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INTERACTIVE INFLUENCE OF MATURITY, STORAGE TEMPERATURE AND DURATION ON QUALITY OF MAIZE HYBRID SEEDS

ABSTRACT

Seeds of two single-cross maize hybrids, Ulla and Benicia, harvested at eight stages during seed development and maturation were stored at –20°C and under ambient room temperature. Changes in quality were monitored with standard germination, accelerated ageing and two types of cold tests at three months intervals. The aim of this study was to investigate whether relative differences in quality of the seeds prior to storage were maintained during medium-term storage. Interactions between maturity stage and storage temperature were practically negligible. Ulla seeds were more sensitive to storage temperature and warm seed testing conditions while Benicia seeds were more sensitive to duration of storage and cold testing conditions. Seed dry weight did not play any consistent role and Ulla seeds harvested when seed dry weight was still significantly lower ($P<0.05$) than the maximum had the highest quality. Significant hybrid differences were observed for the stage of maturity when quality was the highest, the range of time during which high quality seeds could be harvested, response to storage conditions and sensitivity to seed quality test conditions. When the need arises, early harvesting of commercial maize seed crop with seed moisture above 40% will not adversely affect storability and vigour.

Key words: genotype, seed dry weight, seed quality, seed testing, storage

INTRODUCTION

Commercial seed production of grain crops is the final and very important step of a long breeding process. Following production, seed storage is inevitable because there is always an intervening period between harvesting and the natural onset of conditions conducive for emergence and subsequent growth. Dry and cool storage conditions are ideal for the storage of desiccation-tolerant seeds for as long as desirable and practicable. But botanical seeds, being biological in nature, undergo genetic, physiological and biochemical changes during storage (Ross, 1982; Priestley, 1986; Bernal-Lugo and Leopold, 1992). And, depending on the conditions and duration of storage, these inevitable changes will affect seed quality, the ultimate manifestation being the failure to germinate and/or produce a normal seed-

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ling (Roberts and Ellis, 1984). This kind of loss of seed quality with time is termed deterioration or ageing (Priestley, 1986; Coolbear, 1995).

The influence of seed maturity on storage longevity is a well-researched branch of seed biology. Among other factors, seed maturity and the pre-storage history of a seed lot such as mother plant environment during growth and development have significant influence on storage quality (Ellis *et al.*, 1993). Attainment of maximum seed dry weight is the commonest measure of maturity (Harrington, 1972; Shephard *et al.*, 1995; Nkang and Umoh, 1996). But many authors have reported that seed dry weight is insufficient to characterize seed quality, including storability (Burris and Bdliya, 1987; Chamma *et al.*, 1990; Shephard *et al.*, 1995; Nkang and Umoh, 1996). It is generally accepted that 'immature seeds' do not store well and therefore deteriorate faster during storage than 'mature seeds' (Priestly, 1986). But Ajayi *et al.* (2005a) reported that maximum levels of storage quality, measured by accelerated ageing test, was attained at least two to six weeks before actual maximum seed dry weight, depending on hybrid and seed production year. However, it is not enough that seeds attain maximum quality at harvest, the potential to maintain this quality must also be present and empirical data on changes in quality during medium-term storage of such seeds are rare. Therefore, it was further investigated how duration and storage condition affected the relative differences between seeds of different maturity status during medium-term storage of maize hybrid seeds.

MATERIALS AND METHODS

Seeds of two single cross hybrids of maize, Ulla and Benicia, were harvested at eight stages during maturation in 2000. Pertinent seed maturity indices are shown in Table 1 and described in detail by Ajayi *et al.* (2005a). All samples were dried at 35-40°C, depending on seed moisture content (SMC) at harvest and the sensitivity of the hybrid to drying injury, to 11.5±0.5% seed moisture, manually shelled and

