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Full Length Research Paper

Effects of low cost drying methods on seed quality of *Sorghum bicolor* (L.) Monech

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The effect of low cost drying methods on the seed quality of different genotypes of sorghum was investigated. Fresh seeds from five genotypes were subjected to three drying regimes, namely sun, shade and silica gel, and were compared to the standard recommended drying condition using a seed dryer (Munter seed dryer Model M120) as control. The effects of the drying regimes on seed moisture content, viability and quality were studied. All the drying methods were able to dry seeds to safe seed moisture contents levels (range of 5.6 - 7.5%) for conservation. None of the alternative drying methods examined proved to be better than drying in a seed dryer. Seeds dried with the seed dryer gave the highest germination percentage compared to those dried using silica gel, or under shade and sun. However, this study indicates that drying with silica gel and shade are good alternative methods. Sun drying is quicker, but is harmful to the seeds and affects long-term seed viability.

Key words: Genebank, low cost drying, sorghum, seed storage, Sudan.

INTRODUCTION

It is well known that the most important factors influencing seed longevity are temperature, seed moisture content and relative humidity (Ellis and Roberts, 1980; Dickie et al., 1990). It is also recognized that the extent to which potential longevity of a seed is maximised depends on the storage condition as well as on its initial quality (Roberts, 1992). Seeds are generally harvested at high moisture content and need to be dried before storage, and to do this, attention should be paid to the rate and extent of artificial post-harvest drying. If drying is too slow, there is a possibilty of reduction in seed quality during the drying process due to seed aging. On the other hand, if seeds are dried rapidly, a large proportion may be lost due to desiccation damage (Ellis and Roberts, 1980) . There is no fixed rule that applies to all species. Delay in drying or slow drying together with high temperature (above 25°C) will tend to reduce viability considerably in orthodox seeds.

The recommended methods for safely drying seeds of germplasm collections to very low moisture content using seed drying facilities, such as seed drying chambers, seed dryers, where the relative humidtiy of the drying environment is controlled (Ellis et al., 1985), may not be easily implemented in many developing countries due to the high cost of establishing, running and maintaining such facilities. Therefore, there is a need for low cost drying methods to be used as alternatives to such expensive seed drying equipment in genebanks within those countries. Ellis and Roberts (1991) recommended a variety of methods for seed drying such as shade, sun, vacuum, freeze and refrigeration drying with low relative humidity depending on species, the initial seed moisture content and the resources available. Several studies have demonstrated the potential of these low cost methods in reducing the seed moisture content to an acceptable levels for long term storage (Vodouhe et al., 2008; Probert, 2003), but their impacts on seed quality has not been adequately studied. In a study on wild shrub, *Millettia leucantha* Vatke, endemic to east Africa, Muthoka (2003) showed that neither sun nor shade drying were detrimental to seed quality. In crop plants various desiccants have been used to dry seeds (Probert, 2003).

Sorghum bicolor (L.) Moench is a a major staple crop in sub-Saharan Africa, where it had orignated and was

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domesticated (De Wet and Harlan, 1971). Its primary centre of origin is located in north east Africa and has spread to other continents (Asia, Australia and America). India and China are considered as secondary centres of diversity. It is now considered to be one of the five top cereal crops and is an important part of the diets of many people in the world, it is also used as animal feed and a range of other products. Because it is such an important crop for food and agriculture, its diversity in genebank collections needs to be effectively conserved. A global strategy for sorghum developed with support from Global Crop Diversity Trust (GCDT) (GCDT, 2007) has identifed the major collections of sorghum in the world. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (India), and United States Department of Agriculture, Agricultural Research Service (USDA-ARS) collection in USA, hold the highest number of accessions, but the strategy also recognises other key collections in Asia, America and Africa including India, China, Brazil, Ethiopia, Russia, Australia, Zimbabwe, and Sudan (GCDT, 2007).

The objective of this study was to investigate the effect of sun, shade and silica gel as alternative drying procedures on seed quality of different sorghum genotypes (accessions) compared to the recommended drying procedure at low temperature and relative humidity using a conventional seed dryer.

