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Impact of drying methods on the seed quality of sorghum (*Sorghum bicolor* (L.) Moench)

Manish Kumar Vijay[1], Sushil Pandey[2], Chitra Devi Pandey[2] and Yasin Jeshima[2]*

[1]Division of Seed Science and Technology, Indian Agricultural Research Institute, New Delhi – 110012, India.
[2]National Bureau of Plant Genetic Resources, New Delhi – 110012, India.

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Seed storage is being affected by factors *viz.* seed moisture content, temperature and relative humidity. The effects of four drying methods using silica gel, saturated salt solution of lithium chloride, concentrated sulphuric acid and dryer drying on different physiological and biochemical characteristics of genotypes CSH 16 and CSV 18 of sorghum (*Sorghum bicolor* (L.) Moench) were investigated. Faster drying rate was observed in acid and silica gel while dryer and saturated salt solution of lithium chloride exhibited slow drying rate. Acid drying was efficient in drying, but detrimental to the seed quality. Results obtained by silica gel and lithium chloride salt solution drying were comparable with those obtained by seed dryer. Among the various parameters investigated, germination, vigour, total protein content, dehydrogenase, amylase, superoxide dismutase (SOD) and peroxidase activity were found to show a decreasing trend, whereas electrical conductivity (EC) increased during storage irrespective of drying methods. Seed quality was preserved in conventional drying method (drying chamber at 15°C and 15% R^H), which was comparable to the quality of seeds dried using lithium chloride; though drying rate was slow. Silica gel resulted in faster rate of drying to maintain moisture content and seed quality.

Key words: Sorghum, silica gel, acid, dryer, lithium chloride, drying methods, seed quality.

INTRODUCTION

The drought tolerant crop, Sorghum (*Sorghum bicolor* (L.) Moench) predominantly cultivated in arid and a semi-arid region is gaining importance due to climate change. In India it is grown in 6.32 million hectares to yield 6.03 million tonnes of grain (DES, 2011). Sorghum is grown for food, feed and fodder in drought prone area and is expected to play an important role in dry land economy in the changing environmental conditions. Low seed moisture content is a pre-requisite for long-term storage and is the most important factor affecting longevity. A combination of 3 to 7% seed moisture content (mc) and a storage temperature below 0°C was reported to be suitable for long-term preservation of orthodox seeds (FAO/IPGRI, 1994). Seeds lose viability and vigour during processing. The process of drying decreases the seed weight and volume.

Diverse methods of seed drying, such as shade and sun drying, vacuum drying, freeze drying and refrigeration drying with low R^H are available (Ellis and Roberts, 1991) along with recommended methods for

*Corresponding author. E-mail: jeshimakhanyasin@gmail.com, Tel: 07827885869.

safe drying of seeds such as seed drying chambers, seed dryers and controlled conditions (Ellis et al., 1985). In developing countries, such drying facilities for germplasm storage are not available. With an objective of developing efficient, alternative and energy efficient drying methods to reduce seed moisture content without compromising seed health and quality, the present investigation was executed to elucidate the effects of silica gel, saturated salt solution of lithium chloride, concentrated sulphuric acid and dryer drying on the different physiological and biochemical seed characteristics of sorghum genotypes CSH 16 and CSV 18.

MATERIALS AND METHODS

Sorghum cultivars CSH 16 and CSV 18 procured from Directorate of Sorghum Research, Hyderabad with an initial seed moisture content of 11± 0.2%. Four drying methods were used to obtain two different drying rates. Rapid drying (RD) was achieved by placing seeds in glass desiccators containing silica gel and concentrated sulphuric acid. For slow drying seeds were placed in glass desiccators containing saturated salt solution of lithium chloride and seed dryer maintained at 15% R^H and temperature at 15°C.