Table 1

Seed maturity indices

HN	Ulla		Benicia	
	SMC	RSDW	SMC	RSDW
1	60.73a	55.77a	61.07a	35.57a
2	50.86b	74.50b	51.28b	54.36b
3	37.54c	83.61b	43.07c	73.01c
4	35.93c	98.81c	38.04d	87.83de
5	28.23d	99.20c	33.16e	93.68ef
6	18.63e	92.02c	27.16f	99.91f
7	19.32e	90.56c	24.27f	100.00f
8	17.14e	94.51c	19.02g	97.75f

Means with different letters in a column are significantly different at $P<0.05$
HN= Harvest Number, SMC= Seed moisture content (%), RSDW= Relative seed dry weight (% of the final SDW)

cleaned, packed in double-lined polyethylene bags, and stored in a freezer maintained at -20°C and under ambient room conditions (ART) at Parndorf, Austria. Ambient temperature of the storage room at Parndorf was recorded every 30 minutes with a HOBO® H8 Temperature Logger (Onset Computer Corporation, Pocasset, USA). Ambient temperature varied widely, ranging from 3°C during winter to 28°C during summer (Fig. 1).

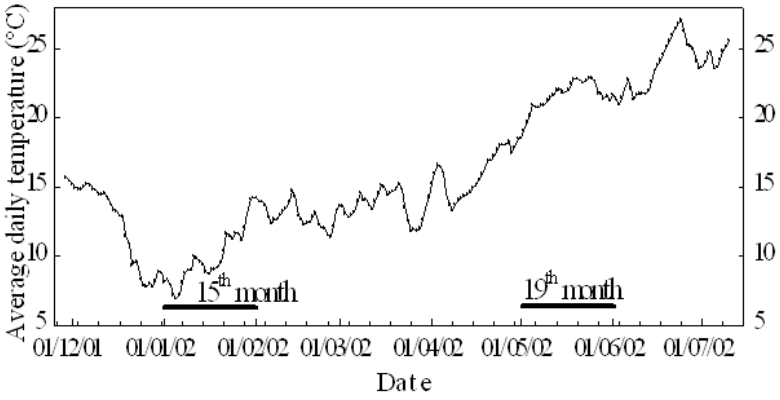

Fig. 1: Changes in ambient room temperature of seed store at Parndorf, Austria.
15^{th} and 19^{th} represent duration of storage of seeds and the time of the year when the seeds were tested

Standard germination test was used to assess viability and germination potential, cold test (both tray and rolled paper towel methods) for physiological quality (vigour) and accelerated ageing test for storage quality (Delouche and Baskin, 1973; Hampton and TeKrony, 1995). These tests were carried out on remnant seed samples before storage and at three to four months intervals over a storage period of 19 months. The procedures used for standard germination, accelerated ageing and rolled-towel cold tests were as described by International Seed Testing Association (1999), Hampton and TeKrony (1995) and tray method cold test as described by Munamava *et al.* (2004).

SAS software version 8.1 (SAS Institute, 1999a, b) was used for the analysis of all the data collected. Analysis of variance was done using General Linear Model (GLM) procedures (SAS Institute, 1999b) to detect differences between treatments. Variations in each dependent variable were partitioned into 2 components: variations attributable to known (experimental factors and their interactions) and unknown (random error) components based on a fixed effects model. Tukey-Kramer's test was used to compare treatment means (SAS Institute, 1999b).

RESULTS

Significant effects ($P<0.05$) due to hybrid, maturity stage at which seeds of each hybrid were harvested, duration of storage prior to seed testing as well as the interaction of stage of harvest with storage duration on the one hand and storage temperature on an-

other were detected for the proportion of normal seedlings recorded in all the four germination-based seed quality tests used (Table 2). Similarly, mean squares due to first order interaction- storage duration by storage temperature and second-order interaction- hybrid by storage duration by storage temperature, were highly significant (P<0.01). The effect of storage temperature per se was significant in all other tests except standard germination test. The R^2 for all the models of analyses of variance were highly significant (P<0.001) and CVs were less than 5.2.