MATERIALS AND METHODS

The study was carried out during the period 2000 - 2002 at the Plant Genetic Resources Unit of Agricultural Research Corporation (PGR/ARC) of Sudan. Five genotypes were used in this study including four accessions of Sudanese origin and one improved cultivar. The Sudanese sorghum accessions were PI 570120, PI 570300, PI 570342 and PI 570356 representing four sorghum groups, namely Kafir, Milo, Feterita and Hegari, respectively, while the improved cultivar was Tabat, a variety officially released by ARC in the early nineties. Seeds of these accessions were obtained from genebank of the PGR/ARC and the Sorghum Research Programme of Agricultural Research Corporation.

The accessions used in this study were first multiplied to bulk up the numbers of seeds in order to obtain adequate amounts for the study. Sowing was carried out in a sub-plot of five rows on ridges 3 m long at spacing of 0.8 m between rows and 0.3 m within rows. One hunderd and fifty plants were established from each lot per sub-plot at the rate of three plants per hole. The multiplication process was conducted in the Farm of the Gezira Agricultural Research Station in Wad Medani, Sudan, which lies at latitude of 14°24` N., longitude of 33° 29` E and altitude of 406.9 m above sea level (ASL). The climate of the area is hot semi-arid, the soil is vertisol with clay content (40 - 65%), pH value ranging from 8 to 9.6, less than 1% organic carbon, 300 ppm total nitrogen and 406 - 700 ppm total phosphorus (Ishag and Said, 1985). Cultural practices including irrigation, nitrogen fertilization and weeding which followed the current practices at PGR/ARC for sorghum (Elash Abdelhi Elash, pers.com). The newly harvested seeds were then used for moisture content determination, viability testing, drying and storage. Seed moisture content and viability levels were assessed both before and after drying. Seed testing, drying and storage were undertaken in the laboratory of the PGR/ARC using the procedures as thus described.

Determination of seed moisture content

Moisture content of seeds was determined twice; immediately after harvesting and after drying to a constant weight. The moisture content was determined using high constant oven drying method, as recommended by Rao et al. (2006). Two replicate samples of ground seeds, five grams each, were dried at 130 -133°C for 2 h. Seed Moisture Content (SMC) was then calculated (using the mean of the two replicates) on fresh weight basis using the following formula:

SMC = (Weight of fresh seeds – Weight of dry seeds) × 100% / Weight of fresh seeds

Drying procedures

After harvest, the seed samples from different genotypes were sub-divided into four groups for drying, using four different drying regimes, namely: Sun, shade, silica gel and a seed dryer. Seed samples to be dried under sun and shade were spread evenly in a monolayer on mesh sieves, held above ground level. The sieves were placed in a bird-and rodent-proof structure, made up of wooden framework covered by a fine mesh wire netting, which would prevent the entry of these pests, while at the same time allowing free air movement. The mean ambient temperature over the drying period was 26°C with a range of 17 - 35°C and the mean Relative Humidity (RH) was 43%. The sun dried seed samples were kept under direct sun light for six hours each day, while shade dried samples were placed in a ventilated room with an ambient temperature of 22°C and similar RH as aforementioned. Changes in seed weight were monitored every 7 - 10 days until it reaches a constant weights. Each sun and shade dried sample was then packaged hermetically, sealed into a laminated aluminium foil packet of the type used in the long term storage of seeds at sub-zero temperature in the genebank provided by International Plant Genetic Resources Institute (now Bioversity International) and stored in a room at temperature ranging between 20 and 25°C .

Seed samples to be dried over silica gel were put inside porous cloth bags. They were placed over activated silica gel inside dessicators at the ratio of 2:1 (seeds : silica gel), and left inside a room at temperature ranging between 20 and 25°C. The silica gel was activated by heating an oven whenever the need arose. As a control treatment, seed samples were also dried using a Munters Rotaire M120 Dehumidifier and Refrigeration Packaged Seed Dryer, Serial Number F3/662 (from Munters Rotaire, England) adjusted at about 20°C and 15% relative humidity. Seed samples were spread evenly in a monolayer on mesh sieves and placed inside the seed dryer. Seed moisture contents of those samples dried over silica gel or inside the seed dryer were monitored regularly at 7 - 10 days intervals until reaching constant weights, then the samples were packaged hermetically in sealed laminated aluminum foil packets and stored in a room at temperature ranging between 20 and 25°C.

