Investigating the effects of low input drying procedures on maize (*Zea mays* L.), cowpea (*Vigna unguiculata* L.) and bambara groundnut (*Vigna subterranea* (L.) Verdc.) seed quality in Benin

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Summary

Investigating the effects of low input drying procedures on maize (*Zea mays* L.), cowpea (*Vigna unguiculata* L.) and bambara groundnut (*Vigna subterranea* (L.) Verdc.) seed quality in Benin

Four drying regimes (sun, shade, silica gel and conventional drying room) were compared using seeds of *Zea mays* L. (cv. DMR-ESR-W), *Vigna unguiculata* (L.) Walp. (cv. NI 86-650-3) and *Vigna subterranea* (L.) Verdc. (local white variety). The seeds were harvested before mass maturity, at mass maturity and after mass maturity. Moisture contents of seeds were measured on wet basis according to ISTA rules and seed viability was determined through germination tests before and after drying. Silica gel allowed the lowest moisture content to be attained in all three species when seeds were harvested at mass maturity: *Zea mays* (7–5%), *Vigna unguiculata* (3–2%) and *Vigna subterranea* (8%). Sun drying as a low-cost alternative also allowed low moisture contents to be reached: 3.9–7.8% for maize, 3.2–5.1% for cowpea and 8.4–9.6% for bambara groundnut. For all drying regimes, most of the seed samples germinated well, with a mean time to germination between 3 and 5 days for all the crops studied.

Key words: bambara groundnut, Benin, cowpea, low input drying procedure, maize, seed quality, sun drying

Résumé

Etude de l'effet de plusieurs méthodes de séchage sur la qualité de semences de maïs (*Zea mays* L.), niébé (*Vigna unguiculata* L.) et de voandzou (*Vigna subterranea* (L.) Verdc.) au Bénin

Quatre procédures de séchage (silica gel, à l'ombre, au soleil et en chambre froide) des semences de *Zea mays* L. (cv. DMR-ESR-W), de *Vigna unguiculata* L. (cv. NI 86-650-3) (niébé) et d'une variété locale de *Vigna subterranea* (L.) Verdc. (voandzou) ont été comparées. Les semences ont été récoltées à trois stades différents: pré-maturité, maturité et post-maturité. Les teneurs en eau des semences ont été déterminés en suivant les protocoles de l'ISTA sur une base fraîche des semences et leur viabilités sur le taux de germination avant et après le séchage. Le séchage avec du silica gel a permis d'atteindre des teneurs en eau (par rapport à la matière fraîche) les plus bas pour les semences récoltées à maturité : *Zea mays* (7–5%), *Vigna unguiculata* (3–2%) and *Vigna subterranea* (8%). Le séchage au soleil a permis au maïs, au niébé et au voandzou d'atteindre des teneurs en eau de 3,9–7,8%, 3,2–5,1% et 8,4–9,6% respectivement. Les taux de germination étaient élevés pour la plupart des échantillons, avec un temps moyen de germination entre 3 et 5 jours pour toutes les espèces..

Resumen

Investigación del efecto de procedimientos de secado de bajos insumos en la calidad de las semillas de maíz (*Zea mays* L.), caupí (*Vigna unguiculata* L.) y cacahuete bambara (*Vigna subterranea* L.) en Benin

Se compararon cuatro regímenes de secado (sol, sombra, sílice gelatinoso y secadero tradicional) utilizando semillas de *Zea mays* L. (cv. DMR-ESR-W), *Vigna unguiculata* (L.) Walp. (cv. NI 86-650-3) y *Vigna subterranea* (L.) Verdc. (variedad local blanca). Las semillas fueron recogidas antes, en el momento y después de la maduración de la masa. El contenido de humedad de las semillas se midió sobre base húmeda de acuerdo con las regulaciones ISTA, y la viabilidad de las semillas se determinó a través de ensayos de germinación antes y después del secado. La aplicación de sílice gelatinoso permitió alcanzar el más bajo contenido de humedad en las tres especies cuando las semillas se cosecharon en la madurez de la masa: *Zea mays* (7–5%), *Vigna unguiculata* (3–2%) y *Vigna subterranea* (8%). El secado al sol, como opción alternativa más económica, permitió igualmente lograr un bajo contenido de humedad: 3,9–7,8% para el maíz, 3,2–5,1% para el caupí y 8,4–9,6% para el cacahuete bambara. La mayoría de las muestras de semillas germinaron bien con todos los regímenes de secado, siendo el tiempo promedio de germinación entre 3 y 5 días para los cultivos estudiados.