Table 2

Mean squares from analysis of variance for the proportion of normal seedlings

Source of variation	DF	Seed quality tests			
		Standard germination	Accelerated aging	Tray-method cold test	Rolled-towel cold test
Replication	3	1.33	47.24	17.04	46.48*
Hybrid, HB	1	881.94***	2234.51***	2224.28***	2159.15***
Stage(Hybrid), HN	14	12.93***	486.73***	3795.53***	1018.13***
Storage Duration, SDR	5	26.53***	670.87***	1512.39***	466.69***
Storage Temperature, ST	1	2.41	678.76***	1177.61***	85.15*
HB × SDR	5	20.51***	221.57***	235.50***	0.08
HB × ST	1	1.98	584.50***	35.45	43.78***
HN × SDR	70	6.32***	59.26***	85.55***	183.32***
HN × ST	14	6.42**	55.84***	85.81***	29.75*
SDR × ST	5	11.87***	1162.39***	120.15***	86.06***
HB × SDR × ST	5	12.40***	180.57***	90.40***	55.60**
HN × SDR × ST	70	2.85	47.44***	30.17*	20.31
Error		2.51	18.12	21.27	16.19
Overall mean [%]		97.99	91.17	89.08	93.18
C.V.		1.62	4.67	5.18	4.32
R^2 [%]		60.06***	74.21***	86.14***	73.33***

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively

Averaged over harvest numbers and duration of storage, performance of Ulla seeds in tests carried out under warm conditions, namely standard and accelerated ageing germination tests, was significantly lower (P<0.05) compared with performance of Benicia seeds (Table 3). A reverse trend was observed in the two cold tests. Differences between the storage temperatures were significant for all the tests except standard germination test (P>0.05). Seeds stored in freezers had significantly higher mean values than seeds stored under ambient conditions. The magnitude of the overall difference between the two hybrids in accelerated ageing test was greater than the corresponding difference between the storage temperatures.

In both Ulla and Benicia, germination potential of seeds of all HNs over 19 months storage was higher than 95%. In the standard germination test, variabilities associated with seed maturity and storage temperature in Ulla seeds were higher than in Benicia seeds (Figure 2A). Across storage temperature and duration, the performance of Ulla HN3 and 4 seeds in the accelerated ageing test was significantly higher (P<0.05) than that of previous and subsequent harvests. There was a progressive decline in performance of seeds harvested after these stages (Table 2). But in Benicia, performance of

Table 3:

