Seed viability of active collections in ex-situ genebanks: an analysis of sorghum germplasm conserved at ICRISAT genebank

DVSSR Sastry*, HD Upadhyaya and **CLL Gowda**

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India

*Corresponding author: dvssr.sastry@cgiar.org

Citation: SastryDVSSR, Upadhyaya HD and Gowda CLL. 2008. Seed viability of active collections in ex-situ genebanks: an analysis of sorghum germplasm conserved at ICRISAT genebank. Journal of SAT Agricultural Research 6.

Abstract

A study was undertaken to assess and analyze the seed viability data of 36,483 sorghum germplasm accessions conserved as active collection at ICRISAT genebank, Patancheru, India. The viability tests were conducted for seven years. The period of storage was less for freshly regenerated accessions while for majority of the accessions (35,221) it ranged between 5 and 21 years. The seed viability of 34,894 accessions (95.6% of the total tested accessions) was >85%, a minimum standard for orthodox seeds for conservation as active collection in international genebanks. This exercise has resulted in identifying several important areas like basic and intermediate races of sorghum, seed covering structures, the nature of endosperm, etc, critical for improving the operational procedures and protocols for the management of the ex-situ sorghum germplasm collection.

Introduction

Maintenance of seed viability is a basic condition for successful preservation of germplasm as seeds. The initial germinabilty of the seeds, seed moisture content and its interaction with relative humidity of the air and the storage temperature have significant influence on seed longevity (Roberts 1973). Even in seeds stored under optimal conditions suitable for long-term storage, viability may decrease as a result of deterioration processes. These deterioration processes include: an increase of the free radical content, changes in protein structure, depletion of food reserves, development of fat acidity, changes in enzymatic activity, membrane damage, chromosomal changes and an increase of respiration (Justice and Bass 1979). These processes can manifest at different levels resulting in a decrease in germinability, production of numerous abnormal seedlings, and even complete loss of viability. Data on baseline viability of conserved accessions and monitoring at regular intervals enable taking appropriate decisions for managing the genebank collection.

Under controlled environmental conditions it is estimated that the seeds come to equilibrium moisture content (*emc*) during storage. The *emc* is a function of temperature, relative humidity and seed oil content (Cromarty et al. 1990) and seeds of the same genus but differing in size and chemical composition reach different *emc* (Pabis 1967). Seeds are hygroscopic and their moisture content comes to equilibrium with the relative humidity of the atmosphere around them. At a given relative humidity and temperature, seed that has high protein or starch content and low oil content will have much higher moisture content than seed with high oil content. Sastry et al. (2003) observed low *emc* in groundnut (*Arachis hypogaea*) seeds followed by cereals and pulses when seeds were dried under 15ºC and 15% relative humidity.

The environmental conditions influence the chemical composition during the development of seed and any change in the percentage of oils or proteins or thickness of the seed coat will result in a different moisture equilibrium value. Variations in seed size will change the proportion of the compounds and, therefore, give different moisture equilibrium values. The moisture equilibrium value at a given humidity may vary as much as 1.5% with extremes in storage temperature.

The genebank at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Patancheru, India with over 118,800 accessions from 144 countries, serves as a world repository for the conservation of the genetic resources of sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), chickpea (*Cicer arietinum*), pigeonpea (*Cajanus cajan*), groundnut and six small millets – finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*), kodo millet (*Paspalum scrobiculatum*), proso millet (*Panicum miliaceum*) and barnyard millet (*Echinochloa crus-galli*). Seeds of these germplasm collections are essentially of orthodox nature and conserved as active collection at 4ºC and 30% relative humidity (medium-term) for maintenance and distribution, and at –20ºC (long-term) as base collection. The sorghum active collection at ICRISAT genebank represents different botanical races and wide diversity for important seed traits like shape, size and chemical composition. The objective of this study was to test the seed viability of the sorghum active collection and to analyze its relationship with storage durations and related seed traits in different races.