Introduction

The retention of seed viability during storage depends primarily on their water content (FAO/IPGRI 1994). Recently, the importance of other hydric parameters has been recognized. Bound water, activity water, water potential and ice formation have been introduced as factors involved in the mechanisms and kinetics of seed deterioration (Ellis et al. 1989; Leopold and Vertucci 1989; Walters and Engels 1998). A good understanding of the behaviour for these factors helps to improve seed quality during processing and storage. From traditional wisdom and according to many authors, dry seeds for many species have a higher longevity than moist ones, particularly for orthodox seeds. This has been aptly documented. Harrington (1973) has reported that seed longevity is doubled by each 1% reduction in moisture content. Cromarty et al. (1982) and Ellis and Roberts (1991) have emphasized that there is a curvilinear relationship between moisture content and the logarithm of longevity. They have indicated that a 1% decrease in moisture content has a relatively greater effect on longevity at lower moisture contents. The international preferred standard of seed moisture content for long-term storage is 5±2% mc (fresh weight basis) for orthodox seeds (FAO/IPGRI 1994) depending on species.

While a large amount of research has focused on the optimal seed moisture content for storage, relatively less information exists on how to dry seeds (Hu et al. 1998; Kong and Zhang 1998). Ellis and Roberts (1991) recommended a variety of methods for seed drying, such as shade and sun drying, vacuum drying, freeze drying and refrigeration drying with low relative humidity, depending on the species, the initial seed moisture content and the resources available.

In most African countries, particularly in Benin, adequate drying facilities for germplasm storage are not available. The most serious factor adversely affecting seed drying and storage is the unreliability of the main electricity supply, which is often interrupted for long durations. Developing low input drying methods may reduce the dependency on main electricity supply for seed drying. However, the impact of low input methods on seed quality must be evaluated. Another factor that may influence seed storage potential is the maturity stage. Immature seeds are often sensitive to damage from desiccation to very low moisture contents (Ellis and Roberts 1991; Hong and Ellis 1996). Delaying harvest (over-maturity) may also render seeds sensitive to damage from desiccation to very low moisture contents. For example, the harvest of seeds of a *japonica* rice grown in a hot seed production environment resulted in reduced desiccation tolerance, compared with those harvested at mass maturity (Ellis and Hong 1994).

The present experiment investigates the effect of sun, shade and silica gel drying procedures on the quality of *Zea mays* L. (maize), *Vigna unguiculata* (L.) Walp. (cowpea) and *Vigna subterranea* (L.) Verdc. (bambara groundnuts) seeds sampled at three maturity stages. The three drying regimes were compared with the conventional drying at low temperature.

Materials and methods

Study site

The experiment was carried out in 1999 at Niaouli (2°19'E, 6°12'N) in Benin during the dry (August–February) and wet (February–August) seasons. The dry season was characterized by a short rainy season followed by a long dry season with a total rainfall of around 823 mm; the mean temperature was around 29°C and the average relative humidity was about 65%. The total rainfall during the wet season was about 951 mm, while the average temperature and the average relative humidity (RH) were 25.5°C and 85%, respectively.

Table 1. Varieties of the three species used in the experiments

Species	Variety (days to maturity)
Zea mays (maize)	DMR-ESR-W (90 days)
Vigna unguiculata (cowpea)	NI 86-650-3 (60 days)
Vigna subterranea (bambara groundnut)	Local white variety (105–120 days)

Plant material

The same protocol was used during the two seasons. For each species, the same variety was used during both trials (Table 1). Maize and cowpea cultivars were obtained from Niaouli Agricultural Research Centre and are both released varieties. Bambara groundnuts were bought locally at the market.

The seeds were multiplied in order to obtain an adequate amount of seeds for the experiments. The trial was run in three replicate blocks and seeds were harvested per block. The first block was harvested before maturity, the second block at mass maturity and the third block after mass maturity. The maturity stage was defined according to the number of days to maturity of each variety (Table 1), which was provided in the technical leaflet of the released variety. For the local variety of bambara groundnuts, the information was derived from farmers. The pre- and post-maturity stages were then estimated at 54 and 66 days for cowpea (6 days before and after mass maturity respectively), at 76 and 104 days for maize (14 days interval) and at 90 and 120 days for bambara groundnut (15 days interval).

Drying procedure

Shade, sun and silica gel drying were compared with cold room drying. For each species, four random samples of 50 g of seeds were used for each drying treatment. For shade drying, seeds were laid on a black linen sheet and set under shade conditions where the temperature varied between 24 and 27°C and the RH between 60 and 70% during the dry season. In the wet season the same procedures were applied, the variations in temperature were about the same, but RH was 85%.

For sun drying, samples were laid on black linen sheet and set under sunbeams from 10 a.m. to 4 p.m. The temperature varied between 30 and 40°C and the relative humidity was below 40% during the dry season. At night, the seeds were safely kept in a room. In the wet season it is not possible to display seeds for drying every day because of the bad weather conditions. The seeds were then kept inside the room. The temperature was around 26°C and the relative humidity was 85%.