Mean differences in quality test of maize seeds produced in 2000

Factor	Level	Standard germination [%]	Accelerated ageing [%]	Tray-method Cold test [%]	Rolled-towel cold test [%]
Hybrid	Ulla	96.92^{a}	89.47^{a}	90.78^{a}	94.88^{a}
	Benicia	99.06^{b}	92.88^{b}	87.38^{b}	91.52^{b}
Storage temperature	-20°C	98.05^{a}	92.11^{a}	90.32^{a}	93.53^{a}
	ART	97.93^{a}	90.23^{b}	87.84^{b}	92.84^{b}
			Ulla		
Maturity stage	HN1	97.19^{ab}	90.17^{a}	72.77^{a}	82.75^{a}
	HN2	96.60^{bc}	90.00^{a}	94.00^{bc}	97.25^{bc}
	HN3	95.50^{ab}	94.21^{b}	95.27^{b}	97.33^{bc}
	HN4	98.02^{a}	93.25^{b}	94.75^{bc}	98.03^{b}
	HN5	96.92^{abc}	87.79^{ac}	92.83^{cd}	95.92^{bc}
	HN6	96.31^{bc}	87.79^{ac}	92.88^{cd}	95.83^{c}
	HN7	96.92^{abc}	86.79^{cd}	92.54^{cd}	95.83^{c}
	HN8	95.90^{c}	84.75^{d}	91.19^{d}	96.00^{bc}
Storage temperature	-20°C	97.03^{a}	91.28^{a}	91.80^{a}	95.20^{a}
	ART	96.81^{a}	87.66^{b}	89.76^{b}	94.55^{a}
Storage duration	Begin	97.88^{a}	91.13^{a}	91.25^{a}	93.94^{ac}
	3 months	96.61^{b}	91.41^{a}	92.36^{a}	93.53^{ac}
	7 months	96.39^{b}	88.69^{b}	90.78^{a}	96.38^{b}
	11 months	96.14^{b}	87.22^{b}	87.31^{b}	93.06^{a}
	15 months	98.00^{a}	93.81^{c}	88.39^{b}	95.31^{bc}
	19 months	96.50^{b}	84.56^{d}	94.58^{c}	97.03^{b}
			Benicia		
Maturity stage	HN1	98.38^{a}	88.96^{a}	62.88^{a}	83.21^{a}
	HN2	99.29^{b}	89.46^{a}	86.63^{b}	92.42^{b}
	HN3	99.17^{b}	88.83^{a}	94.56^{c}	96.46^{d}
	HN4	99.29^{b}	94.63^{b}	92.33^{cd}	92.54^{b}
	HN5	99.13^{b}	96.38^{b}	89.73^{bd}	88.08^{c}
	HN6	99.02^{b}	95.33^{b}	89.46^{b}	91.38^{b}
	HN7	99.08^{b}	94.46^{b}	91.83^{cd}	92.63^{b}
	HN8	99.17^{b}	95.00^{b}	91.58^{cd}	95.46^{d}
Storage temperature	-20°C	99.08^{a}	92.95^{a}	88.83^{a}	91.86^{a}
	ART	99.06^{a}	92.81^{a}	85.92^{b}	91.18^{a}
Storage duration	Begin	99.31^{a}	95.13^{a}	91.5^{a}	93.25^{a}
	3 months	99.34^{a}	92.47^{b}	91.81^{a}	89.09^{b}
	7 months	99.30^{ab}	90.78^{b}	85.98^{b}	93.03^{a}
	11 months	98.80^{bc}	91.75^{b}	82.97^{c}	87.72^{b}
	15 months	98.92^{abc}	94.75^{a}	81.53^{c}	92.61^{a}
	19 months	98.69^{c}	92.41^{b}	90.45^{a}	93.13^{a}

For each factor, values in a column with different letters are significantly different at $P<0.05$.
ART = Ambient room temperature

HN1-3 was significantly lower (P<0.05) than that of HN4-8. Mean value for Ulla seeds stored at –20°C was higher than that of seeds stored at ART but these differences were not significant (P>0.05) for Benicia seeds. The first significant reduction (P<0.05) in performance in accelerated ageing test was observed seven and three months after storage of Ulla and Benicia seeds, respectively. Despite some interactions between maturity, hybrid and storage temperature, the superior performance of earlier (HN1-4) over latter harvests (HN5-8) in Ulla at different sampling points and, to a large extent, vice versa for Benicia, were noticeable (Figure 2B).