Materials and methods

The seed samples of sorghum germplasm accessions for the study were harvested from the postrainy season regenerations carried out at ICRISAT, Patancheru from 1976 to 2002 (27 sets/batches of germplasm). Regeneration of the germplasm was necessitated mainly for increasing the original sample of the accessions for conservation, maintenance, distribution and seed multiplication of accessions with low seed stocks and/or with viabilities below a critical level (FAO/IPGRI 1994). In total, 39 accessions identified during this exercise with <75% seed viability were subsequently regenerated. Seed germination data on 36,483 regenerated accessions over these years was analyzed. These accessions originated or were assembled from 91 countries and belonged to 15 different botanical races (five basic and 10 intermediate races) of sorghum.

Preparation of seed for storage. Germplasm accessions were regenerated during the postrainy season (*rabi*) at ICRISAT, Patancheru (18º N and 78º E) in Vertisols under good management conditions and plant protection. The number of accessions or accessions in a specific race grown for regeneration in a season was not uniform. During flowering, about 50 earheads in an accession were covered with standard brown kraft paper bags to avoid cross-pollination for maintaining genetic integrity of the accessions. These bags were removed after 30 days to enhance natural maturation of the earheads. After reaching maturity, the earheads were individually harvested, sun-dried for about two weeks to bring down the seed moisture content to about 10% (wet basis). Random samples of seed from each earhead were collected and cleaned for constituting the original population for conservation. Seeds were compared with original reference samples of the accessions and approximately 350 g was transferred to aluminum cans having a screw lid and a rubber gasket (to avoid air flow) and stored in a cold room maintained at 4ºC and 30% relative humidity. The storage environment (temperature and relative humidity) of the cold room holding sorghum active collection was constantly monitored using standard hygrothermographs supplemented by electronic and digital data logger systems. Stable storage environments were maintained with standby power supply systems and technical back-up.

Estimation of seed moisture content and viability. The seed moisture content of the active collection in equilibrium with 4ºC and 30% relative humidity was estimated following the methods suggested by International Seed Testing Association (ISTA 1993). An inventory of the seed samples of all sorghum accessions conserved as active collection was carried out. This included recording data on season of harvest, available seed quantity (g), 100-seed weight (g) and evaluation of seed viability (%). Seed samples for viability were evaluated in the laboratory attached to the genebank. A random sample of 50 seeds in each accession was used for viability testing following BP (between paper) method using 400T standard paper towels from SeedBuro™. Seeds were incubated at 25ºC for 10 days (ISTA 1993). Alternating temperatures of 20ºC/30ºC (16 h/8 h) were provided and germination period extended for further 10 days to facilitate germination in dormant seeds. The number of accessions tested for viability differed in each race and also in different years. Observations on normal seedlings, abnormal seedlings and diseased/dead seeds were made on the final day of the test and the percentage of normal seedlings was considered as viability percentage. The data on seed viability were entered on an inventory module of the Genebank Information Management System (GIMS) for analysis and future monitoring. The mean, range, standard deviation and variance of seed viability were estimated using Genstat 5.1. The seed viability data was analyzed for different storage durations, botanical races of sorghum and some important seed traits drawn from the characterization data that was recorded over the years and using the descriptors for sorghum (IBPGR and ICRISAT 1993).

Results and discussion

Equilibrium moisture content (*emc*) during storage. The details of seed *emc* on random samples of 45 diverse accessions representing different races and sub-races and some important seed traits along with storage duration are presented in Table 1. The mean *emc* for the tested accessions was 8.2% (wet basis). Considerable variation in *emc* was observed among the accessions. The *emc* across the races and the accessions ranged from 7.2% in IS 28122 (*durra*) to 9.4% in IS 20610 (*caudatum*) and IS 29958 (*kafir-caudatum*). Seeds of sorghum maintain an *emc* of 8.5% when stored at 25ºC and 30% relative humidity, and at cooler temperatures the *emc* is slightly higher at the same relative humidity because the water molecules are adsorbed on the macromolecules and capillary surfaces of the seed coat (Harrington 1972). The observed difference of 2.2% in *emc* among the tested accessions (a small fraction of the collection) is significant and this could be even more considering

Table 1. Equilibrium seed moisture content and related seed traits of different races of sorghum germplasm accessions stored in ICRISAT genebank.

