Seed Research, Vol. 36(2): 191-203, 2008

Assessing Natural Low Temperature Conditions in Himalayan Region for Long-Term Storage of Seeds: Facilitating Cost-effective Conservation of Plant Genetic Resources

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ABSTRACT Long-term conservation of plant genetic resources is commonly managed through storage of seeds in refrigerated chambers maintaining sub-zero temperatures, which is expensive. Hence, cost-effective long-term conservation is one of the research priorities. High altitude site, Khardung La at the height of 18,338 ft. in the Himalayan region with sub-zero temperatures for most part of the year, is explored for storage of seeds of 149 representative accessions in 47 major field and horticultural crops, belonging to various crop groups. The quality (germination) of stored seed was monitored at periodic intervals viz., one year, two years and four years. The results indicated that nearly all accessions were able to maintain their seed quality very close to their original values; suggesting that the seed material of diverse crop species can be cost-effectively stored for long-term duration under natural low temperature conditions prevailing in the Himalayan region.

Key word: Orthodox seeds, physiological maturity, storability, seed quality, conservation, plant genetic resources

Seed storage problems are more common in tropical countries, like India, because a large part of the country has predominantly hot and humid tropical and sub-tropical climate with great variation in temperatures, rainfall and relative humidity across the year, which adversely effect the temperatures and moisture contents in the stored seeds, critical for retention of seed in dormant stage, to maintain the original seed quality and genetic constitution. Therefore, in countries like India, long-term conservation of plant genetic resources is managed through storage of seed, after drying them to three to seven per cent moisture contents [1] in refrigerated chambers maintaining sub-zero temperatures. Ninety per cent of the world's seed propagating plants produce orthodox or desiccation tolerant seeds [2], which can be dried to these low moisture levels without loss of seed quality. It involves a huge expenditure on, establishment cost, energy cost for operation and maintenance. Hence, a cost-effective long-term conservation of important plant genetic resources for food and agriculture (PGRFA) is one of the research priorities.

Passive seed storage in cold arid zone was proposed as early as in 1984 [3] at Abra Pampa, Argentina to utilise radiation cooling. Scandinavian countries established the Nordic genebank in abandoned mines on Spitsbergen Island, within the Arctic Circle with sub-zero temperatures to store seed germplasm. Recently, Argentina has experimented with the storage of rice accessions at Antarctica.

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Received April 2008 Revised November 2008 Accepted December 2008

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In India, there are several high altitude areas in the Himalayan region with sub-zero temperatures combined with low RH for most part of the year, and hence these conditions will be able to support long-term conservation of orthodox (desiccation tolerant) seeds in a cost-effective manner. Recognizing this, an exploratory project was launched in 2001 surveying various high altitude regions of Himalayas. Meteorological data were collected from several locations, such as Defence Research and Development Organisation ((DRDO) Laboratories, Pithoragarh in Uttranchal, Research Station of Directorate of Wheat Research in Lahul Spiti Research Station of Chaudhary Sarwan Kumar Krishi Vishvavidyalya, Palampur at Kinnaur in Himachal Pradesh, DRDO, Field Research Laboratory (FRL) at Leh and Khardung La pass on way to Siachen glacier in Ladakh (Table 1). Based on meteorological data and ground survey, Khardung La at the height of 18,338 ft was jointly identified by National Bureau of Plant Genetic Resources (NBPGR) and FRL, Leh for an exploratory experiment. Khardung La has sub-zero temperatures and low relative humidity (RH) for most part of the year, except in summer months, June to August, when temperature rises up to 12^0 C for a few hrs in the day and RH to a maximum of 35 per cent.

MATERIALS AND METHODS

Seed samples of 149 representative accessions in 47 major field and horticultural crops belonging to various crop groups viz., cereals, millets, pulses, oilseeds, fibre crops, and vegetable crops were selected. Seed material was processed as per the established genebank standards [4], i.e. checked for physical purity, germination percentage and dried to a moisture level ranging between 5 to 10 per cent depending on the kind of crop/species. Two hundred fifty seeds of each accession in two replicates totaling to twelve packets were prepared for periodic monitoring during storage, one set of each accession was kept in the national genebank at NBPGR New Delhi, served as control. The seeds were hermetically sealed in aluminium foil pouches, air lifted to Leh and then transported to Khardung La by road. The aluminium foil pouches containing the seed material were kept in a wooden box and this box was kept inside the Hanuman temple situated at the Khardung La pass, and stored for a period of four years. The seed material was retrieved for monitoring of germination at three periodic intervals viz., one year, two years and four years from the start of seed storage.

Seed quality (germination percentage) was monitored following ISTA rules [5, 6] for standard germination test, with a modification of using two replications of 50 seeds each.

Statistical analysis

For analysis of variance (ANOVA) between the treatments, analysis was conducted using SPSS version 14. The level of significance was tested at 5 per cent. The graphs depicting seed germination of different crops in crop groups and among the crop groups were generated using the average mean values of germination for better understanding the seed storage trend.