Ageing assessment

After drying, the different seed lots were subjected to accelerated ageing, based on methods described by Agrawal (1986) and Delouche and Baskin (1973) . A sample of four hundered seeds from each drying treatment was placed in small mesh containers supported above the water inside a tightly closed plastic pot in order to maintain a high relative humidity of about 100%. The whole pot was then placed into an oven adjusted at a temperature of 43°C for four days. At the end of the ageing period, the seeds were removed and immediately assessed for viability and vigour.

Table 1. Mean percentage seed moisture contents (SMC %) (means of 2 replicates) of different Sorghum genotypes before and after drying. SDr = Seed dryer; SH= Shade drying; SG= Silica Gel; SN= Sun drying.

Before drying		After drying					
		Drying method					
Genotypes		**SDr**	**SH**	**SG**	**SN**	**mean**	**SD**
PI 570120	20.97	7.52	6.84	6.27	5.81	6.61	0.739
PI 570300	18.65	7.29	6.5	6.1	5.64	6.38	0.7
PI 570342	19.37	7.19	6.63	6.11	5.77	6.43	0.621
PI 570356	19.52	7.36	6.79	6.03	5.98	6.54	0.66
Tabat	19.30	7.48	6.73	6.14	5.99	6.59	0.677
Mean		7.368	6.698	6.13	5.838		

Table 2. Effect of drying method and genotype on seed germination percentage before drying, after drying and after ageing.

Main effect	Before drying	After drying	After aging
Drying method			
Seed dryer	76.9 a	91.6 a	60.4 b
Shade	76.9 a	87.0 b	57.6 c
Silica gel	76.9 a	83.7 c	66.2 a
Sun	76.9 a	82.4 c	52.7 d
Genotype			
PI 570120	80.0 b	93.0 a	71.0 b
PI 570300	85.9 a	82.9 c	39.6 e
PI 570342	80.6 b	88.1 b	75.0 a
PI 570356	77.2 c	83.5 c	65.7 c
Tabat	60.8 d	83.4 c	44.8 d

*** Significant at 0.001 probability levels.
Means followed by the same letter(s) within a column are not significantly different at 0.05 probability level according to the least significant difference test (LSD).

Assessment of seeds for viability and vigour

Seeds were assessed for viability and vigour using germination test. This was conducted at three different stages during the study; immediately after harvesting, drying and ageing. Seed samples assessed after drying were hydrated by holding the seeds in porous cloth bags that inside a dessicator over water for 24 h at room temperature ranging between 20 and 25°C (Ellis et al., 1985). The germination tests were conducted according to the recommendations by ISTA (1999). A complete randomised design of four replications with 100 seeds per replication was used. Seeds were germinated on sand medium using plastic pots that were placed inside a dark room with temperature ranging between 25 and 30°C. Emerging normal seedlings, which had well developed shoot and root systems with green expanding primary leaves and well developed straight coleoptile (ISTA, 1999) were counted three times during the test (that is, four, seven and ten days after sowing). Viability was then expressed as germination percentage of the total normal seedlings.

Seed vigor was evaluated on the normal seedlings at the end of the germination test. It was assessed as radicle length, shoot dry weight and germination speed. A sub-sample of ten seedlings was taken randomly for measuring their radicle lengths from which the average radicle length was calculated. Radicles were then removed, while the shoots were dried in an oven at 100°C for 2 h to obtain the shoot dry weight from which the average shoot dry weight per seedling was calculated. The germination speed was calculated using the following equation:

$$MTG = (D \times G)/N$$

Where MTG is the mean germination time, D is the number of days after sowing, G is the number of seedlings which were counted as normally germinated seeds within D days, and N is the total number of seeds normally germinated at the end of test (Walters et al., 1998).

Statistical analysis

The data were analysed using the computer statistical software (Mstat-c) and least significant difference (LSD) tests was used for comparison of means.

Table 3. Effect of drying methods on seed vigour.