Other samples were put in desiccators that contained self-indicating silica gel (containing cobalt chloride) with a 1:1 (silica gel:seed) ratio by weight. Silica gel was replaced when 70% or less of the gel had changed its colour to pink (Fischler 1993). On this basis, the silica gel was replaced each morning for the first two days, then every 2–3 days during the desiccation process. The temperature in the desiccators was always around 27°C.

In the drying room, samples were put in small open containers. The temperature inside the room was around 10°C and the RH was around 40%. The seed moisture content (MC) was determined gravimetrically and expressed on a fresh weight basis. The dry weight was measured after heating seeds in the oven for 17 h at 103°C according to the International Seed Testing Association rules (ISTA 1993). The weight of all replicates was monitored daily until no further change in weight was observed. The duration (number of days) after which constant weight was attained was recorded.

Seed viability and vigour

Seed viability was determined through germination tests before and after drying at the Niaouli research station laboratory. Seeds were germinated in sterilised sand and kept at ambient temperature (25–27°C). Two replicates of 100 seeds were used in each case. Before the germination test, the seeds were humidified by placing them in a saturated environment for 48 h. The number of germinated seeds was counted every day for 6 days for cowpea, 7 days for maize and 8 days for bambara groundnut. The total germination percentage was calculated accordingly. The mean time of germination (MTG) was calculated to provide a measure of seed vigour following Walters et al. (1998):

$$MTG = \sum(tn) \ / \ \sum n$$

where MTG is the mean germination time and n is the number of seeds germinating at time t.

Seed vigour was also studied by measuring the length of seedlings and seedling dry weight. Seedling mean length was measured using random samples of 60 seedlings from each replicate 6, 7 and 8 days after germination for *V. unguiculata*, *Z. mays* and *V. subterranea*, respectively. The dry matter of these seedlings was measured after a period of 72 h in the oven at 105°C.

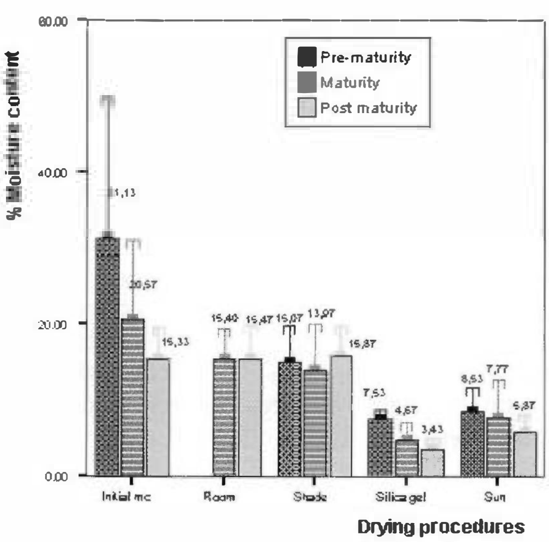

Figure 1. Percentage of moisture content of seeds at different maturity stages before and after drying.

Statistics

The statistic software SPSS (version 10.0) was used to compute the test of analysis of variance (ANOVA) using the general linear model (GLM). The ANOVA test allowed a comparison