RESULTS

Variation in seed germination was recorded during three periodic monitoring of seed quality for- a) within a crop species, b) among crops in a crop group and c) among crop groups is presented in table 2 along with ANOVA estimation for each crop at P=0.05.

a. Variation in seed germination among accessions of a crop species

Details of accessions used, the seed moisture contents of seed samples at the start of seed storage and mean seed germination registered in seed samples of different accessions, belonging to various crops from different crop groups, at different intervals of three monitoring are presented in table 2.

Cereals

Seed materials (28 accessions) belonging to five major cereal crops were stored (Table 2). The monitoring of seed germination in accessions of these crops showed following trend during their storage. *Paddy*: Of the nine accessions, three maintained the seed quality near to their original

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values, whereas four accessions had conspicuous decrease, two showed first increase and then in one it came down to initial seed quality level; *Wheat*: Of the six accessions stored, four maintained the seed quality near to their original values, one expressed slight increase, whereas, the others showed decrease; *Maize*: Of the seven accessions stored, four maintained the seed quality near to their original values, whereas, three showed gradual decrease leading to poor seed germination, irrespective of whether they had high or low initial seed germination (Table 2); *Barley*: Of the five accessions stored, three maintained the seed viability near to their initial, whereas, remaining two showed decrease (88 to 42%); *Oat*: The only accession stored, maintained high seed quality, near to its original value.

Pseudocereals

All nine accessions of amaranth stored, maintained seed germinability near to their original values, the accession IC-255555 showed significant increase (67 to 90%).

Millets

Seed materials (18 accessions) belonging to six major millet crops were stored, which registered following trend in seed germination (Table 2), *Pearlmillet*: Of the three accessions stored, two maintained the seed germination near to their original values, whereas, the third showed a slight decrease; *Sorghum*: All the three accessions stored, despite moisture content difference maintained seed germination closer to their initial values; *Italian millet*: Both accessions stored, maintained seed germination closer to their initial values; *Finger millet*: Of the four accessions, three showed increased seed germination, and one showed decrease (52%), despite high seed germination (94%) at the start of seed storage; *Prosomillet*: Both accessions stored maintained high seed germination; *Barnyard millet*: Of the four accessions stored, two maintained the seed germination near to their original values, in one it increased (62 to 90%) and in other it decreased (Table 2).

Grain legumes

In grain legumes, 20 accessions belonging to eight major crops were stored. The seed germination registered during storage is listed in table 2. *Blackgram*: Both accessions maintained the seed germination near to their original values; *Greengram*: Both the accessions maintained the seed germination near to their original values; *Pigeonpea*: Of the four accessions stored, three maintained seed germination near to their original values, whereas, long-duration Bahar, showed an increase in the germination percent; *Lentil*: Of the two accessions stored, K-75 showed slight increase in seed germination, which was maintained subsequently, whereas, Sapna maintained seed germination near to its original value; *Pea*: Of the four accessions stored, three maintained seed germination near to their original values, whereas, Arkel, recorded slight decrease; *Gardenpea*: Both the accessions recorded increase in seed germination; *Guar*: All three accessions stored, maintained high seed germination near to their original values; *Cowpea*: The only accession, Pusa Sukomal maintained seed germination near to its original value.

Oilseeds

In oilseeds, 33 accessions belonging to five major oilseed crops were stored, which showed the seed germination during storage as presented (Table 2). *Rapeseed-mustard*: Of the ten accessions stored, in four the final germination increased (72 to 96%), whereas, in five it was maintained closer to their seed germination at the start of seed storage, and in one, it decreased (78 to 67%); *Groundnut*: Of the six accessions stored, four maintained the seed germination near to their original values, one showed a gradual increase (82 to 91%), whereas, the one with poor initial seed germination (42%) deteriorated further (24%); *Sunflower*: Of the four accessions stored, three maintained seed germination near to their original values, whereas, one showed increase that was maintained subsequently; *Soybean*: Of the four accessions stored, three maintained seed germination near to their original values, whereas, one that had moderate germination (83%) at the start of seed storage showed gradual decrease to complete loss (Table 2); *Safflower*: Of the five accessions stored, four maintained seed germination near to their original values, whereas,

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one showed slight decrease; *Castor*: Of the four accessions stored, three showed an increase in germination per cent during first monitoring interval. Two of these showed further increase, whereas the fourth showed decrease in second and third monitoring intervals (Table 2).

Fibre crops

In fibre crops three accessions of two major fibre crops stored, showed the seed germination summarised in table 2. *Cotton*: Both accessions showed increase in germination (66 to 86%) during first two monitoring intervals, maintained subsequently; *Jute*: The only accession stored maintained high germination percentage with slight increase (92 to 98%).