IS no.	Race	Equilibrium moisture content (%)	Storage duration (years)	Seed viability (%)	Glume covering	Seed color	Seed luster	Seed sub-coat	Seed size (mm)	100-seed weight (g)	Endosperm texture
20195	*Bicolor*	7.9	8	90	Three-fourth grain covered	Light brown	Non-lustrous	Present	2.8	3.6	Partly corneous
31190	*Bicolor*	7.6	12	90	Grain fully covered	Brown	Lustrous	Absent	2.0	1.4	Partly corneous
37948	*Bicolor*	8.2	4	90	Three-fourth grain covered	Reddish brown	Non-lustrous	Absent	2.5	1.3	Completely starchy
877	*Caudatum*	8.1	11	78	One-fourth grain covered	Brown	Non-lustrous	Present	3.0	3.0	Mostly starchy
20610	*Caudatum*	9.4	15	78	One-fourth grain covered	Reddish brown	Non-lustrous	Absent	2.5	2.2	Mostly starchy
33357	*Caudatum*	8.6	10	78	Half-grain covered	Reddish brown	Non-lustrous	Absent	2.5	1.7	Completely starchy
506	*Caudatum-bicolor*	8.0	11	80	Half-grain covered	Reddish brown	Non-lustrous	Present	3.0	1.5	Completely starchy
5960	*Caudatum-bicolor*	8.3	9	78	Three-fourth grain covered	Reddish brown	Non-lustrous	Present	2.0	2.0	Partly corneous
38165	*Caudatum-bicolor*	8.7	4	84	Three-fourth grain covered	White	Lustrous	Absent	3.5	3.0	Partly corneous
296	*Durra*	8.7	1	78	Half-grain covered	Straw	Lustrous	Absent	3.5	3.5	Mostly starchy
1464	*Durra*	8.0	13	84	Half-grain covered	Light red	Lustrous	Absent	4.0	3.2	Mostly starchy
28122	*Durra*	7.2	6	76	Half-grain covered	Straw	Lustrous	Absent	3.5	5.5	Completely starchy
37243	*Durra*	7.6	5	80	Half-grain covered	Straw	Lustrous	Absent	3.0	2.4	Completely corneous
19011	*Durra-bicolor*	8.1	8	88	Three-fourth grain covered	Straw	Lustrous	Absent	3.0	3.6	Mostly starchy
23433	*Durra-bicolor*	8.0	6	84	Three-fourth grain covered	Straw	Lustrous	Absent	3.0	3.3	Partly corneous
2931	*Durra-caudatum*	7.8	3	78	One-fourth grain covered	Yellow	Lustrous	Absent	3.5	3.8	Partly corneous
28856	*Durra-caudatum*	8.6	9	82	Half-grain covered	Gray	Non-lustrous	Present	3.0	3.6	Completely starchy
32071	*Durra-caudatum*	8.8	11	80	Half-grain covered	Gray	Non-lustrous	Present	3.0	3.7	Completely starchy
14339	*Guinea*	8.0	6	88	Grain not covered	Straw	Lustrous	Absent	1.5	3.3	Mostly corneous
24201	*Guinea*	9.2	16	86	Grain not covered	Straw	Lustrous	Absent	3.0	3.4	Partly corneous
33640	*Guinea*	8.2	8	88	Half-grain covered	White	Lustrous	Absent	2.0	2.3	Mostly corneous
7981	*Guinea-bicolor*	8.2	8	90	Half-grain covered	Light red	Lustrous	Absent	4.0	4.4	Partly corneous