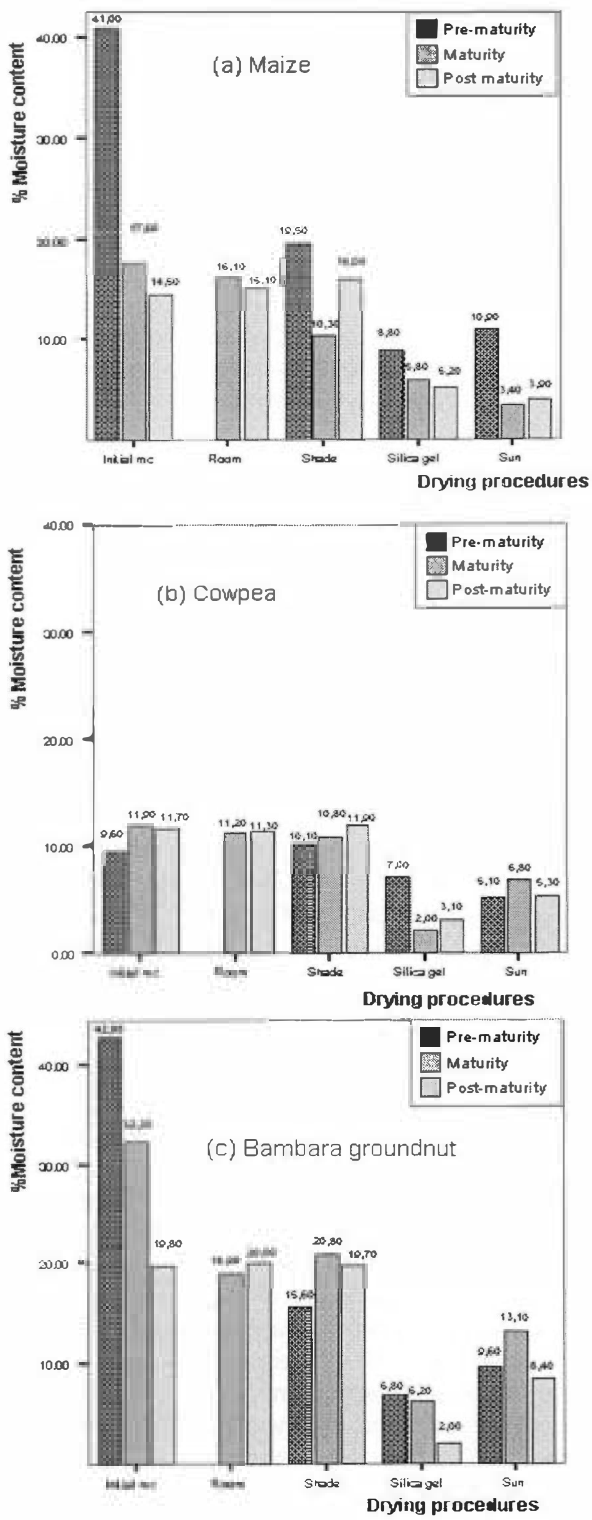

Figure 2. Percentage of moisture content of seeds at different maturity stages before and after drying: (a) maize; (b) cowpea; (c) bambara groundnut.

Table 2. Analysis of variance of moisture content of seeds at different maturity stages using four drying regimes

Source of variation	Sum of square	Degree of freedom	Mean square	Computed F	Significance
Corrected model†	2728.367	16	170.523	6.572	0.00
Intercept	7158.598	1	7158.598	275.877	0.00
Procedure	1737.422	4	434.356	16.739	0.00
Maturity	184.030	2	92.015	3.546	0.044
Variety	488.728	2	244.364	9.417	0.001
Procedure variety	355.034	8	44.379	1.710	0.145
Error	648.713	25	25.949	–	–
Total	10366.300	42	–	–	–
Corrected total	3377.080	41	–	–	–

†R^2=0.808 (adjusted R^2=0.685)

of means and a determination of significant differences. In addition we used the Test of Duncan to compare means two by two and to cluster variables when any least difference can be observed at a 0.05 level of significance.

Results

Although the study was conducted during both the dry and wet seasons, the results obtained on seed viability and vigour were very similar during both seasons, even though drying took a longer time during the wet season because of bad weather conditions. Thus, we only present here the dry season results, but comparisons have been made where relevant.

Seeds moisture content

As expected, the initial seed moisture content (IMC) was generally higher before mass maturity than at and after mass maturity (Figure 1). However, this was true for maize (41.0–14.5%), and bambara groundnut (42.8–19.8%), but not for cowpea (9.6–11.9%), (Figure 2) where immature seeds had a lower IMC than at and after maturity. A plausible explanation for this is discussed later. The MC of seeds, of all three species, after mass maturity did not change noticeably when seeds were dried in the shade or the drying room (F=1.71; d.f.=8; p=0.14, see Table 2).

Drying under shade was comparable with room drying for all materials tested. However, the variation in moisture content increased when seeds were dried in the sun and in desiccators compared with room and shade drying (F=16.73; d.f.=4; $p\leq0.001$). Both sun and silica gel drying allowed drying seeds to lower moisture contents than the other procedures, irrespective of the maturity stage, except for premature sun-dried maize seeds. The difference between sun and silica gel procedures was not significant (F=16.73; d.f.=4; p=0.39) for all varieties combined together. The MC of cowpea seeds reached 2–3% when dried over silica gel, while those of maize and bambara groundnut were dried to 5–7% and 6–8%, respectively. Sun drying also allowed very low MCs to be reached, especially during the dry season, since seed MC decreased to 3–7% in maize, 5–8% in cowpea and 8% in bambara groundnut. The data show that there is an important difference between sun and silica gel drying for cowpea (2–3% and 5–8% MC, respectively), even though the moisture content resulting from both drying methods is around 5±2%. Besides, seeds harvested before mass maturity, when dried under sun and in silica gel, were observed to shrivel.

Figure 3 shows the number of days necessary to reach constant seed weight under the various drying conditions tested. The drying time was found to vary depending on the drying procedure and the seed maturity stage. Seeds harvested before mass maturity generally needed more time to reach constant MC. Desiccation in the drying room led rapidly to constant weight in maize (5 days) and cowpea (5 days) seeds at mass maturity. The results for bambara groundnut were very variable (16–30 days) in every treatment, the time to reach constant weight depending on the maturity stage. The drying patterns for seeds harvested at and after mass maturity were rather similar whatever the drying procedure employed.