Vegetables and spices

Among vegetables, 37 accessions belonging to six major vegetable crop groups and 19 crops, including spices, were stored, which registered seed germination summarized in table 2. *Solanaceous vegetables - Brinjal*: Of the four accessions stored, three showed initial increase (74 to 96%) followed by gradual decrease, whereas, the fourth maintained seed germination near to its original value; *Tomato*: Of the three accessions stored, two showed significant increase (18 to 90%) in seed germination, maintained in subsequent monitoring interval, whereas, the one recorded double germination during second monitoring interval, that decreased subsequently; *Chilli*: Of the two accessions stored, one maintained seed germination near to its original value, whereas, the other, showed significant increase with slight decrease in subsequent monitoring; *Cucurbitaceous vegetables - Watermelon*: The only accession stored, showed a gradual decrease (50 to 41 per cent); *Spongegourd*: The only accession stored, showed increase in seed germination from 78 to 92 per cent; *Muskmelon*: Of the two accessions stored, one with high germination at the start of seed storage, maintained its seed germination (Table 2), whereas, the other one with poor seed germination (24%) at the start of seed storage deteriorated further to complete loss; *Ashgourd*: The only accession stored, showed increase in seed germination from 60 to 97 per cent; *Roundgourd*: The only accession stored, showed increase in seed germination from 54 to 86 per cent; *Bottlegourd*: The only accession stored, showed gradual increase in seed germination from initial 38 to 100 per cent; *Cole crops - Turnip*: The only accession stored with poor seed germination (9%) at the start of seed storage recorded a complete loss; *Radish*: Of the three accessions stored, China Pink maintained its high seed germination, PR showed increase (66 to 78%), and PC stored with poor germination (42%) registered initial increase followed by drastic decrease (28%) table 2; *Cabbage*: Both accessions of Chinese cabbage maintained seed germination near to their original values; *Tuberous vegetables - Beetroot*: The only accession stored, showed increase in first monitoring (88 to 98%) followed by subsequent decrease (98 to 82%) in germination (Table 2); *Sugarbeet*: The only accession stored with low initial germination (64%) showed a gradual decrease to complete loss (Table 2); *Carrot*: The only accession stored with poor germination (50%) showed decrease (38%) followed by subsequent increase (58%), that was maintained; *Others - Okra*: Of the five accessions stored, three showed increase in the germination per cent (73 to 94), of which one recorded decrease in subsequent monitoring intervals. The accession kept with poor germination (40%) further deteriorated (25%); *Spinach*: Of the three accessions stored, one maintained the high seed germination with a drop in first monitoring interval, the other two recorded an increase (75 to 84% and 87 to 94%), respectively, maintained subsequently; *Spices - Coriander*: Of the three accessions, one PD1 showed a significant increase (51 to 86%) in the subsequent monitoring by pre-washing treatment; the other two maintained their seed germination near to their original values (Table 2); *Fenugreek*: Of the two accessions stored, one showed slight increase, whereas the other maintained the high seed germination (Table 2).

b. Seed germination in various crops within a crop group

Cereals

Of the five cereals stored with different number of accessions, wheat accessions showed an increase in germination during second monitoring interval followed by a drop to original

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germination values during third monitoring interval. Barley accessions showed a slight decrease during second monitoring followed by further decreases (Fig. 1a). Oat accession maintained the high germination per cent of over 90 per cent during all three monitoring intervals (Fig. 1a). In paddy and maize, most accessions maintained the seed quality, but equal number accessions showed slight decrease in germination. Therefore, cereals in general maintained the seed germination near to their original values with an exception for barley.

Millets

Most millets accessions maintained seed germination near to their original values except for finger millets and barnyard millet, where a few accessions for some reason recorded little decrease (Fig. 1b).

Grain legumes

Among grain legumes, gardenpea, though showed minor fluctuations in seed germination during monitoring, but over all changes were not very significant and most accessions maintained seed germination near to their original values (Fig. 1c). Guar showed similar trend in maintaining the seed quality very close to its initial value. The seed germination in pea, ranged from 88-94 per cent with an initial drop followed by a slight increase. Blackgram showed a slight increase during first and second monitoring followed by a drop near to its original value. In lentil trend was more or less similar to pea, with little fluctuations, recorded a slight increase in seed germination over the initial values. Greengram showed significant increase in germination, which was maintained subsequently. Cowpea showed a gradual increase in germination up to second monitoring, followed by a drop during third monitoring. Pigeonpea, alike greengram, showed increase during first monitoring, which was subsequently maintained (Fig. 1c).

Oilseeds

In sunflower, safflower and groundnut the seed germination showed a very little change, and most accessions maintained seed germination near to their original values. Rapeseed-mustard and castor showed similar trend with an increase in germination in initial monitoring, which was more significant in castor than rapeseed. Soybean showed a gradual decrease in the germination percentage from 92 to 72 per cent (Fig. 1d).

Fibre crops

In fibre crops, both jute and cotton maintained the initial seed germination up to first monitoring, followed by an increase during second and third monitoring (Fig. 1e). Increase was greater in cotton (66 to 75%), compared to jute, where it increased from 92 to 98 per cent (Fig. 1e).