10839	*Guinea-bicolor*	7.9	3	94	Half-grain covered	White	Lustrous	Absent	3.5	3.9	Mostly corneous
38094	*Guinea-bicolor*	8.6	4	98	Half-grain covered	White	Lustrous	Absent	3.0	1.7	Partly corneous
2429	*Guinea-caudatum*	7.6	3	78	Half-grain covered	Chalky white	Non-lustrous	Present	4.0	3.8	Mostly starchy
18735	*Guinea-caudatum*	8.2	11	78	One-fourth grain covered	Chalky white	Non-lustrous	Present	2.8	4.5	Partly corneous
34358	*Guinea-caudatum*	8.0	7	80	One-fourth grain covered	Reddish brown	Non-lustrous	Present	1.5	2.5	Mostly starchy
7164	*Guinea-durra*	9.2	21	90	Half-grain covered	White	Lustrous	Absent	4.0	3.5	Mostly corneous
19398	*Guinea-durra*	7.6	4	92	One-fourth grain covered	White	Lustrous	Absent	3.0	4.2	Mostly corneous
26946	*Guinea-durra*	7.8	1	94	Half-grain covered	Straw	Lustrous	Absent	3.0	2.2	Mostly starchy
862	*Guinea-kafir*	7.9	12	94	Half-grain covered	Chalky white	Non-lustrous	Present	4.0	1.6	Completely starchy
19450	*Guinea-kafir*	8.0	7	98	One-fourth grain covered	Light red	Lustrous	Absent	3.0	4.1	Partly corneous
29501	*Guinea-kafir*	8.1	12	98	Half-grain covered	White	Non-lustrous	Present	2.8	2.5	Partly corneous
1601	*Kafir*	8.2	4	82	Half-grain covered	White	Lustrous	Absent	4.0	2.9	Partly corneous
18100	*Kafir*	8.0	7	86	Half-grain covered	White	Lustrous	Absent	3.0	2.7	Partly corneous
35141	*Kafir*	8.2	7	88	Half-grain covered	White	Lustrous	Absent	1.8	1.9	Partly corneous
1211	*Kafir-bicolor*	7.6	9	90	Three-fourth grain covered	Light brown	Non-lustrous	Present	3.0	2.2	Mostly corneous
14320	*Kafir-bicolor*	8.2	7	96	Half-grain covered	Light red	Lustrous	Absent	2.5	3.0	Partly corneous
35705	*Kafir-bicolor*	8.2	8	98	One-fourth grain covered	Straw	Lustrous	Absent	3.0	3.4	Partly corneous
2261	*Kafir-caudatum*	8.0	5	84	One-fourth grain covered	Chalky white	Non-lustrous	Present	3.5	3.3	Partly corneous
18102	*Kafir-caudatum*	8.0	2	90	Three-fourth grain covered	White	Lustrous	Absent	2.5	2.8	Partly corneous
29958	*Kafir-caudatum*	9.4	12	92	Half-grain covered	White	Lustrous	Absent	2.8	2.8	Mostly corneous
312	*Kafir-durra*	8.0	3	88	One-fourth grain covered	Light red	Lustrous	Absent	4.0	2.8	Mostly starchy
13068	*Kafir-durra*	9.0	16	92	Half-grain covered	Light red	Lustrous	Absent	3.0	2.8	Partly corneous
34701	*Kafir-durra*	7.9	8	92	Half-grain covered	Straw	Lustrous	Absent	2.0	2.0	Partly corneous
	Mean	8.2									