Effect of drying procedure on seed viability

The effect of the drying procedure on seed viability was evaluated through germination tests (Figure 4). It was found that drying by any method improved germination of maize and bambara groundnut seeds harvested at any of the maturity stages studied. There was no difference between germination percentages either according to maturity stages (F=0.64; d.f.=2; p=0.53) or according to drying procedures (F=1.9; d.f.=3; p=0.15). However, the initial germination percentages were lower with both maize and bambara groundnut before and at mass maturity (58–70% germination for *Z. mays* and 30–40% in *V. subterranea*) than after drying (F=26.64; d.f.=4; $p\leq0.001$). By contrast, the germination percentage of cowpea seeds gave variable results; sun drying improved seed germination percentages at all maturity stages, in particular when they were harvested prematurely. The reasons for such a situation are discussed later.

Effect of drying procedure on seed vigour

The effect of the drying method on seed vigour was estimated by measuring the average seedling length and dry matter weight per treatment (Figures 5 and 6). According to the results, there was no significant influence of the drying method on seedling growth and dry weight matter (F=1.275; d.f.=3; p=0.304 for seedling length and F=0.675; d.f.=3; p=0.576 for dry weight matter), even if the dry weight of maize seedlings harvested before mass maturity showed reduced growth (Figure 6). Probably, the maize seeds harvested before mass maturity were not capable of producing vigorous seedlings. The mean length of maize seedlings after 7 days for all treatments was between 17.3 and 23.3 cm, whereas that of cowpea (after 6 days) and bambara groundnut (after 8 days) seedlings was between 21.6–26.1 and 16.9–21.5 cm, respectively. The range of dry seedling weight was 0.7–1.8 g for maize; 1.3–1.8 g for cowpea and 1.4–1.9 g for bambara groundnut. For both seedling length and dry weight matter, the differences between species were significant (F=25.492; d.f.=3; p≤0.001 for seedling length and F=3.832; d.f.=3; p=0.035 for dry weight matter).

The mean time for germination (Table 3) also provides a good indication of seed vigour. Fifty percent (50%) of maize seeds germinated in 3–4 days; nearly 100% of cowpea seeds germinated in 3–4 days, whilst 50% of bambara groundnut seeds germinated in 5–6 days, showing that seed vigour was not affected by either the drying method used or the maturity stage (F=0.23; d.f.=2; p=0.79 for the maturity stages and F=0.33; d.f.=3; p=0.8 for the drying procedure). However, there was a significant difference between species (F=35.84; d.f.=3; p≤0.001).

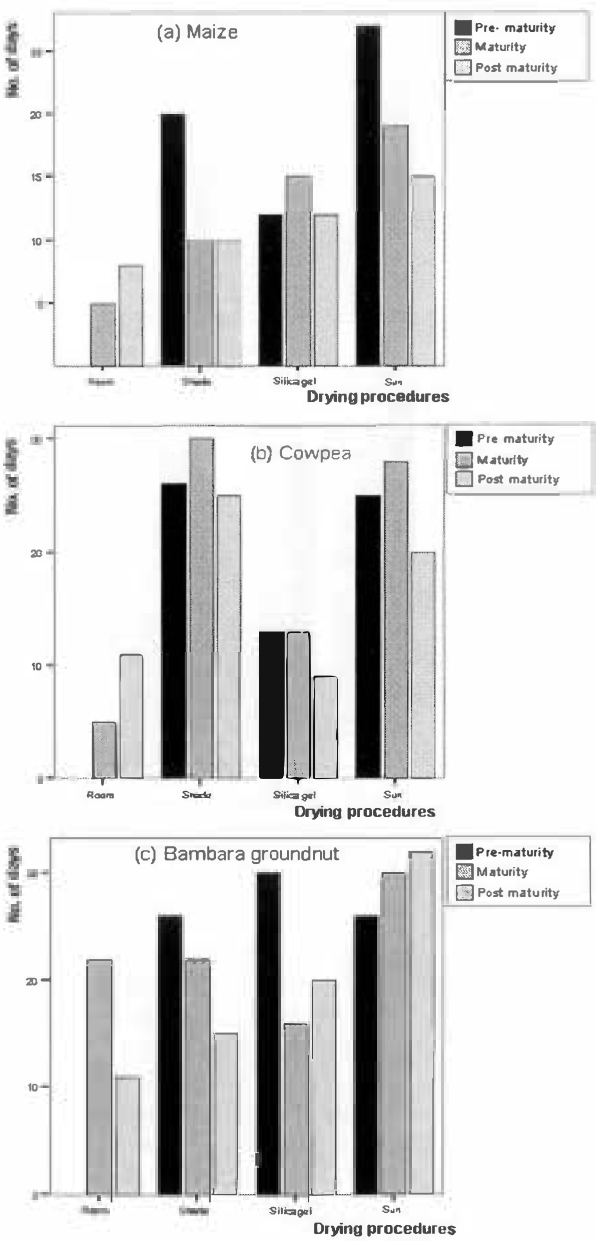

Figure 3. Number of days after which seed weight became constant: (a) maize; (b) cowpea; (c) bambara groundnut.