Seed vigour parameter	Drying method	Before drying	After drying	After aging
Radicle length (cm)	Seed dryer	17.9 a	17.5 a	13.1 a
	Shade	17.9 a	15.5 b	12.2 b
	Silica gel	17.9 a	13.7 c	13.2 a
	Sun	17.9 a	13.7 c	10.8 c
Seedling shoot dry weight (mg)	Seed dryer	7.100 a	6.367b	4.605 b
	Shade	7.100 a	6.250 b	4.417 b
	Silica gel	7.100 a	6.667 a	4.817 a
	Sun	7.100 a	6.000 c	4.133 c
Mean time to germinate (days)	Seed dryer	6.3 a	4.2 b	5.5 ab
	Shade	6.3 a	4.1 c	5.3 b
	Silica gel	6.3 a	4.2 b	5.7 a
	Sun	6.3 a	4.5 a	5.5 b

RESULTS

Effect of drying method and genotype on seed moisture content

The data in Table 1 showed that among all the genotypes, sun drying consistently produced the lowest moisture content, followed by silica gel, shade and seed dryer, respectively. A simple one-way ANOVA test on drying methods, indicated a significant difference between drying methods ($p < 0.001$). However, there was no significant difference among genotypes, the mean percentage moisture contents of the seeds among genotypes before and after drying varied between 18.7 and 21% among all the different drying methods (Table 1).

Effect of drying method and genotype on seed viability

Seed viability as represented by germination percentage was significantly affected by the seed drying method, irrespective of the genotype. The highest germination percentage after drying (91.6%) was observed in the seeds that were dried in the seed dryer, which was significantly different from those dried under shade (87%) ($p < 0.001$) . On the other hand, seeds dried over silica gel and under sun had the lowest germination percentages (83.7 and 82.4%, respectively) (Table 2, Figure 1).

The result on seed germination also showed differences among genotypes when tested before drying, and after drying. The highest germination percentage before drying (85.9%) was recorded in the accession PI 570300, while the lowest (60.8%) was recorded in the cultivar Tabat. Irrespective of the drying method, the highest germination level after drying (93.0%) was recorded by the accession PI 570120, which was significantly different from the others; whereas, the lowest germination levels of 83.5, 83.4 and 82.9% were recorded in the genotypes PI 570356, cultivar Tabat and PI 570300, respectively (Table 2 and Figure 2). However, it was interesting to observe a general trend of increase in the germination percentages after seed drying, compared with those recorded before drying.

When seeds of the different treatments were subjected to accelerated aging, the germination levels differed significantly from each other ($p < 0.001$). Drying using silica gel resulted in the highest germination percentage (66.2%), followed by the seed dryer (60.4%) and shade (57.6%), whereas, the lowest germination level was given by sun drying (52.7%). After accelerated ageing, the accession PI 570342 gave the highest germination percentage (75%), while the lowest (39.6%) was obtained by the accession PI 570300, indicating different responses among genotypes (Table 2).

Effect of drying methods on seed vigour

The effect of drying method on seed vigour was assessed in the form of radicle length, shoot dry weight and germination speed. Radicle length was significantly affected by the drying methods. Irrespective of genotype, the longest radicle length (17.5 cm) was obtained in the seeds dried with the seed dryer, followed by those dried under shade (15.5 cm) with the radicle length significantly different from each other (Table 3). Both drying methods (that is, seed dryer and shade drying) also resulted in radicle lengths that were significantly different from those of the seeds dried over silica gel or under sun, which in effect have the same radicle length (13.7 cm).