larger number of accessions conserved in the races. The *emc* of sorghum seed did not show any relationship with duration of storage, the different races of germplasm tested and various seed traits like glumes covering, color, luster, sub-coat, size, weight and endosperm texture. This shows that moisture equilibrium in seeds of sorghum is independent of the accessions, and wide differences could be due to the chemical composition of the seed. More studies in this area are required using large sample sizes among and in between the races.

Storage duration and seed viability. The mean seed viability, standard deviation and variance of sorghum accessions conserved from different regeneration seasons are presented in Table 2. The mean seed viability of 36,483 accessions over the periods of storage was 95.1%. There are 1,589 accessions (4.4%) with viability between 76% and 85% that require frequent monitoring compared to 34,894 accessions (95.6%) that have higher levels of viability (86 to 100%). This classification largely helps in making suitable modifications in germplasm documentation systems and in projecting future viability monitoring and regeneration schedules.

The mean viability for different regenerations ranged from 90.0 to 96.73%. The highest mean seed viability was identified from regeneration carried out during the year 1999. The number of accessions regenerated during this year was also highest (3,131) compared to other seasons. As a result, the number of accessions in the unfavorable viability range of 76 to 85% was low (0.4%) representing 14 accessions regenerated from this season. Out of 27 regeneration seasons, the mean seed viability was >95% for 19,733 accessions in 15 years and between 90 and 95% for 16,750 accessions in 12 years. A low mean seed viability (90%) was from seven accessions regenerated during the year 1997. This is followed by 92.5% for 297 accessions for the regeneration year 2001 and 92.7% for 1,888 accessions regenerated during 1987. In both these years the low mean seed viability could be attributed largely due to a higher number of accessions (16.8% in 2001 and 10.2% in 1987) in the unfavorable viability range of 76 to 85%. The oldest seed in the

Table 2. Seed viability of sorghum active collection from 27 years of regeneration conserved in ICRISAT genebank.

Year of regeneration	Number of tested accessions	No. of accessions in viability (%) range					Mean viability (%)	SD (%)	Variance (%)
		76–80	81–85	86–90	91–95	96–100			
1976	120		2	8	25	85	96.27	3.67	13.44
1977	272	2	4	24	61	181	95.94	4.02	16.19
1978	295	7	2	25	53	208	95.97	4.57	20.84
1979	112	4	4	19	29	56	93.98	5.03	25.33
1980	1264	16	17	136	278	817	95.67	4.30	18.52
1981	1078	7	7	100	213	751	96.04	3.91	15.32
1982	1342	12	18	167	305	840	95.37	4.24	17.94
1983	1398	7	8	117	229	1037	96.49	3.73	13.92
1984	1997	13	11	144	403	1426	96.40	3.70	13.67
1985	2610	19	25	249	523	1794	96.00	3.96	15.68
1986	2222	19	25	297	545	1336	95.20	4.16	17.27
1987	1888	78	114	449	489	758	92.65	5.44	29.64
1988	1290	50	68	189	262	721	94.07	5.62	31.54
1989	965	28	44	193	245	455	93.55	5.23	27.35
1990	2145	48	63	314	494	1226	94.71	4.95	24.50
1991	2935	63	97	367	606	1802	94.96	4.93	24.30
1992	1279	44	51	189	301	694	94.16	5.29	27.94
1993	2289	67	99	386	559	1178	93.92	5.22	27.22
1994	1747	36	57	206	374	1074	95.03	4.82	23.26
1995	3098	75	102	425	724	1772	94.62	4.97	24.67
1996	1292	12	26	135	259	860	95.71	4.26	18.15
1997	7	1		3	2	1	90.00	5.77	33.33
1998	445	9	22	75	109	230	94.08	5.12	26.17
1999	3131	6	8	287	445	2385	96.73	3.68	13.57
2000	547	17	15	68	95	352	95.16	5.35	28.59
2001	297	22	25	60	53	137	92.48	6.54	42.71
2002	418	5	8	39	98	268	95.60	4.33	18.73
Total/Mean	36483	667	922	4671	7779	22444	95.11	4.74	22.54

sorghum active collection represented by 120 accessions from 1976 regeneration had a higher mean seed viability of 96.3% compared to 95.6% in freshly regenerated accessions (418 accessions) from 2002 season and stored for one year. This shows that differences in sorghum seed viability as active collection is largely due to the growing environmental conditions for the season in which the accessions were regenerated. Good quality of seed for the 19,733 accessions regenerated during 15 years resulting from favorable growing conditions could be the main reason for a higher mean seed viability compared to other years especially 1987 and 2001 in which several accessions had seed viability <85%.