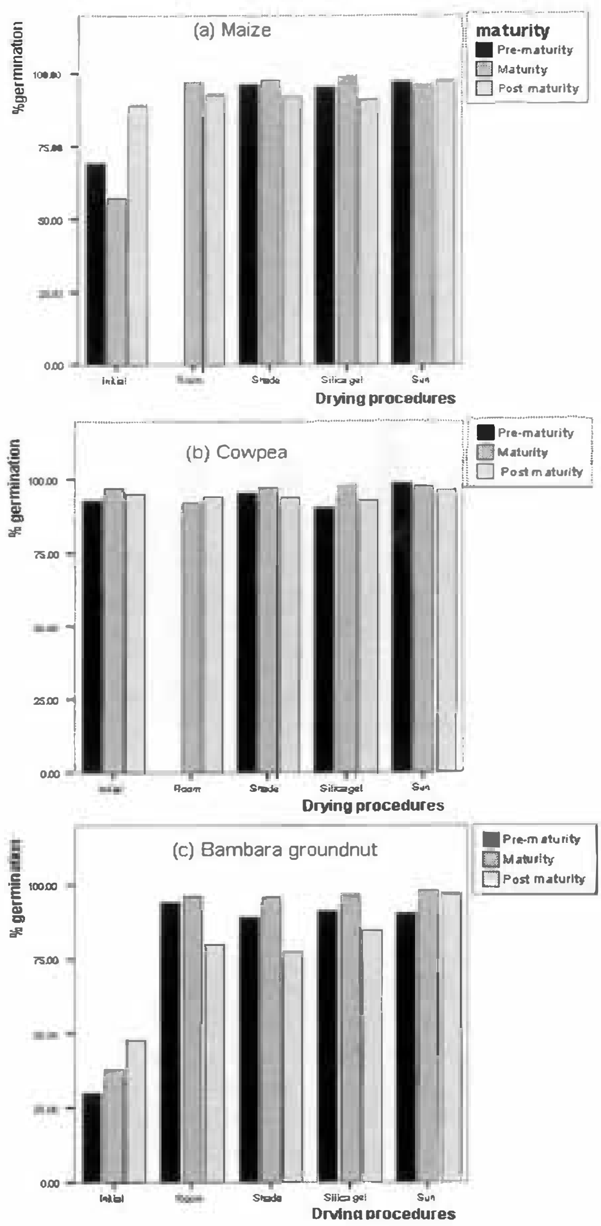

Figure 4. Percentage of germination before and after drying using four drying procedures: (a) maize; (b) cowpea; (c) bambara groundnut.

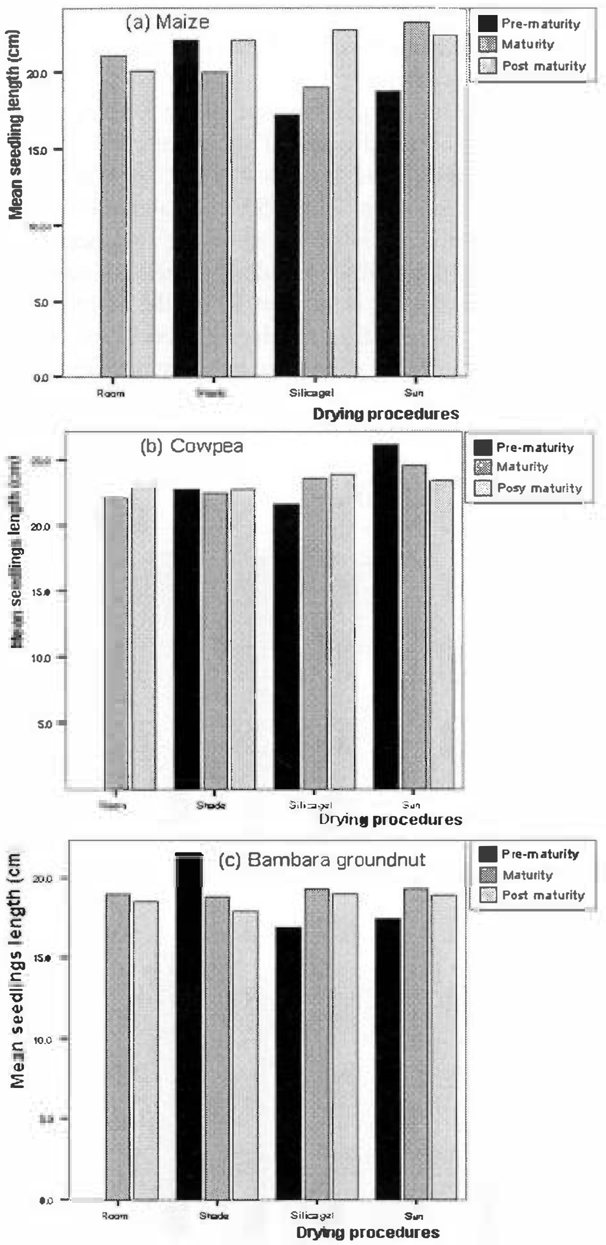

Figure 5. Effect of drying procedures on seedling mean length (cm) at three maturity stages: (a) maize; (b) cowpea; (c) bambara groundnut.