Vegetables and spices

Solanaceous, brinjal and tomato showed increase in the germination per cent, with tomato showing an increase from 40 to 80, and brinjal 65 to 75 percent. Chilli maintained the initial seed quality with minimum variation. In cucurbitaceous vegetables, ashgourd, bottlegourd and roundgourd (tinda), the initial germination was poor (40-60%), however, in ashgourd and bottlegourd the germination increased to almost 100 per cent during first monitoring interval and continued to maintain it by second and third monitoring intervals. But in muskmelon and watermelon the poor seed quality at the start of seed storage decreased further (Fig. 1f). Among cole crops, cabbage and radish maintained their seed quality near to their original values, whereas, in turnip, which had poor initial seed germination, germination was completely lost during storage. Spinach maintained the seed quality near to its original value, whereas, okra, which had initial seed germination only 60 per cent, recorded a slight increase during third monitoring interval. Among seed spices fenugreek maintained the seed quality, near to its initial value, whereas, coriander showed a steep increase during second monitoring, followed by a drop during third monitoring. Therefore, among vegetables, except for sugarbeet and the melons, most of the vegetables maintained the seed quality around initial values with an initial increase in some cases (Fig. 1f).

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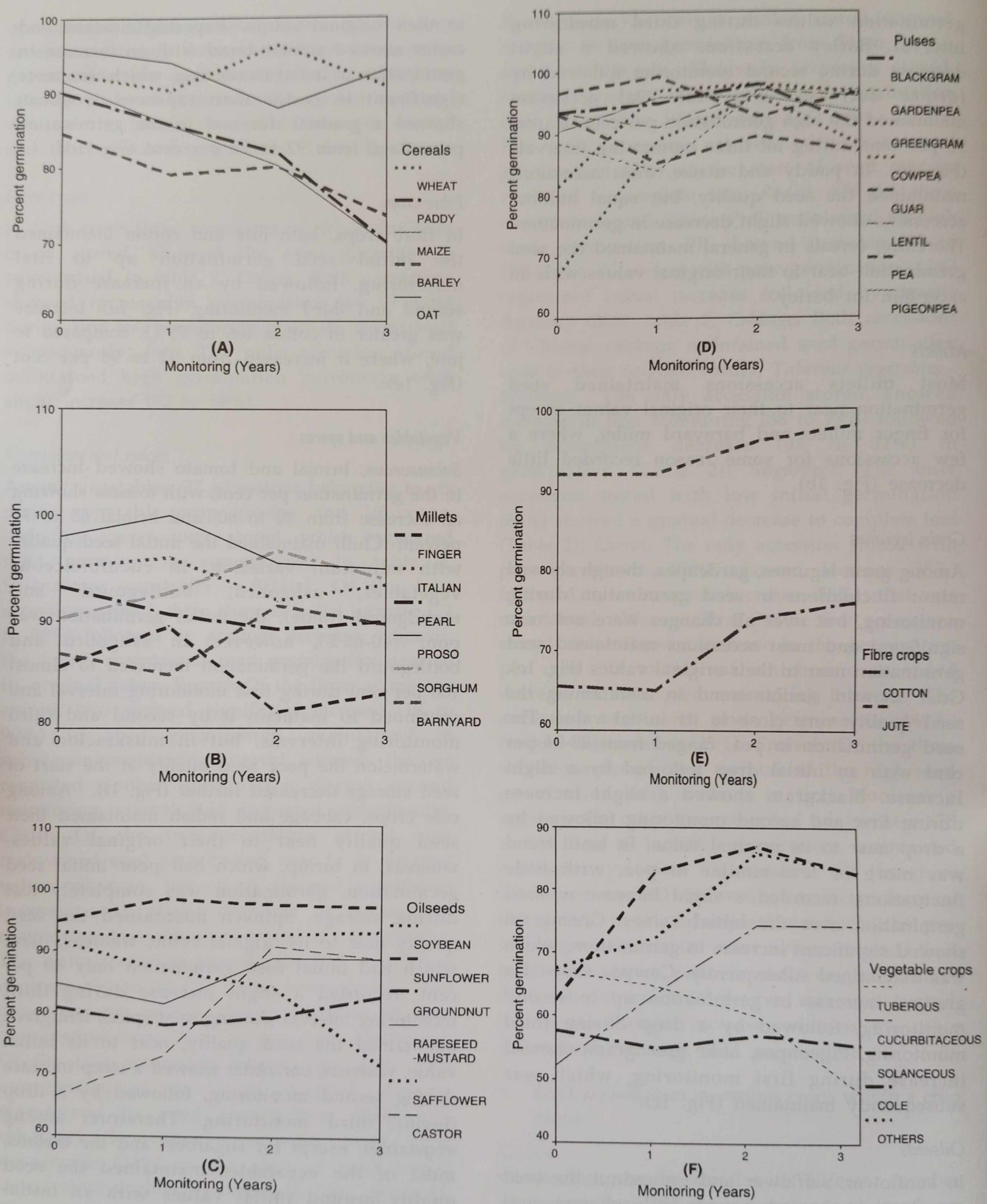

Fig. 1. Seed germination of different crops within a crop group stored under sub-zero temperatures at Khardung La, (a) Cereals, (b) Millets, (c) Pulses, (d) Oilseeds, (e) Fibre crops and (f) Vegetables and spices

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c. Variation in seed quality (seed germination) among crop groups

Among crop groups, in totality, millet crops maintained the seed quality near to their initial germination values with an exception of a few accessions. In cereals, most crops maintained the initial seed quality, except for barley. Grain legumes depicted better storability, recorded an increase in germination during the initial monitoring. Among oilseeds, the variability in seed quality between different crops was less than that of other groups. Soybean, recorded decreased seed germination during storage. The fibre crops depicted an increase from initial seed germination that was maintained subsequently. Most vegetable crops except for sugar beet and the melons maintained the seed quality around initial germination values (Fig. 2). In all the crops, the accessions stored with poor initial seed quality (germination %) than the recommended standard values, recorded further deterioration in seed quality. However, in most grain legumes, seeds stored with higher moisture contents (8-11%) were able to maintain their seed quality up to four years of study period.

