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Ultra-dry seed storage: A novel technology for enhancing seed longevity

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Abstract
Ultra-dry storage, also called low moisture content storage, it is a technique for decreasing seed moisture content to below 5-6 per cent using desiccants. Desiccant is a hygroscopic substance that induces or sustains a state of dryness (desiccation) in its vicinity. The most common desiccant is silica and other common desiccants include activated charcoal, bentonite, calcium sulphate, calcium chloride and zeolites. Ultra-dry storage, also called low moisture content storage, is a technique for decreasing seed moisture content to below 5- 6 % using different methods and then stored hermetically at ambient, but preferably cooler temperatures. Some studies have confirmed that low moisture content storage can not only be used to maintain the quality of seeds, but also improve their storability (Wang *et al*., 2005). It can greatly reduce the cost of constructing and maintaining the gene bank (Zheng *et al.*, 1998). Ultra-dry seed storage technology is the one of an ideal method to store seeds for longer period by using desiccants in an air tight container without seed quality reduction. Hence, it is a suitable technology to low volume seeds, seed companies and seed banks to store precious seed material for a longer period.

Keywords: ultra-dry, seed storage, desiccant, silica gel and zeolite beads

Introduction
Seed is a basic input in agriculture. Strictly speaking seed is an embryo, a living organism embedded in the supporting or the food storage tissue. In seed, the importance is given to the biological existence whereas; in grain the importance is given to the supporting tissue the economic produce.
As per Seed Act, (1966) seed includes: Seed of food crops including edible oil seeds and seeds of fruits & vegetables, cotton seeds, seeds of cattle fodder, jute seeds, seedlings, tubers, bulbs, rhizomes, roots, cuttings, all types of grafts and other vegetatively propagated material for food crops (or) cattle fodder

Importance of quality seed
- Ensures genetic and physical purity of the crops
- Gives desired plant population
- Capacity to withstand the adverse conditions
- Seedlings produced will be more vigourous, fast growing and can resist pest and disease incidence to certain extent
- Ensures uniform growth and maturity
- Development of root system will be more efficient that aids absorption of nutrients efficiently and result in higher yield.
- It will respond well to added fertilizer and other inputs.
- Good quality seeds of improved varieties ensures higher yield at least 10 – 12 %.

Bradford's Metronome Rule: The "clock" starts running as soon as the seeds are mature and they have a total number of ticks before death. The rate at which the metronome ticks depends upon the temperature and moisture content.

Seed Storage
Seeds are considered to be in storage from the moment seed reach to physiological maturity until they germinate or thrown away because they are dead.

Importance of Seed Storage

- Helps preserve viability from harvest to sales;
- Protects producers investment, profit and reputation

Seed Drying

This is the process of reduction of seed moisture content to the below recommended levels for safe seed storage for longer periods

Why are seeds dried?

Seeds which are dry will retain their viability for longer periods of storage. For example:-

Cereals – 12-13 %
Pulses– 9-11 %
Oil seeds – 7-9 %

Seeds which are dry will retain their viability for longer period of storage. The amount of moisture in the seeds is the most important factor influencing seed viability during storage. If seeds are kept at high moisture content, the losses could be very rapid due to mould growth. The seed moisture content and storage life of seed is inversely proportional to each other. Since, the life of a seed largely revolves around its moisture content, it is necessary to dry seeds to safe moisture content. Seed drying is the reduction of seed moisture content to the below recommended level for seed storage.

Seed longevity is reduced by approximately half for every 1 per cent increase in seed moisture content or 5^0C increase in temperature and the effects are additive. Thus, seeds stored at 10 per cent moisture content and 30^0C will last only one-quarter as long as seeds stored at 9 per cent moisture content and 25^0C. This principle implies that, seed storage life can be enhanced considerably by lowering both moisture and temperature. However, moisture content is the key factor that can be lowered for successful seed storage.