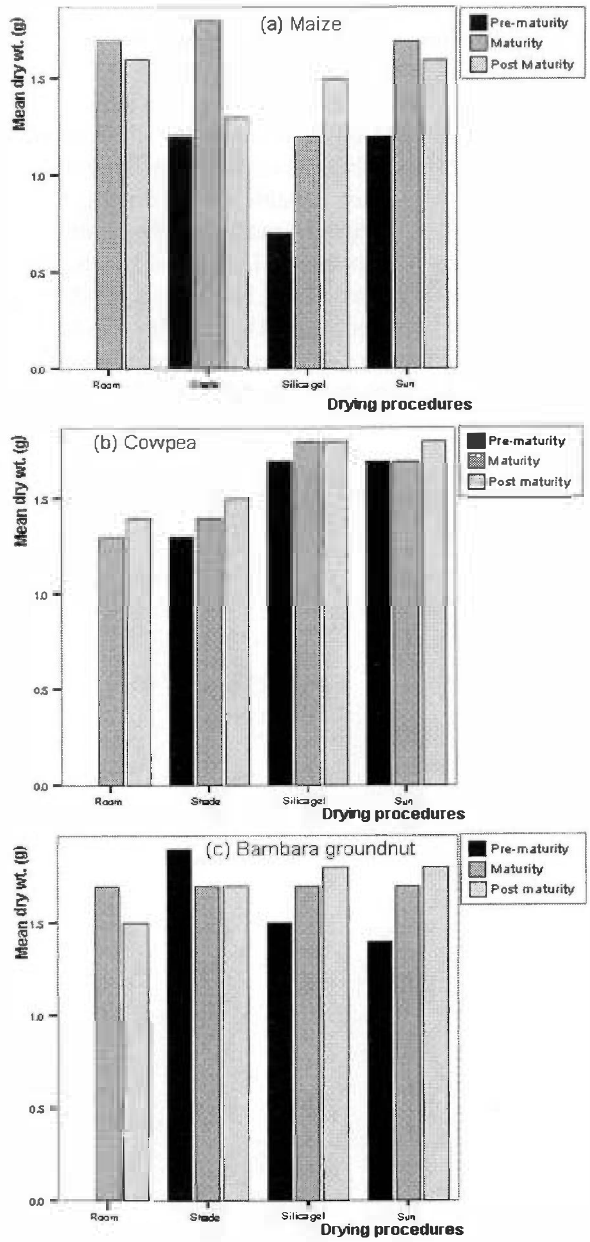

Figure 6. Effect of drying procedures on seedling dry matter weight (g) at three maturity stages: (a) maize; (b) cowpea; (c) bambara groundnut.

Discussion

The impact of the time at which seeds are harvested on seed quality is a controversial subject (Probert and Hay 1999). Harrington (1972) argued that the maximum seed viability and vigour are attained at mass maturity, whilst many other authors have shown that seed quality continues to increase during the post-abscission phase (Hay and Probert 1995; Kameswara Rao et al. 1991; Pieta Filho and Ellis 1991). Monitoring the moisture content and dry weight of seeds during their development can often be useful in helping to decide when to harvest seeds (Hong and Ellis 1996). These authors also indicate that immature seeds, with MCs above 40–60%, may be very sensitive to damage, even though the mature seeds show orthodox behaviour. Delay in harvest beyond mass maturity may also render seeds sensitive to damage from desiccation to very low moisture content (Ellis and Hong 1994). In the present study, the initial moisture content of seeds before mass maturity was found to be variable (9.6–13.3% in cowpea, 41.0–49.0% in maize, 30.1–42.8% in bambara groundnut). The result of the low initial moisture content before mass maturity obtained for cowpea is rather uncharacteristic for a non-oily crop. This may be due to a too short period (i.e. 6 days) considered in this study between the three maturity stages for cowpea, which would explain

Table 3. Mean time to germination (days) for maize, cowpea and bambara groundnut seeds at different maturity stages after drying using various procedures

Maturity stage	Drying regime	Maize (DMR-ESR-W)	Cowpea (NI 86-650-3)	Bambara groundnut (local white variety)
Before mass maturity	Sun	3.7±0.61	4.0±0.50	7.0±0.21
	Shade	4.7±0.40	3.5±0.50	6.5±0.20
	Silica gel	4.8±0.39	4.6±0.23	6.8±0.19
At mass maturity	Sun	4.0±0.42	5.0±0.91	4.6±1.01
	Shade	4.7±0.38	3.5±1.00	7.0±0.99
	Room	4.8±0.37	3.6±1.10	6.2±1.10
	Silica gel	4.1±0.42	5.2±1.00	5.4±0.89
After mass maturity	Sun	4.1±0.35	4.0±0.61	7.0±0.31
	Shade	4.8±0.32	3.5±0.59	6.4±0.35
	Room	4.5±0.37	3.6±0.63	6.3±0.34
	Silica gel	4.1±0.33	4.9±0.55	6.2±0.23

why cowpea seeds did not show any difference in their initial moisture content when harvested at different times.