DISCUSSIONS

The study was conducted to explore the feasibility of long-term storage of orthodox seeds under natural low temperature conditions in the Himalayan region, to facilitate cost-effective conservation of plant genetic resources. The critical appraisal of meteorological data (Table 1) indicated that Khardung La pass situated at the height of 18,338′ on a way to Siachin glacier is the most appropriate place with sub-zero temperatures (–32° to –0.8°C) during most part of the year, with mean temperature of –6°C.

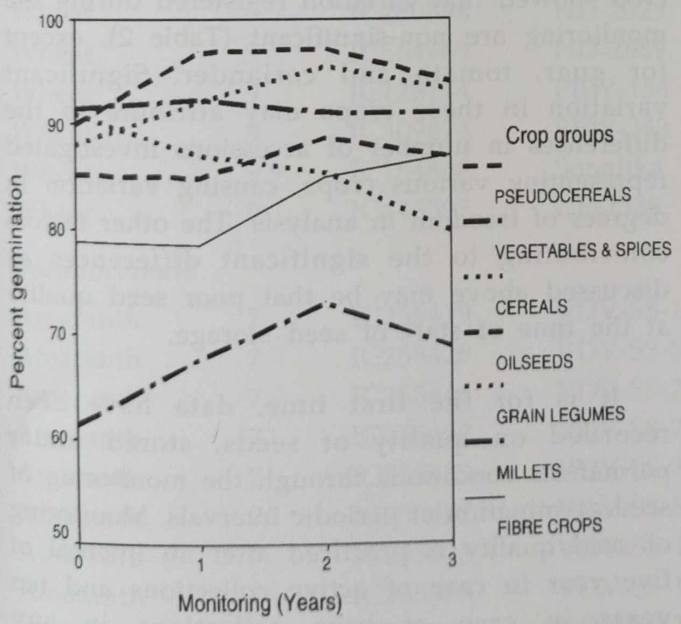

Fig. 2. Seed quality among various crop groups stored under natural sub-zero temperatures at Khardung La

Monitoring of the seed quality (Germination %) in 47 different crops, belonging to both agriculture and horticulture crop groups, stored under the natural low temperatures, prevailing at Khardung La, at three periodic intervals during storage, starting from 1 year, 2 years and 4 years from start of seed storage, registered various trends in maintaining the seed quality between the accessions of the same crop species. This could either be because of the genotypic differences among accessions or due to differences in physiological maturity of the seed materials, at the start of the seed storage. Further, the monitoring results indicated that differences between the crops of a group and between the crop groups in the maintenance of seed germination were not significantly high alike those of between accessions. Thus, suggesting that most crop species are able to maintain the seed quality near to their initial values. The results were similar to those of the seed material stored under artificial low temperature conditions of –20°C in refrigerated chambers or cold storage vaults. Thereby, suggesting that in general all the crops could be stored under the natural low temperature conditions (permafrost) of Himalayan Region with similar level of success. However, differences may occur, mostly due to the differences in quality of seed samples at the start of seed storage.

Among various crop groups, the millets depicted most consistent trend in maintaining the seed quality, very near to their original values (Table 2). Minor variations observed in case of finger millets and barnyard millets in a few accessions, need further investigation. Following millets, the oilseed crops depicted consistent results, except soybean; other crops maintained seed quality closer to their original values. Castor, in fact showed a sharp increase in the

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Table 1. Temperature and relative humidity at various locations surveyed for identification of site for zero energy based seed conservation 2001

Months	Leh Temperature (°C) Min	Leh Temperature (°C) Max	Leh R.H. (%)	Khardung La Temperature (°C) Min	Khardung La Temperature (°C) Max	Khardung La R.H. (%)	Pithoragarh Temperature (°C) Min	Pithoragarh Temperature (°C) Max	Pithoragarh R.H. (%)	Kinnaur Temperature (°C) Min	Kinnaur Temperature (°C) Max	Kinnaur R.H. (%)	Lahul Spiti Temperature (°C) Min	Lahul Spiti Temperature (°C) Max	Lahul Spiti R.H. (%)
January	-15	-3	68	-31	-8	-	-5	9	57	-6	4	80	-19	-5	51
February	-14	11	61	-24	-4	-	2	12	52	-4	7	83	-21	-8	42
March	-10	16	54	-19	-3	-	4	16	43	-1	13	76	-18	-5	43
April	-3	24	49	-12	-1	-	10	21	30	-4	15	70	-5	3	69
May	8	30	41	-6	5	-	11	21	56	7	19	64	-1	12	49
June	12	34	35	0.8	10*	-	13	21	75	11	24	71	6	18	81
July	11	33	52	2	12*	-	15	20	89	13	25	84	10	23	87
August	7	26	61	2	11*	-	16	21	85	17	29	86	11	25	87
September	4	18	64	-2	8	-	14	20	82	14	21	81	7	17	81
October	-3	19	63	-8	3	-	8	17	58	5	17	71	3	15	86
November	-10	16	66	-16	-2	-	6	15	48	2	13	63	-3	8	75
December	-19	-4	74	-28	-6	-	3	11	53	-3	6	77	-12	1	71