Races in sorghum germplasm and seed viability. Results of germination data on the basis of races are presented in Table 3. The mean seed viability of accessions among five races and ten intermediate races of sorghum ranged between 94.21% (*durra-caudatum*) and 96.42% (*guinea-bicolor*). A large number of accessions (7,771) tested were represented by race *durra* followed by *caudatum* (7,448) and the mean seed viabilities of these races were 94.24% and 95.26%, respectively. A mean seed viability of >96% was observed in *guinea*, *guinea-bicolor* and *kafir* races while it was <95% for *durra*, *durra-caudatum*, *durra-bicolor* and *guinea-durra* races. This indicates that some of the associated seed traits with race *durra* and the intermediate forms of *durra* are less suitable for seed storage. Additional studies on different races of sorghum in relation to seed associated traits and the chemical composition on seed viability are needed for drawing precise conclusions and developing plans for viability monitoring and regeneration schedules for germplasm of different races.

Associated seed traits and seed viability. The germplasm accessions tested for seed viability represent several races showing large variation for traits associated with seeds that could influence seed longevity in genebanks. An understanding of these traits and their relation to seed viability in storage could be useful in developing protocols for safe handling of seeds before their storage in cold rooms.

The seed viability data on 36,483 accessions in relation to some important seed traits recorded during morphological characterization of the accessions is summarized in Table 4. These include glumes covering the seed, seed color, seed sub-coat, seed luster, and endosperm texture. Some of the accessions where data was not available were excluded for interpreting the results. Glume covering could be grain fully covered, grain not covered and three intermediate forms with different levels of glume covering. The mean seed viability for different forms ranged between 94.8% in 15,554 accessions with half grain covered and 96.3% in 1,360 accessions in which grains were not covered. Glume coverage in sorghum is closely related to the race of the accession. Accessions with highest seed viability are from the group with seeds not covered, a typical seed trait of *guinea* race and its intermediate forms representing

Table 3. Seed viability of sorghum active collection of different races conserved in ICRISAT genebank.

Race	Number of tested accessions	No. of accessions in viability (%) range					Mean viability (%)	SD (%)	Variance (%)
		76–80	81–85	86–90	91–95	96–100			
Bicolor	1433	25	25	138	278	967	95.84	4.59	21.02
Caudatum	7448	112	171	931	1613	4621	95.26	4.57	20.92
Caudatum-bicolor	1446	21	28	155	327	915	95.41	4.46	19.88
Durra	7771	217	281	1203	1882	4188	94.24	5.10	26.02
Durra-bicolor	2349	58	64	345	543	1339	94.59	4.93	24.35
Durra-caudatum	4296	103	164	725	988	2316	94.21	5.10	25.98
Guinea	4763	40	75	406	821	3421	96.21	4.18	17.44
Guinea-bicolor	329	2	2	28	49	248	96.42	3.80	14.47
Guinea-caudatum	3389	47	51	428	677	2186	95.48	4.43	19.67
Guinea-durra	223	6	6	32	47	132	94.66	5.29	28.03
Guinea-kafir	108	1	3	10	21	73	95.78	4.31	18.57
Kafir	1325	9	15	111	217	973	96.33	3.96	15.68
Kafir-bicolor	140	2	6	12	27	93	95.63	4.59	21.04
Kafir-caudatum	408	7	7	34	76	284	95.84	4.39	19.30
Kafir-durra	282	5	5	28	68	176	95.40	4.60	21.17
Others	773	12	19	85	145	512	95.63	4.52	20.43
Total/Mean	36483	667	922	4671	7779	22444	95.11	4.74	22.54

99.7% of the tested accessions. Incidentally, the mean seed viability of these groups was the highest (>96%) when compared to other races. The lowest mean seed viability represented by large number of accessions tested was in the group with half grain covered with glumes. This trait is commonly associated with accessions belonging to *durra*, *caudatum* and their intermediate forms. Also, the mean seed viability was <95% for the *durra* and its intermediate forms. This analysis could be valuable for developing/changing existing protocols for monitoring seed viability in the genebanks relating to the type of material conserved.

Table 4. Seed viability according to seed traits of sorghum accessions conserved as active collection in ICRISAT genebank.