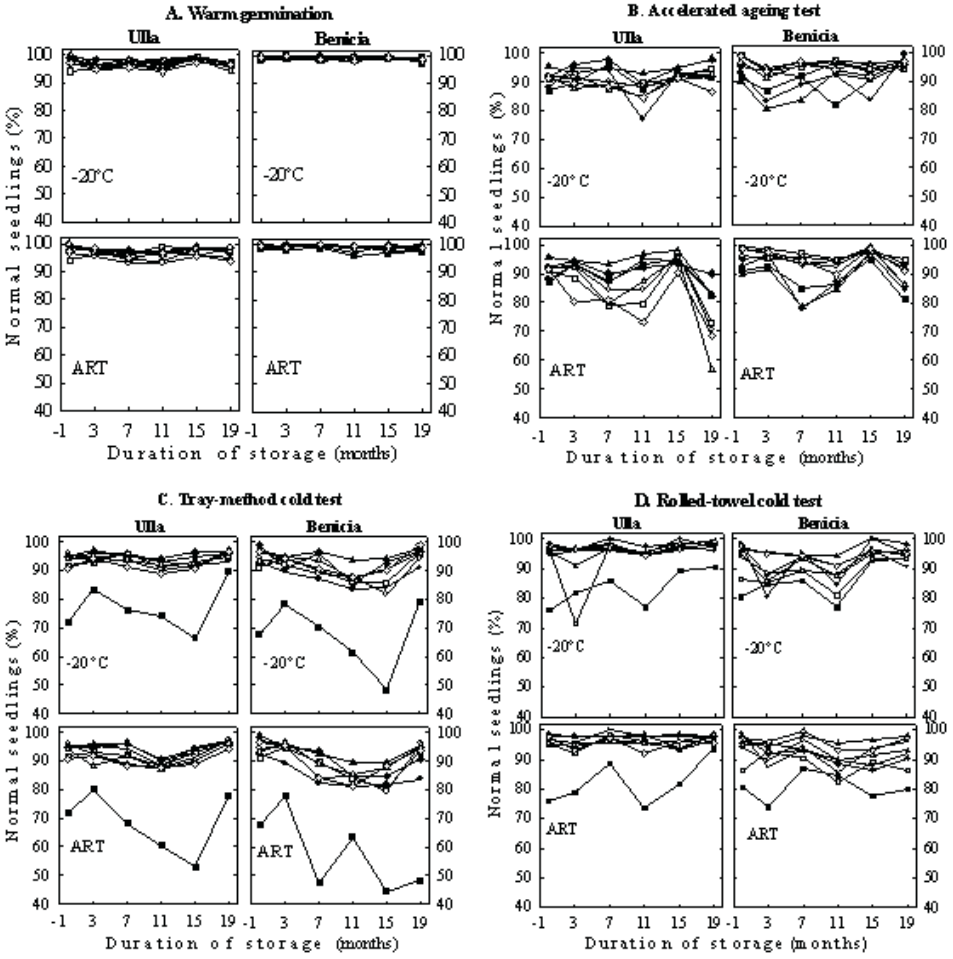

Fig. 1. Changes in quality during storage of seed harvested at different maturity stages (HN)
—■— HN1, —●— HN2 , —▲— HN3, —◆— HN4 , —□— HN5 , —○— HN6 ,
—△— HN7 , —◇— HN8 ART: Ambient room temperature

In many respects both hybrids followed the same trend in the tray method and rolled-towel cold tests for physiological quality (Figures 2C and D). Quality of HN1 was distinctly and significantly lower (P<0.05) compared with all other HNs and HN3s in both hybrids had the highest mean values. But while the first signifi-

cant reduction in quality was observed after 11 months storage of Ulla seeds, it was observed after 7 months storage of Benicia seeds. Physiological quality measured by rolled towel cold test was generally higher than in tray method cold test. As observed in standard germination and accelerated ageing tests, the superiority of HN3 and 4 over other HNs in Ulla was also maintained while the relative differences between Benicia HNs changed with HN3 and 8 having the highest mean values in tray method cold test. In both hybrids, differences as a result of storage temperature were not significant. As noted above, the time to the observation of first significant difference was longer in Ulla than in Benicia. Unlike in standard germination and accelerated ageing tests, variabilities associated with seed maturity at each sampling point were generally lower in Ulla than in Benicia.

DISCUSSION

The factors that induce changes in seed quality during storage can be grouped into two: seed and non-seed or environmental factors. The main seed characteristics that determine storability of seeds are seed moisture, seed maturity and the level of deterioration or damage at the beginning of storage (Delouche and Baskin, 1973; Roberts and Ellis, 1984; Priestley, 1986). In this study, all seed samples were dried to about 11.5% seed moisture content and no significant deviation from this initial seed moisture during storage was observed. Seed damage was minimal because harvesting, shelling, cleaning and sieving were done manually. It is generally agreed that mature seeds are those with the highest dry weight and that they store better (Harrington, 1972; Chin, 1981). On the basis of this general belief, HN1-3 seeds of both hybrids would therefore be considered as immature. But at each time during storage when the seeds were tested as well as averaged over the duration of storage, the overall performance of Ulla HN3 seeds was consistently higher than that of seeds harvested at and after attainment of dry weight. Thus, the association of the physiological status and maturity of a seed with seed dry weight can be misleading if it is broadly applied to all crops and cultivars. This corroborates similar conclusion by Ajayi *et al*. (2001) from investigations with tropical maize cultivars and by Ellis and Pieta Filho (1992) who worked on spring and winter cultivars of barley and wheat. However, unlike the trend in Ulla, the differential performance of Benicia seeds of different maturity in different tests suggests a strong genotypic influence on the relationship between seed dry weight and seed quality. It also implies that there is a risk of bias when a single test is used to assess the relationship between seed maturity and quality. The performance of all HN1 seeds in accelerated ageing and cold tests relative to that of seeds of all other HNs suggests that physiological quality is more dependent on dry weight than storage quality because physiological quality was assessed by germination-based test which in turn is dependent on the amount of stored materials. Furthermore, the development of physiological component is, *sensu stricto*, not dependent on that of storage quality.