*The higher temperatures are only for 1-3 hrs in the afternoon

germination, which continued to increase in subsequent monitoring. This may be because of variations in the physiological maturity of the seeds. On the other hand, soybean, which is known as poor seed storer (Genotypic variations have been reported), registered loss in seed germination during storage, because of the delicate seed coat. In cereals, most crops maintained the seed quality near to their original values, except in barley. Alike oilseed crops, most grain legumes maintained seed quality closer to their original values. Some seeds namely, greengram registered increase in seed quality during the first monitoring interval, which was maintained in subsequent monitoring interval. This can be attributed to basic differences in physiological maturity of seeds or due to physical dormancy (hard-seeded-ness). Both the fibre crops have maintained the seed quality, closer to their original values with a little increase in germination in the first monitoring interval. Most of the vegetables, irrespective of their association to groups, such as solanceous, cucurbitaceous, cole crops, tuber crops, including spices depicted a consistent behaviour in maintaining the seed quality closer to their original values during the four years of seed storage with an exception of sugarbeet.

ANOVA analysis of these results based on mean germination per cent of accessions in each crop showed that variation registered during the monitoring are non-significant (Table 2), except for guar, tomato and coriander. Significant variation in these crops may attribute to the differences in number of accessions investigated representing various crops, causing variation in degrees of freedom in analysis. The other factors contributing to the significant differences as discussed above may be that poor seed quality at the time of start of seed storage.

It is for the first time, data have been recorded on quality of seeds, stored under permafrost conditions through the monitoring of seed germination at periodic intervals. Monitoring of seed quality is practiced after an interval of five year in case of active collections and ten years in case of base collections in any international seed genebank.

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Table 2. Seed germination at periodic intervals in seed samples of various crops stored at Khardung La during 2001

Group/ crop name	mc (%)	National ID	Alternate ID	Mean germination(%) during monitoring of seed germination				P value at 0.05
				Initial[1]	I	II	III	
Cereals								
Barley	7	IC283459	VKS-SCC-4/4	91	90	96	91	**0.256**
Barley	7	IC283462	VKS-SCC-4/7	94	84	88	88	
Barley	7	IC283576	VKS-SCC-4/121	70	56	48	42	
Barley	7	IC283590	VKS-SCC-4/135	88	86	73	50	
Barley	7	IC283611	VKS-SCC-1/156	100	100	96	98	
Maize	9	IC73180	A-Popcorn	96	81	59	40	**0.29**
Maize	9.9	IC564964	G-11	100	74	66	50	
Maize	9	IC564965	Ganga Safed	95	96	92	92	
Maize	9	IC564966	PHEM-1	98	96	96	89	
Maize	9	IC 564967	Shakthi	61	55	54	22	
Maize	9	IC262023	Co-VRS-CM-910	99	100	100	100	
Maize	7	IC317315	Hybrid Seed Tech-2324	99	98	96	98	
Oat	9	IC103123	Kent	96	94	88	93	**ND**
Paddy	9	IC454553	IR-36	70	75	80	68	**0.09**
Paddy	9	IC374708	IR-64	82	81	92	90	
Paddy	9	IC 564968	JBT-6/11	89	82	62	18	
Paddy	9	IC388910	Jyothi	95	90	100	97	
Paddy	7	IC213663		90	78	54	44	
Paddy	7	IC259432		100	100	80	70	
Paddy	7	IC259450		94	88	92	87	
Paddy	7	IC259458		90	80	82	63	
Paddy	7	IC277886		100	98	96	96	
Wheat	9	IC280398	HD-2329	87	82	98	94	**0.473**
Wheat	9	IC564969	HD-2689	95	92	94	89	
Wheat	9	IC128144	PBW-154	98	96	100	100	
Wheat	9	IC309874	PBW-343	88	86	90	68	
Wheat	9.9	IC184868	Sonalika	95	94	100	100	
Wheat	9	IC445595	UP-2338	93	92	96	94	
Pseudocereals								
Amaranth	7	IC255419	VDV-SS-147	92	96	100	93	**0.055**
Amaranth	7	IC255428	VDV-SS-5	89	98	100	98	
Amaranth	7	IC255446	VDV-SS-23	93	92	90	95	
Amaranth	7	IC255452	VDV-SS-23	90	100	100	94	
Amaranth	7	IC255453	VDV-SS-30	95	100	100	92	
Amaranth	7	IC255481	VDV-SS-58	94	96	100	100	
Amaranth	7	IC255523	VDV-SS-100	95	100	100	98	
Amaranth	7	IC255555	VDV-SS-132	67	90	88	82	
Amaranth	7	IC255608	VDV-SS-185	95	97	90	94	