Cold storage is expensive and difficult to maintain because electricity supplies are often inconsistent and unreliable. In addition, seeds that are dried to low moisture content are more tolerant of storage at high temperature. However, even prolonged sun drying in high humidity cannot reduce seed moisture content to the levels low enough to assure long-term viability. These problems can be overcome by drying seeds to ultra-drying (low moisture contents) using inexpensive hermetic containers and desiccants. Ultra-dry storage, also called low moisture content storage, it is a technique for decreasing seed moisture content to below 5-6 per cent using desiccants. Desiccant is a hygroscopic substance that induce or sustain a state of dryness (desiccation) in its vicinity. The most common desiccant is silica and other common desiccants include activated charcoal, bentonite, calcium sulphate, calcium chloride and zeolites.

Ultra-dry seed storage

Ultra-dry storage, also called low moisture content storage, is a technique for decreasing seed moisture content to below 5-6 per centusing different methods and then stored hermetically at ambient, but preferably cooler temperatures. Some studies have confirmed that low moisture content storage can not only be used to maintain the quality of seeds, but also improve their storability (Wang *et al*., 2005) [6]. It can greatly reduce the cost of constructing and maintaining the gene bank (Zheng *et al.*, 1998) [7].

Experimental proof of ultra-dry seed storage: Oat Sample

Professor Dr. Haberlandt (25th Nov. 1877) University Vienna used oat seeds and stored for stored at 15^0C with the 3.14 % MC initially they recorded about 97 per cent germination and after 110 years got 81 per cent. Seeds of other species as impurities also recorded good germination per cent (*Hordeum vulgare, Vaccaria hispanica* and *Agrostemma githago*).

In 1989, IPGRI initiated a project on ultra-dry seed storage in cooperation with the University of Reading, U. K., the Genetic Resources Unit, Horticultural Research International, Welles borne, UK. And Centre for Plant breeding and Reproduction Research (CPRO-DLO), Wageningen, Netherlands.

Different Ultra drying methods

1. Dry room or drying chamber
2. Desiccant - Silica gel / charcoal
3. Saturated salts / Lithium Chloride solutions
4. Air conditioned room / vehicle
5. Incubator drier

1. Dry room or drying chamber/Cabinet

- Drying rooms should be fitted with an airlock to minimize moisture entering from outside.
- A typical dry room, set at 10-15% RH at 10-25°C, will dry seeds of any species and at any mc in about 30 days.

2. Desiccant - Silica gel, charcoal, *etc.*

Seed drying procedures, drying time (~one month) depends on the initial moisture content of the seeds, the amount of seeds and the dryness of the desiccant.

3. Saturated salts

Lithium Chloride: at 20°C produces a RH of about 12%
Calcium Chloride: at 25°C produces a RH of about 30%
Air-tight jar with lithium chloride solution, showing plastic mesh support to hold seeds above solution. Only plastic coated metal components should be used as salts may be very corrosive.

Advantages of Desiccants over other Ultra-Drying methods

Ultra-Drying methods	Desiccants
May cause damage to the seed by over heating	No damage to the seed because of no heating
Cannot be reused	Can be reusable for several times
Cost of investment is less and maintenance cost is high	Cost of investment is high and maintenance cost is less
Seed quality is reduced rapidly	Seed quality is reduced very slowly
Seed quality is maintained for short period of storage	Seed quality is maintained for longer period of storage
Indicators are absent to overcome over drying	Indicators are used to overcome drying
Toxic to seeds- corrosive salts	Non-toxic to seeds
Insect activity is more	Insect activity is less

Desiccants

- A desiccant is a hygroscopic substance that induces or sustain a state of dryness (desiccation) in its vicinity.
- Commonly pre-packaged desiccants are solids that absorb water.
- Industrially, desiccants are widely used to control the level of water in gas streams.

Types of desiccants

The most commonly used desiccants are Silica gel, Activated charcoal, Bentonite and Beads (Zeolites).

Coloured saturation indicators

- Sometimes a humidity indicator is included in the desiccant to show, by colour changes, the degree of water-saturation of the desiccant.
- One commonly used indicator is cobalt chloride ($CoCl_2$).
  - Anhydrous cobalt chloride is blue.
  - When it bonds with two water molecules, ($CoCl_2 \cdot 2H_2O$), it turns purple.
  - Further hydration results in the pink hexaaquacobalt chloride complex $[Co(H_2O)_6]Cl_2$.