Samples of both the genotypes were weighed to 42 g each and packed in muslin cloth bags for drying. Silica gel drying was carried out as described earlier by (Fischler, 1993). Lithium chloride saturated salt solution (12 to 13% R^H) was placed at the bottom of a desiccator for seed drying. For sulphuric acid drying, acid was directly placed in the bottom of a desiccator. After 24 h the samples were kept in muslin cloth bags and placed over the desiccator plate. Drying chamber was maintained at 15°C temperature and 15% R^H; samples were placed in the drying trays for drying in drying chamber.

Enough time was allowed to reach the seed moisture at the desired level of 6±0.1% from the initial 11±0.2% level. When the desired moisture content was achieved, one sample of each genotype was taken out for assessing various quality parameters under replicated trials. The remaining seed sample was packed in aluminium foils with a vacuum proof seal. The remaining second sample of each genotype was kept as such to assess drying trend.

Drying time was predicted by weighing after every four-day interval and based on weight loss using following formula

Final seed weight = Initial weight of seeds × [(100 - Initial moisture content) / (100 - Target moisture content)]

Final moisture content was confirmed by high constant temperature method as per high constant temperature oven method (ISTA, 2011) and then samples were stored for 6 months. Various quality parameters were recorded from control, initial storage after drying, three months after storage and six months after storage.

Standard seed germination was assessed using between paper method with three replicates of 50 seeds each (ISTA, 2011). Vigour Index (VI) and seed leachate conductivity were calculated using the formulae

Vigour Index I= Germination % × Seedling length (cm)

Vigour Index II= Germination % × Seedling dry weight (g)

$$\text{Conductivity}\,(\mu s/cm/g) = \frac{\text{solution conductivity} - \text{control conductivity}}{\text{weight of replicate (g)}}$$

Dehydrogenase (Kittock and Law, 1968), amylase (Murata et al., 1968), superoxide dismutase (Dhindsa et al., 1981) and Peroxidase activity (Castillo et al., 1994) were estimated.

RESULTS

Assessment of drying rate

The initial moisture content was 11 ± 0.2% for all seed lots. Time taken to reduce the moisture content to 6±0.1% was about 7 to 11 days in rapid drying methods while it is about 19 to 24 days in slow drying methods. On continuous drying of the remaining second sample up to 36 days, it is evident that in both the genotypes drying rate was found to be highest in acid drying methods followed by silica gel. The impact of drying methods on seedling shoot length and root length were also analysed (Figures 1 and 2).

Seed viability

Decline of about 11 and 9% in acid drying followed by 8 and 7% in control was observed in CSH 16 and CSV 18 genotypes, respectively. All other drying methods showed only 2 to 6% decline from the initial value after 6 months of storage.

Vigour index

In the present study, vigour index showed a steady decline over the storage period. The total reduction in vigour was more pronounced in acid drying (40 to 45%) and control which were found to be on par in both the genotypes of sorghum. Silica gel and seed dryer method showed maximum vigour index of 3068 and 3026 in CSH 16 and CSV 18 genotypes of sorghum respectively, after six months of storage. In CSV 18 lithium chloride showed significantly higher vigour index value of 2968 followed by seed dryer drying and silica gel drying. Vigour index II also showed similar trend of decline by acid drying followed control. Only 10 to 15% decline was observed in other drying methods.

Electrical conductivity

The EC of leachates observed under different drying methods increased significantly with loss in seed viability. Maximum value was observed in control and acid dried seeds of sorghum (42 to 50%) while minimum was observed in the seed lot dried with seed dryer followed by lithium chloride (Table 1).

Amylase activity

As the storage duration progressed, decline in amylase

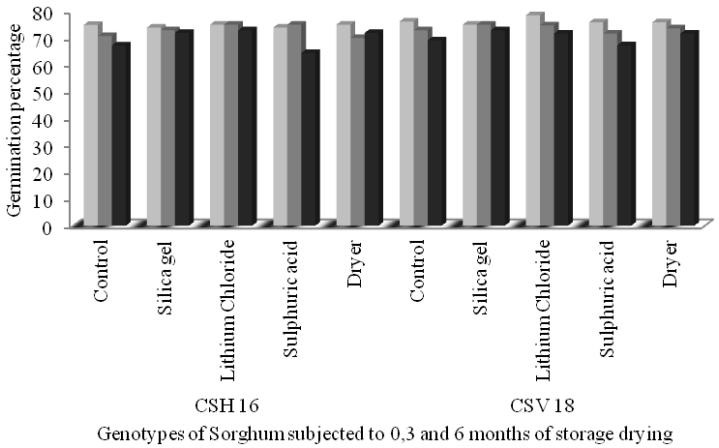

Figure 1. Effects of different drying methods on seed germination of sorghum.