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Group/ crop name	mc (%)	National ID	Alternate ID	Mean germination(%) during monitoring of seed germination				P value at 0.05
				Initial[1]	I	II	III	
Millets								
Barnyard millet	7	IC283506	VKS-SCC-4/51	98	100	100	100	**0.927**
Barnyard millet	7	IC283507	VKS-SCC-4/52	94	100	96	93	
Barnyard millet	7	IC283594	VKS-SCC-4/139	62	56	84	90	
Barnyard millet	7	IC283610	VKS-SCC-4/155	92	84	86	76	
Finger millet	7	IC283557	VKS-SCC-4/102	74	92	92	89	**0.898**
Finger millet	7	IC283583	VKS-SCC-4/128	94	92	50	52	
Finger millet	7	IC283589	VKS-SCC-4/134	87	86	86	94	
Finger millet	7	IC283609	VKS-SCC-4/154	88	88	98	98	
Italian millet	7	IC283558	VKS-SCC-4/103	98	96	94	96	**0.63**
Italian millet	7	IC283592	VKS-SCC-4/137	92	96	90	91	
Pearlmillet	8	IC295945	HHB-50	97	94	92	86	**0.619**
Pearlmillet	8	IC295946	HHB-60	90	90	92	90	
Pearlmillet	6	IC275099	MSSR-001234	93	88	84	94	
Prosomillet	6	IC283520	VKS-SCC-47/65	98	100	98	96	**0.16**
Prosomillet	6	IC283539	VKS-SCC-47/84	98	100	93	94	
Sorghum	10	IC564970	N-35-1	88	86	90	94	**0.605**
Sorghum	6	IC262003		85	96	100	90	
Sorghum	6	IC275092	MSSR-001236	98	96	100	98	
Grain legumes								
Blackgram	7	IC548282	LBG-623	92	100	96	86	**0.664**
Blackgram	7	IC73523	T-9	95	90	100	96	
Cowpea	8	IC305230	Pusa Sukomal	87	89	96	88	**ND**
Gardenpea	8.2	IC564971	Palam Priya	93	90	100	100	**0.224**
Gardenpea	8.2	IC564972	AP-1	84	78	94	94	
Greengram	8.6	IC296167	K-851	99	100	98	99	**ND**
Greengram	8.6	IC73536	SML-32	94	94	98	94	
Guar	8.5	IC564973	G-1	98	100	92	98	**0.031[2]**
Guar	8.5	IC296189	PNB	93	100	92	98	
Guar	8	IC564974	RGC-93	99	98	94	94	
Lentil	9.6	IC560208	K-75	93	94	100	100	**0.537**
Lentil	9.6	IC564975	Sapna	94	88	94	92	
Pea	8	IC405262	Aparna	93	88	100	94	**0.864**
Pea	8	IC28061	Arkel	90	63	62	66	

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Group/ crop name	mc (%)	National ID	Alternate ID	Mean germination(%) during monitoring of seed germination				P value at 0.05
				Initial[1]	I	II	III	
Pea	8	IC489630	Rachna	97	98	98	98	
Pea	8	IC564976	Shikka	93	92	98	90	
Pigeonpea	10	IC296187	Bahar	80	96	94	90	**0.287**
Pigeonpea	10	IC296269	Guj-100	94	98	100	98	
Pigeonpea	10	IC240820	ICPL-85063	95	94	94	96	
Pigeonpea	9	IC296186	ICPL-87119	93	96	96	90	
Oilseeds								
Castor	5	IC304916	48-1	50	48	90	91	**0.17**
Castor	5.4	IC564977	BP-1	96	100	90	86	
Castor	5.7	IC564978	Geetha	79	74	92	88	
Castor	5.5	IC564979	HS-72	41	70	90	89	
Groundnut	6.1	IC305009	TAG-24	42	30	22	24	**0.99**
Groundnut	5	IC304518		81	82	85	91	
Groundnut	5	IC304519		94	91	90	94	
Groundnut	5	IC304521		92	92	98	100	
Groundnut	5	IC304557		89	89	90	94	
Groundnut	5	IC304558		86	84	90	92	
Mustard	5.6	IC73188	B-9 Yellow	90	86	98	90	**0.467**
Mustard	6.5	IC564980	BNP-2000-01	79	78	96	96	
Mustard	6	EC257781	GSL-SEL-1	77	72	74	74	
Mustard	6.5	IC564981	HR-30	72	72	92	92	
Mustard	6	IC305066	Hyola-401	95	90	98	96	
Mustard	6	IC257780	Pusa Bold	94	90	88	86	
Mustard	6.5	EC386314	Pusa Agarni	98	100	100	100	
Mustard	6.5	IC305064	Pusa Jai Kisan	80	86	96	91	
Mustard	6	IC494400	T-59	84	78	94	92	
Mustard	6	IC564982	T-9	78	61	50	67	
Safflower	5	IC113142	Bhima	95	96	98	96	**0.985**
Safflower	4	IC308549	JSI-10	94	92	92	94	
Safflower	4	IC308548	JSI-103	90	90	84	82	
Safflower	4	IC308547	JSI-97	96	92	94	94	
Safflower	5	IC274725		90	90	94	98	
Soybean	5	IC255553		98	98	95	96	**0.774**
Soybean	5	IC262053		94	94	98	100	