Seed trait	Number of tested accessions	No. of accessions in viability (%) range					Mean viability (%)	SD (%)	Variance (%)
		76–80	81–85	86–90	91–95	96–100			
Glume covering									
Grain fully covered	1303	20	21	150	259	853	95.64	4.59	21.03
Grain not covered	1360	12	19	114	235	980	96.27	4.28	18.33
Half grain covered	15554	326	453	2174	3477	9124	94.78	4.87	23.76
One-fourth grain covered	13390	207	312	1644	2764	8463	95.31	4.62	21.31
Three-fourth grain covered	4108	89	96	506	905	2512	95.10	4.79	22.90
Others	768	13	21	83	139	512	95.48	4.68	21.91
Total/Mean	36483	667	922	4671	7779	22444	95.11	4.74	22.54
Seed color									
Black	1					1	96.00		
Brown	3063	45	55	400	647	1916	95.29	4.52	20.39
Chalky white	1195	12	15	107	242	819	96.05	4.14	17.14
Gray	1783	37	69	309	394	974	94.32	5.08	25.82
Light brown	1730	22	33	193	346	1136	95.65	4.44	19.67
Light red	4327	51	81	476	852	2867	95.65	4.40	19.40
Purple	400	2	2	48	95	253	95.78	3.94	15.51
Red	1070	23	24	123	238	662	95.19	4.83	23.30
Reddish brown	5385	129	175	815	1289	2977	94.48	4.94	24.38
Straw	7846	170	217	1007	1721	4731	94.93	4.86	23.62
Straw and red mixed	2					2	100.00	0.00	0.00
White	6644	102	155	707	1291	4389	95.56	4.60	21.16
White and red mixed	18		2	5	2	9	93.22	5.83	33.95
Yellow	2299	64	76	405	524	1230	94.10	5.18	26.79
Others	720	10	18	76	138	478	95.56	4.52	20.42
Total/Mean	36483	667	922	4671	7779	22444	95.11	4.74	22.54
Seed sub-coat									
Absent	25738	509	705	3304	5467	15753	95.04	4.83	23.31
Present	10691	156	217	1360	2300	6658	95.29	4.55	20.68
Others	54	2		7	12	33	95.31	3.92	15.34
Total/Mean	36483	667	922	4671	7779	22444	95.11	4.74	22.54
Seed luster									
Lustrous	22815	406	574	2813	4779	14243	95.18	4.73	22.41
Non-lustrous	13614	259	348	1851	2988	8168	94.99	4.77	22.75
Others	54	2		7	12	33	95.31	3.92	15.34
Total/Mean	36483	667	922	4671	7779	22444	95.11	4.74	22.54
Endosperm texture									
Completely corneous	1215	24	26	144	208	813	95.51	4.88	23.83
Completely starchy	5093	150	207	871	1223	2642	94.06	5.21	27.17
Mostly corneous	4558	53	78	418	893	3116	95.93	4.34	18.80
Mostly starchy	12012	248	329	1669	2647	7119	94.84	4.85	23.55
Partly corneous	13539	190	282	1560	2794	8713	95.44	4.50	20.26
Others	66	2		9	14	41	95.32	3.70	13.68
Total/Mean	36483	667	922	4671	7779	22444	95.11	4.74	22.54

The seed color of tested sorghum accessions shows large diversity ranging from black to white. Data on seed viability for different states of seed color is represented by one accession for black color, two accessions for variegated seeds of straw and red mixed and 18 accessions for white and red mixed; these states of seed color have small representation in the collection and were excluded for comparing the seed viability results. Rest of the accessions with varying seed coat colors had fair representation (ranging from 400 to 7,846 accessions) (Table 4). The mean seed viability ranged from 94.1% for seeds with yellow color to 96.05% with chalky white seeds. A lower level of seed viability as seen with yellow seed color is associated with race *durra* (48.9% of the accessions) and with the intermediate forms of *durra* (87%).

The sub-coat seed trait in sorghum collection is represented by two states – absent or present. There is no significant difference among these states indicating no influence on seed viability during storage (Table 4). Seed luster in sorghum is represented by two states – lustrous and non-lustrous. The mean seed viability among these states is 95.2% (22,815 accessions) for lustrous and 95% (13,614 accessions) for non-lustrous seed. The lustrous nature of the seed is related to absence of seed sub-coat, as 98.8% of the accessions are common in these two groups.