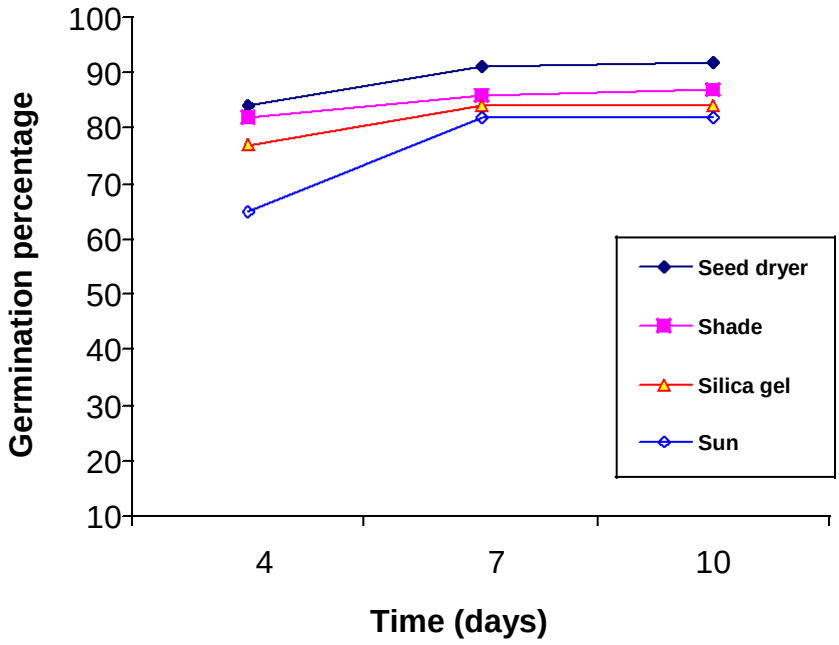

Figure 1. Effect of drying methods on germination percentage.

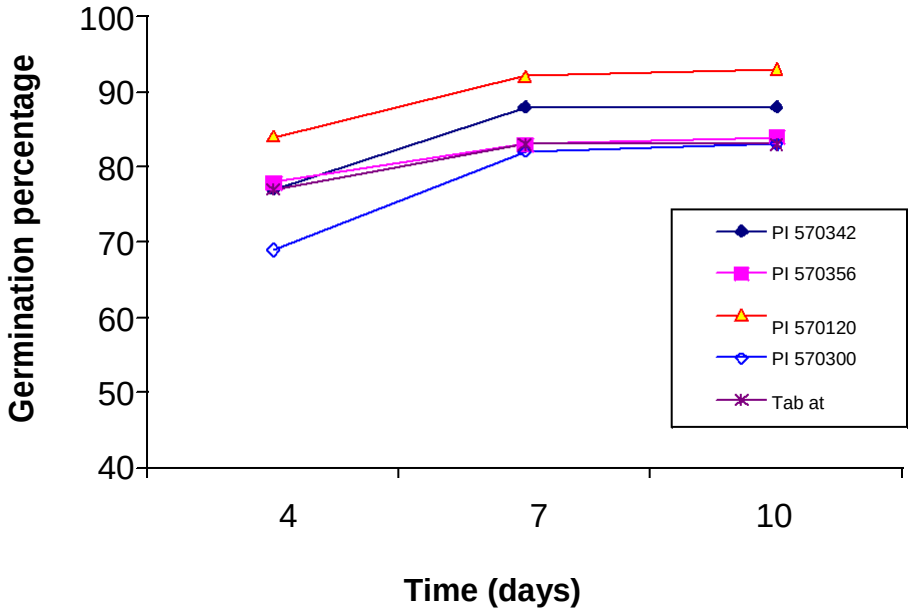

Figure 2. Effect of drying on germination percentage among genotypes.

After ageing, highly significant differences were also observed between the different drying methods. The silica gel and seed dryer gave the longest radicles (13.2 and 13.1 cm) and the differences between the two were not significant (p = 0.05). Shade and sun drying resulted in the shortest radicles of 12.2 and 10.8 cm, respectively, which were significantly different between the two and also from those obtained with silica gel and seed dryer.

The result on shoot dry weight showed that drying over silica gel gave seedlings with the highest shoot dry weight (6.7 mg), which was significantly different from sun drying (6.0 mg) (p = 0.001) as well as those obtained from seed dryer and shade drying (Table 3). After ageing, the different drying methods resulted in the

same trend of significance, where the silica gel gave the highest dry weight (4.8 mg), and sun drying resulted in the lowest dry weight (4.1 mg), while seed dryer and shade drying gave medium dry weights (4.6 and 4.4 mg, respectively) (Table 3).

Drying methods also significantly affected the speed of germination. The quickest germination speed (4.0 days) was obtained by shade drying, while the slowest speed (4.5 days) was obtained by sun drying. Seeds dried in the seed dryer and over silica gel gave the same germination speeds (4.2 days) (Table 3). After ageing, no significant differences were observed between the different drying methods except for the silica gel, which gave the slowest germination speed that was significantly different from those of shade and sun drying (Table 3).