Maize and bambara groundnut seeds, when dried in the sun or over silica gel, shrivelled but did not lose their viability; this indicates that there was no damage caused to the seeds. Although some differences were observed in the drying behaviour of seeds of the three species between the different maturity stages, there is not enough evidence here to draw any generalizable conclusions.

The comparison between the four drying procedures employed showed that shade and room drying did not allow seeds to desiccate to low MCs, since MCs of 16–20% for maize, 10–11% for cowpea and 18–20% for bambara groundnut were reached. During the course of this study, the drying room was not functioning properly and the high RH (40–60%) inside the room resulted in a higher seed MC in comparison with drying under shade. Had RH been maintained at a lower level (10–15%), one would have expected that a more effective drying could have been achieved. Silica gel drying was the most effective method as it allowed seeds to be dried to very low moisture contents (3–8%).

Drying seeds under ambient RH and temperature is a common practice in many countries for small-scale seed drying (Probert and Hay 1999), but the results obtained depend mainly on the season, location and species (Hong and Ellis 1996). The present study was carried out during both the dry and wet seasons in Benin, but the results obtained were very similar during both seasons. It is known that traditional drying methods often do not allow the water content of seeds to reduce sufficiently to ensure long-term storage (Justice and Bass 1978). It has been shown in the present study that sun drying allowed low seed MCs to be achieved that are comparable with silica gel drying. The high germination percentage and vigour of the dried seeds indicate that sun drying did not affect initial seed quality. However, more trials are required to demonstrate the effect of sun drying on seed quality.

Silica gel drying using a 1:1 ratio (silica gel:seed) gave the highest drying rate, compared with other drying methods, and allowed the lowest MCs to be achieved for seeds of all species tested at all maturity stages. This is consistent with other seed drying studies carried out using silica gel. Kong and Zhang (1998) dried asparagus bean (*Vigna unguiculata* Walp ssp. *sesquipedalis* L.) seeds from 12 to 4% using silica gel using a ratio of 4:1 gel:seed. Seeds of two bean cultivars were dried for 50 days with silica gel in desiccators using a gel:seed ratio of 1:2 (Fischler 1993). The same ratio was used by Zhang and Tao (1989) when drying bean seeds from 14 to 5% MC for 30–34 days. By using a higher silica gel to seed ratio, the frequent renewal of silica gel is reduced. Although silica gel is a very effective desiccant for drying seeds to very low MCs, many authors have argued that the cost and labour involved in the daily regeneration of silica gel makes it a less practical method, as compared with oven drying or freeze drying (Hong and Ellis 1996; Kong and Zhang 1998). However, in situations where the supply of electricity is a problem, silica gel may be a viable option.

The results obtained in this study have shown that all the drying methods used improved germination after harvest of seeds at different maturity stages. The drying regimes did not reduce either seed viability or seed vigour. Several studies have shown that desiccation tolerance is improved by slow drying or delayed drying (Hong and Ellis 1997; Hay and Probert 1995). It could be argued that the slow drying process, characteristic of these low cost drying methods, allows seeds to continue to mature after the crop is harvested. In the case of maize and bambara groundnut, the low initial germination percentages could be attributed to an innate dormancy that was subsequently lost after drying (Ellis et al. 1985). Ellis et al. (1983) also demonstrated that germination of *Oryza glaberrima* Steud. seeds was improved after drying and attributed this to after-ripening. The results of the present study also showed that none of the drying methods used adversely affected seed vigour. These observations were consistent for all methods and maturity stages investigated.

Although the drying method did not appear to have any adverse effect on seed quality, as measured by seedling growth and mean time to germination, the impact of the drying method on medium- and long-term seed storage remains to be studied. The present study has shown that sun and silica gel drying gave better results when compared with shade and room drying procedures in achieving low MC in maize, cowpea and bambara groundnut seeds under the conditions available at the experimental sites. It is fair to say that the drying methods and conditions used in the present study are not expected to show any immediate effects on seed quality. From the germplasm conservation perspective, the long-term impact on seed longevity still needs to be clarified. This was beyond the scope of the present work. However, the results obtained here are of value for short-term storage, including farm-saved seeds.

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