Nature of endosperm is an important seed trait for sorghum. Sorghum endosperm is basically either corneous or starchy (floury). Based on the type and extent of endosperm in the seeds, the tested accessions were grouped into five different states (Table 4). The mean seed viability among the different states ranged from 94.1% for completely starchy type to 95.9% for mostly corneous type endosperm. The mean seed viability (95.7%) of corneous nature endosperm (completely corneous and mostly corneous) accessions is relatively higher than starchy endosperm (completely starchy and mostly starchy) accessions (94.8%) indicating a positive relation between corneous seeds and seed viability. A large proportion (54.9%) of corneous endosperm nature is observed in race *guinea*, while 71.3% accessions with starchy endosperm are represented by races *caudatum*, *durra* and *durra-caudatum*.

Analysis of frequency of occurrence, calculated as number of accessions for any range of germinability and period of storage, gives a broader view of changes occurring in conserved germplasm in genebanks. A mean seed viability of 95.1% for 36,483 accessions of sorghum active collection was maintained at ICRISAT genebank. In general, the seed viability of 34,894 accessions, representing 95.6% of the tested accessions covering all groups and storage periods ranging from 5 to 20 years, was in good condition (>85%) and these acessions are safely conserved as active collection. The protocols for seed regeneration, pre- and postharvest operations resulting in higher initial seed quality and maintenance and periodical monitoring the storage environment largely contributed for maintaining the seed viability over these periods of storage. However, accessions in which the viability is under unfavorable range needs critical review to understand the reasons for making necessary improvements/changes in seed handling practices.

Conclusions

Large part of the tested sorghum active collection (95.6%) has maintained recommended levels (>85%) of seed viability for the past 22 years. Differences in sorghum seed viability are attributed largely to the growing environmental conditions of the season in which the accessions were regenerated. The *emc* in sorghum seed is independent of the accessions and their chemical composition. Germplasm accessions of races *guinea* and *kafir* have seed traits more desirable for storage. The classification and analysis of sorghum active collection based on viability is valuable for developing/improving existing protocols in managing the ex-situ collections. Results of these studies and data from future monitoring would be useful in estimating the approximated seed deterioration curves for different races of sorghum germplasm.

Acknowledgment. The authors acknowledge the support received from all technical staff of the Genetic Resources Unit, ICRISAT and thank them for their assistance in collecting data and documenting the results.

References

Cromarty AS, Ellis RH and **Roberts EH.** 1990. Design of seed storage facilities for genebank conservation. 3rd edition. Rome, Italy: International Plant Genetic Resources Institute.

FAO-IPGRI. 1994. Genebank standards. Rome, Italy: Food and Agriculture Organization of the United Nations; and International Plant Genetic Resources Institute.

Harrington JF. 1972. Seed storage and longevity. Pages 145–245 *in* Seed biology. Volume III. Insects and seed collection, storage, testing and certification (Kozlowski TT, ed.). New York, USA: Academic Press.

IBPGR and **ICRISAT.** 1993. Descriptors for sorghum [*Sorghum bicolor* (L.) Moench]. Rome, Italy: International

Board for Plant Genetic Resources; and Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics. 88 pp.

ISTA. 1993. International rules for seed testing. Seed Science and Technology 21 (Supplement):1–288.

Justice OL and **Bass LN.** 1979. Principles and practices of seed storage. London, UK: Castle House Publications Ltd.

Pabis S. 1967. Grain drying in thin layers. Presented at Agricultural Engineering Symposium, September 1967, NCAC, Silisoe, Bedford, England.

Roberts EH. 1973. Predicting the storage life of seeds. Seed Science and Technology 1:499–514.

Sastry DVSSR, Kameswara Rao N and **Bramel PJ.** 2003. Seed drying under controlled environment for long-term conservation of germplasm. Seed Research 31(2):148–153.