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Group/ crop name	mc (%)	National ID	Alternate ID	Mean germination(%) during monitoring of seed germination				P value at 0.05
				Initial[1]	I	II	III	
Soybean	5	IC262087		91	90	95	90	
Soybean	5	IC266916		83	65	48	0	
Sunflower	5	IC501975	Morden	94	94	96	100	0.52
Sunflower	5	EC413054		96	100	100	94	
Sunflower	5	EC413055		100	100	95	95	
Sunflower	5	EC413056		89	99	98	98	
Fibre crops								
Cotton	8	IC564983	H-8	65	66	84	82	0.499
Cotton	8	IC564984	NNH-44	64	64	64	70	
Jute	8	IC430385	JR-524	92	92	96	98	ND
Vegetables and spices[3]								
Brinjal	7	EC133615	PPL	78	94	80	82	0.157
Brinjal	6	IC255530	VDV-SS-107	77	96	86	80	
Brinjal	6	IC264929	DARL-SS-57	76	71	66	68	
Brinjal	6	IC264831	DARL-SS-59	74	96	86	66	
Chilli	7	IC564985	PJ	76	100	92	87	0.288
Chilli	7	IC564986	X-235	88	90	88	88	
Tomato	6.9	IC564987	PED	48	46	92	79	0.017[2]
Tomato	6.9	IC564988	PR	58	90	88	92	
Tomato	6.9	IC564989	SEL-22	18	58	94	88	
Muskmelon	6	IC276358		24	10	0	0	0.99
Muskmelon	6	IC276408		93	94	92	96	
Watermelon	6.5	IC564991	SB	50	44	44	41	ND
Ashgourd	8.6	IC262328		60	100	100	97	ND
Bottlegourd	5.8	IC505642	PSPL	38	72	100	100	ND
Roundgourd	6.5	IC564990	S-48	54	50	82	86	ND
Spongegourd	8.7	IC564992	PC	78	84	88	92	ND
Cabbage	5	EC182628-11		94	88	100	100	0.163
Cabbage	5	IC182664		98	96	100	100	
Radish	5	IC564993	China Pink	92	86	100	100	0.997
Radish	5	IC564994	PC	43	58	36	28	
Radish	5	IC564995	PR	66	62	78	72	
Turnip	8.5	IC564996	PTG	10	4	0	0	ND
Okra	9	IC564997	PK	40	35	34	25	0.73

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Group/ crop name	mc (%)	National ID	Alternate ID	Mean germination(%) during monitoring of seed germination				P value at 0.05
				Initial[1]	I	II	III	
Okra	9	IC399651	Varsha Uphar	74	94	76	41	
Okra	6	EC30669		79	80	92	86	
Okra	5	IC311297		73	86	88	90	
Okra	6	IC329420		70	66	94	94	
Spinach	8	IC564998	48-16A	87	94	92	89	0.546
Spinach	8	IC564999	AG	95	90	96	97	
Spinach	8	IC 565000	BDJ-140	75	84	88	92	
Carrot	7	IC361101	Nantes	49	38	60	62	ND
Beetroot	7.6	IC565001	DDR	88	98	88	82	ND
Sugarbeet	7.6	IC565002	RK	64	58	32	0	ND
Coriander	5	IC311276		51	50	92	86	0.047[2]
Coriander	7.5	IC565003	PD-1	54	54	59	55	
Coriander	7.5	IC565004	PH-1	81	83	80	78	
Kasuri Methi	6	IC57668		88	94	96	98	0.49
Kasuri Methi	6	IC67140		97	98	100	98	

1. Seed germination at the start of seed storage; 2. Significant at P = 0.05; ND = Not determined; 3. Arranged group-wise

To understand the role of seed quality and seed moisture content in storage of seeds under such natural low temperature conditions, those seed samples in certain crops stored with poor initial seed quality (Germination) and higher moisture contents, continued to deteriorate further, resulting in complete loss of seed germination, thereby, suggesting that the initial quality of the seed and following of genebank standard (IBPGR, 1994) is very important for long-term storage of seed. However, the seed with relatively low moisture content (3 to 7%; IBPGR 1994), did not show further decrease in seed germination, suggesting a role of seed moisture content during the study period of four years. These results clearly suggests that the seed material of diverse crop species can easily be stored for longer duration under natural low temperature conditions, provided sound, healthy, physiologically mature quality seeds are sampled for storage to facilitate long-term conservation of plant genetic resources.

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