DISCUSSION

All drying methods used, including those under natural conditions, that is, shade and sun, achieved the seed moisture contents in the range of 5.6 - 7.5% that are safe for conservation of sorghum. Rao and Bramel (2000) recommend the drying of seeds down to 3 - 7% SMC for long-term storage (Base collection) and 8 - 10% SMC for medium term conservation, which is used for regeneration, distribution, characterization and evaluation. Although the result of this study showed that drying in the sun and by silica gel achieved the lowest moisture content, compared to seed dryer and shade drying, these drying methods adversely affected the seed quality in terms of the seed viability and seed vigour. Seed dryer and shade drying gave the highest seed viability for most of the genotypes tested (Table 2), indicating that they ensure high initial quality of the seeds at start of storage.

This point is an important one, as Rao et al. (2006) suggest that high initial seed viability is a pre-requisite for improving seed longevity in genebanks that helps reduce regeneration loads. Many authors have also shown that the moisture content at which seeds were stored had a significant effect on seed longevity (Ellis et al., 1990; Nutile, 1964; Nakamura, 1975; Woodstock et al., 1983; Zheng, 1994). Differences in seed vigour (radicle length, seedling dry weight, and speed of germination) which are measures of seed quality were found between the different genotypes in the present study. The seed vigour test for all three parameters demonstrated that sun drying in particular, affects seed quality and we thus recommend that sun drying should not be used for sorghum seeds intended for long-term conservation. The results showed that drying in silica gel and seed dryer produce the best results in seed quality and they may be the most optimum drying methods to be used. The shorter drying time using the seed dryer for seeds to reach their lowest moisture content is attributed to air flow and low RH, inside the seed dryer. The high mean day temperature (26°C) also allowed seeds to dry faster under sun, whereas, the fluctuating day, night RH and the low mean day temperature (22°C) extended the period for seed dried under shade. Highly significant differences were also observed on seedling shoot dry weight; both after drying and aging. Accessions PI 570342 and PI 570120 recorded the highest seed vigour and this could be attributed to the higher starch content found in the seeds of these genotypes, according to the information available in the genebank documentation system at PGR Unit of Sudan.

Our study also showed that there were no significant differences in final seed viability when the seeds were dried by silica gel or under sun. Similarly, Kong and Zhang (1998) in their study on nine vegetables seeds using three methods of drying, namely: Freeze drying, heating at 50°C for two days and drying over silica gel, found that there was no difference in longevity when seeds were dried by either exposure to silica gel, freeze drying or heating to 50°C as long as the seeds were not over dried.

Drying seeds improved the germination percentages in all drying cases (Table 2), which is a phenomenon demonstrated by many previous studies (Ellis et al., 1983; Kong and Zhang, 1998; Vodouhe et al., 2008). This is explained by the fact that newly harvested seeds show some type of innate dormancy, which can be broken by different external factors such as time, drying or storage conditions. Dormancy that occurs immediately after harvest in sorghum has been reported by many scientists (Goodsell, 1957). Chantoreau and Nicou (1994) stated that dormancy period in sorghum rarely exceeds three weeks to one month and is linked to the high level of tannin that occurs in grains of some varieties. Ellis et al. (1983) demonstrated that germination of *Oryza glaberrima* seed was improved after drying and attributed this to after-ripening.

In this study, different genotypes showed different levels of seed moisture content both, before and after drying, which could be explained by the differences in biochemical composition of seeds. The same variation could also be the reason behind the differences in the final seed viability after drying. Thus, accessions PI 570342 and PI 570120 gave the highest germination percentage after drying and also after the accelerated ageing treatment, which could be attributed to the fact that these two genotypes had higher starch contents (completely starchy) compared to other genotypes with starch content ranging between intermediate to mostly corneous. Harrington (1972) also found some association between low starch level and poor storability among seeds with different starch levels.

In conclusion, none of the alternative drying methods proved to be better than the seed dryer which is the recommended seed drying method. However, this study indicates that silica gel could be a good option, in cases when the optimum recommended facilities are not available. Thus, both viability and vigour of seeds dried

over silica gel were affected to a lesser extents when compared with those dried using the other drying methods. Using silica gel could also be cheaper than the seed dryer when a limited number of seed samples are to be dried.

The study indicated that shade drying could be the second best alternative method for drying sorghum seeds. According to Rao et al. (2006), shade drying can be an effective way of reducing seed moisture content in environment where the RH is low (less than 40%). Shade and sun are both natural low-cost methods. Although sun drying may be a quicker method of drying, the study shows that it has a harmful effect on the seed viability and thus should not be recommended.

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