer storage characteristics in lowland *japonica*, large-seeded *javanica* cultivars and *O. glaberrima* than in *indica* cultivars.

Rice farmers in the Volta Region of Ghana store their seed for a minimum period of 6 months before the next planting (Bam *et al*., 2007). The above results clearly show that those farmers who stored their seed at high moisture contents (Fig. 4 and 6) and in non-moisture proof materials could lose all their seed by the next planting season. However, if stored at lower moisture contents (e.g. 12%), over 70 per cent of seeds survive 6 months' storage at ambient temperatures (Fig. 6).

It, therefore, suggests that if farmers are able to dry their seed to 12 per cent moisture content and also store the seed in moisture proof materials, they can maintain the viability of their seed to 80 per cent and above for the 6 months. Thus, the assumption of the seed viability model that all seed lots, regardless of genotype or initial quality, deteriorate at the same rate when stored under the same conditions seems to be valid for the rice seed lots evaluated in this study.

In conclusion, the results of this study have shown that IDSA 85 and "Kawomo" deteriorate at the same rate under the same storage conditions, and that IDSA 85 is intrinsically somewhat poorer than "Kawomo". The Ellis-Roberts seed deterioration model accurately predicted germination loss of farmer-saved seed stored under ambient conditions.

It is, therefore, recommended that farmers harvest their seed on time and dry them to safe moisture level, about 12-13 per cent, before storage. Seed should also be stored in sealed containers instead of jute sacks and non-lined polyethylene bags, as is the

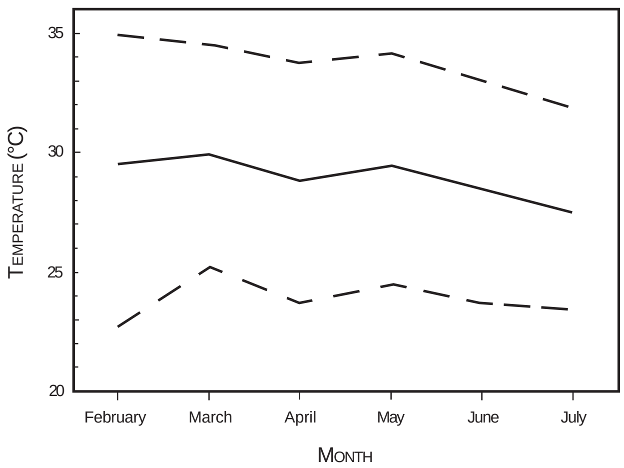

Fig. 5. Minimum and maximum ambient temperatures (lower and upper broken lines) recorded at the Crops Research Institute, Kumasi, Ghana. Effective temperature (solid line) was estimated from minimum and maximum monthly temperatures using equations provided by Hung *et al.* (2001).

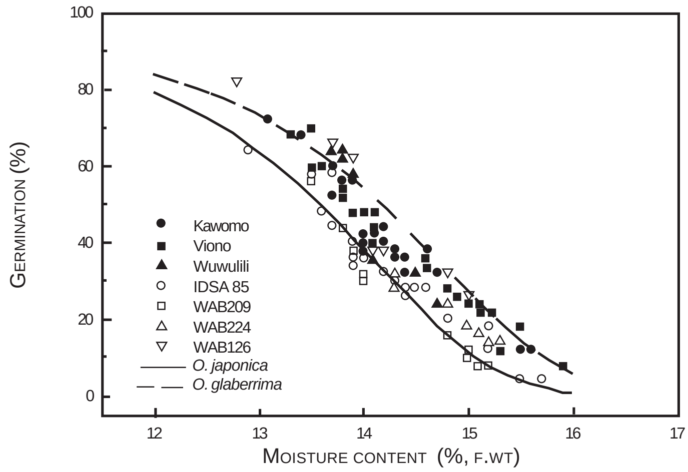

Fig. 6. Relationship between seed storage moisture content and viability after 6 months of hermetic storage. Seeds of 122 lots of seven contrasting cultivars including four *japonica* (open symbols) and three *glaberrima* (solid symbols) cultivars collected from farmers' seed stores were stored in sealed bottles at moisture contents between 12.5 and 16% with ambient temperature at the Crops Research Institute, Kumasi, Ghana. The broken and solid lines provide predicted viability after 6 months' storage at the moisture contents shown for *glaberrima* and *japonica* cultivars, respectively. Loss in viability was calculated at monthly intervals from effective temperature (Fig. 5), with K_i = 1.645 (i.e. initial germination 95%) and the viability constants given in Table 2 for *O. glaberrima* and *O. sativa* ssp. *japonica*, respectively.

practice, to prevent seed moisture content reaching equilibrium with the environment.

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