The distinct higher overall quality of HN3 and 4 seeds, harvested one week apart, over other HNs in Ulla further suggests that the hybrid has a narrow range of time, about a week, whereas Benicia had a wider time span of more than five weeks when high quality seeds could be harvested. In both hybrids, the range was associated

with the time interval of statistical to actual maximum seed dry weight (Ajayi *et al.*, 2005a), statistical maximum seed dry weight being the dry weight after which further increases were no longer significant. Therefore this interval is likely to be a useful index for assessing varietal differences in the range of time over which high quality maize seeds can be harvested.

In the three seed quality tests, the overall hybrid difference in seed quality was greater than the corresponding differences due to the storage temperatures. The higher sensitivity of Ulla seeds to storage temperature than Benicia seeds and of Benicia seeds to duration of storage than Ulla seeds further underscored the influence of genetic make-up on the relationship between seed maturity and storability thereby making it difficult to have a uniform and consistent answer to the question of how maturity, measured by dry weight, is related to seed quality. A useful indicator or test of quality must provide a fair and unbiased assessment of seed quality (Hampton and TeKrony, 1995). The combined effect of differences between the two cold tests in both duration of exposure to cold temperature and in substrata is in favour of rolled towel cold test as a better estimator of physiological quality than the commonly used tray-method or saturated cold test (Hampton and TeKrony, 1995; Munamava *et al.* (2004) .

Within the limits of the temperature and duration of storage in this study, the overall effect of storage temperature was generally minimal. Under ambient conditions, seed moisture and packaging materials have a significant influence on storability (Chai *et al.*, 1998). The effective barrier to movement of moisture between seeds and storage environment in this study enhanced quality of seeds stored under ambient temperature, thereby minimizing the differences in seed quality between the two environments. Contrariwise, some previous investigators (Khan *et al*., 1993; Abba and Lovato, 1999; Ajayi and Fakorede, 2001) reported significant reduction in maize seed quality after three months storage under ambient conditions. This contradiction is attributable to the differences in seed characteristics and experimental conditions. Whereas seed moisture in this study was maintained at about 11.5%, Khan *et al.* (1993) used maize seeds with moisture ranging from 12 to 18%. While the ambient room conditions in the study by Ajayi and Fakorede (2001) were tropical, ambient room conditions in this study were temperate, incorporating winter seasons when room temperature was close to 0°C.

The above trends reported for the seeds produced in 2000 were also observed on seeds of the two varieties that were produced in 2001 and subjected to the same treatments though the duration of storage was shorter (Ajayi, 2003). In summary, the results of this study clearly show that when the need arises to harvest maize seed crop at seed moistures above 40%, the physiological quality of the seeds will not be significantly affected and this was confirmed in field trials by Ajayi *et al.* (2005b). Multiple tests should be employed when assessing the relationship between maturity and quality of seeds. The preliminary results from these two hybrids suggest that it is impossible to apply to all maize cultivars a single general rule of thumb for the stage of development when it is best to harvest seed crop, the time span during which high seed quality can be harvested, cultivar response to storage conditions and sensitivity to different seed quality tests. However, the relevance and validity of this for maize cultivars that are different in maturity, ecological adaptation and

endosperm types under varying climatic conditions need further investigation using a higher number of cultivars.

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