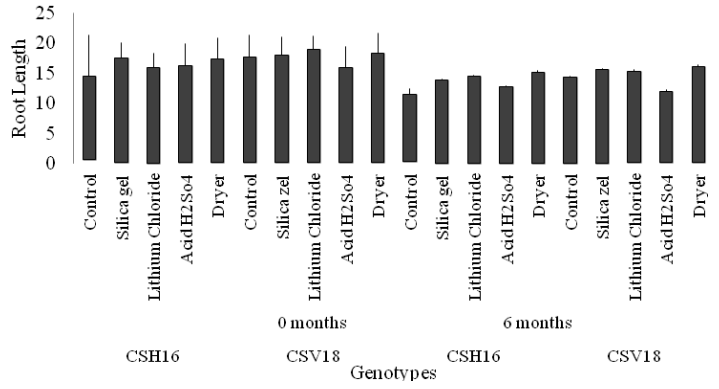

Figure 2. Effects of different drying methods and drying rate on root length of sorghum.

activity was observed; however maximum reduction in enzyme activity was observed in control and acid drying method. Other drying methods also exhibited significant difference in the amylase activity. About 40 to 50% decline in amylase activity was observed after 6 months of storage in control and acid dried seed samples. The maximum decline in amylase activity value was observed in control from 53.79 mg maltose/g of seed to 28.97 mg maltose/g of seed after six months of storage in CSH 16 (Table 2). Seeds dried with lithium chloride, silica gel and dryer showed a decline of about 26 to 34% in CSH-16 as well as CSV-18 genotypes.

Dehydrogenase

Seeds dried using lithium chloride and drying chamber had dehydrogenase activity 0.223 (OD value) and 0.221 (OD value) in sorghum genotype CSH 16 (Table 1). The significant reduction in the dehydrogenase activity was noticed after six months in acid dried seeds and control. In CSV 18, maximum decline was observed in control (43%) while other drying methods showed lower value of 27 to 29%.

Peroxidase activity

Peroxidase activity was high in fresh seeds and decreased gradually with increase in storage period (Table 2). Sorghum genotype CSV 18 showed maximum decline (52%) in peroxidise activity from 139.18 µmolar/min/g of fresh seed to 66.86 µmolar/min/g of fresh seed in seeds dried by acid. Similar trend was observed in CSH 16 which recorded 38% decline from the initial value after six months of storage. All other drying methods showed an activity decline ranging within 26 to 31%.

Table 1. Effects of different drying methods and rate of drying on seed quality of sorghum.

Genotype	Drying methods	Vigour index I			Vigour index II			EC (µ siemens/cm/g seed)			Dehydrogenase activity (OD at 480 nm/ 25 seed)		
		Storage duration (month)			Storage duration (month)			Storage duration (month)			Storage duration (month)		
		0	3	6	0	3	6	0	3	6	0	3	6
CSH 16	Control	3764	2730	2166	16.0	14.1	11.6	121.47	150.32	189.69	0.205	0.144	0.113
	Silica gel	3785	3288	2647	16.4	15.0	13.7	120.35	143.52	165.59	0.213	0.178	0.158
	Lithium Chloride	3639	3313	2968	16.5	15.4	15.0	113.04	132.89	154.79	0.223	0.186	0.15
	Acid (Conc H_2SO_4)	3490	2739	1913	14.6	12.4	10.1	137.74	158.15	187.98	0.192	0.141	0.107
	Dryer	3891	3296	2764	18.4	16.5	16.3	114.47	127.82	159.24	0.221	0.178	0.154
CSV 18	Control	3923	3005	2324	19.5	15.5	13.0	130.74	152.74	182.79	0.317	0.264	0.18
	Silica gel	4292	3508	3069	18.1	16.8	15.0	122.96	136.12	175.89	0.338	0.295	0.23
	Lithium Chloride	3965	3377	2801	19.7	17.6	14.3	119.82	108.78	155.1	0.339	0.283	0.244
	Acid (Conc H_2SO_4)	3554	2810	2077	15.6	11.9	10.1	138.27	158.2	185.49	0.299	0.253	0.216
	Dryer	4380	3343	3026	18.3	16.2	15.5	109.38	122.78	149.51	0.339	0.278	0.24
Source		CD at 5%			CD at 5%			CD at 5%			CD at 5%		
Genotype (G)		17.9			0.085			0.89			0.001		
Drying method (M)		28.31			0.134			1.4			0.002		
Storage Duration (D)		21.93			0.104			1.08			0.001		
G X M		40.03			0.19			1.98			0.003		
G X D		31.01			0.14			1.54			0.002		
M X D		49.03			0.232			2.43			0.003		
G X M X D		69.34			0.328			3.44			0.005		

Superoxide dismutase (SOD)

Activities of different genotypes of sorghum showed a gradual decrease during the storage period. The amount of SOD measuring 3.42 units/g of seed/min and 3.45 units/g of seed/min was observed in CSH 16 genotype of sorghum seed lots dried by silica gel and seed dryer methods respectively, which declined to 2.69 units/g of seed/min and 2.82 units/g of seed/min after six months of storage. In general, maximum decline was observed in control samples followed by acid drying methods. Minimum reduction in SOD activity of 19% was observed in the seed lots which were dried by seed dryer in the genotype of CSV 18.

DISCUSSION

The parameters of the seed quality including seed viability and seed vigour play a key role during long term storage. Seedling vigour is ultimately the most important expression of the seed quality (Heydecker, 1972). In the present study the genotypes showed significant difference for methods of drying. Maximum value of root, shoot, seedling length and vigour index were observed in the seed lots dried by using seed dryer followed by silica gel. However, lithium chloride was also on par with silica gel. Acid drying was harmful as it drastically reduced moisture content causing sudden and abrupt physical and physiological changes in seed which ultimately leads to poor germination and production of more number of abnormal seedlings with low vigour index. Similar

Table 2. Effects of different drying methods and rate of drying on seed quality of sorghum.

Genotype	Drying methods	Protein content (mg/g seed)			Peroxidase enzyme activity (µmolar/min/g fwt)			Super Oxide Dismutase enzyme activity (units/g seed/min)			Amylase enzyme activity (mg maltose/g seed fwt/5 min)		
		Storage duration (month)			Storage duration (month)			Storage duration (month)			Storage duration (month)		
		0	3	6	0	3	6	0	3	6	0	3	6
CSH 16	Control	92.14	83.16	72.07	147.87	116.08	87.36	3.21	2.48	1.58	53.79	40.42	28.97
	Silica gel	95.81	84.74	80.85	150.24	136.58	100.16	3.42	3.10	2.69	57.93	49.56	37.78
	Lithium Chloride	92.6	86.93	80.77	177.33	161.21	118.21	2.96	2.54	1.79	53.82	43.98	39.61
	Acid (Conc H_2SO_4)	95.24	82.26	68.66	145.31	132.1	89.06	2.85	2.32	1.70	49.73	40.82	29.12
	Dryer	94.2	86.97	82.35	162.55	147.77	108.37	3.45	3.13	2.82	59.41	50.88	40.84
CSV 18	Control	97.85	86.05	78.64	126.27	107.34	78.56	2.23	1.71	1.38	51.08	36.6	21.73
	Silica gel	96.89	87.8	80.78	146.81	120.69	107.92	3.33	3.02	2.29	53.03	47.35	33.85
	Lithium Chloride	96.41	85.06	78.66	160.42	145.84	115.86	2.36	2.16	1.90	51.3	44.83	35.62
	Acid (Conc H_2SO_4)	93.34	80.33	75.46	139.89	106.47	66.86	2.28	2.08	1.61	46.99	36.06	27.76
	Dryer	95.03	90.25	84.08	184.08	166.45	126.02	2.78	2.53	2.36	51.95	44.78	37.94

Source	CD at 5%	CD at 5%	CD at 5%	CD at 5%
Genotype (G)	0.491	0.72	0.015	0.25
Drying method (M)	0.776	1.15	0.023	0.395
Storage Duration (D)	0.601	0.89	0.018	0.306
G X M	1.098	1.62	0.033	0.558
G X D	N.S.	1.26	0.025	0.433
M X D	1.34	1.99	0.04	0.684
G X M X D	1.9	2.82	0.057	0.967

results were also reported by acid drying in different vegetable crops (Nutile, 1963) where decline in germination and reduced seedling length was conspicuously observed. Membrane degradation enhances solute leakage from imbibed seed, resulting in loss of viability and seed vigour (Matthews and Bradnock, 1968). In the present study, increase in electrolyte leakage was observed in the acid dried seeds. However the change in relative electric conductivity of acid dried seeds after six months in ambient conditions was lower than control (10 to 11%), while minimum EC value was found in seeds dried in dryer followed by silica gel and lithium chloride drying.

Dehydrogenase plays the leading role in the metabolism and is influenced by aging. Dehydrogenase activity and the seed viability are positively correlated (Ellis et al., 1985). In the present study, dehydrogenase activity of sorghum showed significantly lower values in acid drying as compared to control, which meant that dehydrogenase activity of acid dried seeds were more prone to desiccation and found to be inefficient in maintaining the seed viability.

In the present study, there was significant difference in amylase activity of seeds dried with different methods. Seed lots dried with silica gel and lithium chloride resulted in maximum amylase value. Similar results was also reported in *Melilotus suaveolens* (Liu et al., 2011).

However, there was significant reduction in amylase activity of acid dried seeds, both in case

of sorghum and pearl millet genotypes suggesting that acid drying was detrimental to the seed quality, irrespective of crop species and respective genotypes.

Peroxidase enzyme is involved in dehydrogenation of large number of organic compounds such as aromatic amines and free radicals. The decrease in the level of this enzyme could lead to the accumulation of toxic substances in the seeds. Such accumulation of toxic free radicals accompanied by the decreased activity of antioxidant enzyme has been reported (Hendry, 1993). A decrease in the level of soluble protein is an expression of the loss of activities of the membrane associated superoxide dismutase (Weisiger and Fridovich, 1973). In the present study, peroxidase and SOD activities in sorghum and pearl millet showed a significant decline in the seed lots dried by acid whereas, the minimum value for peroxidase and SOD activity was observed in seed dryer method. However, comparable results were noticed in silica gel and lithium chloride drying.

The results obtained under this study have shown that all the drying methods improved the seed quality parameters except acid drying. Observations showed that drying with acid is most effective in lowering seed moisture content in both the crops at a faster rate, but the seed quality was adversely affected by acid drying. Hence, acid drying is not recommended for seed drying purposes. Silica gel gave the next highest drying rate and the quality of seeds was maintained as in case of drying using drying chamber. Hence, silica gel drying can be suggested as an alternative drying method for less quantity of seed for conservation of germplasm. Lithium chloride drying also showed comparable results with seeds dried using silica gel and dryer methods in terms of quality parameters. However, drying rate was found to be relatively slow. Although silica gel is a very effective desiccant for drying seeds to very low moisture contents, 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). However, in situations where the supply of electricity is a problem, silica gel may be a viable option. From the germplasm conservation perspective, further studies are needed to determine the impact of these drying methods on the long term seed storability in seed gene bank.

Conflict of Interest

The authors have not declared any conflict of interest.

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