Properties of the Desiccants

- Should be Regenerative or Reusable (10,000 times)
- Should be Hygroscopic and water insoluble
- Should be Less cost effective
- Should be Easily available and have long Durability
- Should be non-Toxic to seeds and Eco-friendly
- Should be non-toxic to human beings

Zeolite Drying desiccant for the Seed Industry

Desiccants can be used to absorb moisture from seeds by breaking the bond between water molecule and the seed. Novel seed drying beads make it feasible to efficiently dry and store seeds at low RH.

Regeneration of Desiccants

Safety precautions

You are responsible for the safe and proper use of this product. The MSDS sheet supplied by the manufacturer is available on our website, linked to the silica gel descriptions. When transferring silica gel, take care not to spill beads. Beads can be hard to see and easy to slip on. Silica gel gets very hot during the redrying process. Do not attempt to handle hot silicagel, or any glass container of it, until it has cooled to a safe temperature. We do not recommend moving hot silica gel. If you must move it while it is hot, use a hot pad. Be aware that glass may shatter if it is of the wrong type, is too thin, or is unevenly heated. Do not overheat the gel. Slightly higher than normal drying temperatures, such as 280degrees, are unlikely to overheat they gel; however, overheating can ruin it, and it will take longer and longer to regenerate the gel. It is better to under heatit, than overheat it. Do not spread more than one layer of beads over the surface of the container while drying, as this could result in uneven heating. A good indication of overheated silica gel is the presence of unusually dark or black silica beads.

Do not transfer redried silica gel to another storage container until the gel has thoroughly cooled. If the gel has not cooled you will notice the presence of condensation on the walls of the storage container. Canning jars make good containers for storing silica gel. The drying effect of silica gel can also dry the skin, eyes, and mucous membranes. Avoid contact with eyes and mucous membranes. You may wish to use gloves and/or goggles. In case of accidental ingestion, drink plenty of water. Longtermexposure to silica gel dust may cause lung damage. Under dusty conditions, the use of a mask is recommended. We do not recommend using any colour indicating silica gel to dry foods. Our website product descriptions for silica gel link to the manufacturers Material Safety Data Sheet.

What quantity of beads is needed to dry seeds? The amount of beads required depends on the quantity of seeds, the initial seed MC and the final MC desired. The beads can absorb up to 25% of their weight in water. If a seed lot has 15% MC (fresh weight basis), there is 1.5 kg water in 10 kg of seed. To dry this seed to 7.5% final MC, we need to remove 0.75 kg water. Since 4 kg of beads remove 1 kg water, we need 3 kg beads per 10 kg of seeds. Charts and tables are available to easily calculate the appropriate bead: seed ratio depending upon the initial and final MC of the seed

How do you know the water absorbing capacity of beads? Since the beads have stronger affinity for water than silica gel, a colour change of a small quantity of silica gel mixed with the beads can indicate when the beads need to be regenerated. Other types of humidity indicator labels or monitoring devices could also be used.

Can all seeds be dried using seed drying beads? Only desiccation-tolerant (or "orthodox") seeds should be dried using these beads. Desiccation-intolerant ("recalcitrant") seeds like mango, durian, or citrus should not be dried by these beads.

Why can't we just dry the seed in the sun in sub-tropical/tropical regions? The temperature and humidity of the air determine how much water is present in the seed. The seeds cannot be dried to lower MC than is determined by the ambient humidity, even by multiple and prolonged exposures. Even with heated air drying, only limited seed drying may be possible if the ambient air is already warm and humid. The seeds can only be dried to lower MC by enclosing the seeds away from the ambient air and lowering the relative humidity in the container.

Can the seeds be damaged when dried by these beads? Most orthodox seeds are not damaged even when dried to 3-5 % moisture. Some seeds can be damaged when rehydrated too rapidly from very low MC. Thus, particularly for larger seeds like beans, the seeds should be removed from the storage containers and allowed to absorb moisture from the air for a few days before coming in contact with liquid water.

Are there any precautions needed while using seed drying beads? The beads heat up by an exothermic reaction if free water is added directly to the dry beads, which could result in seed damage. Similarly, do not add beads directly to very wet seeds like cucumber, melons or tomato after washing. These seeds should be surface dried before being brought into contact with the beads. Large seeds like beans become brittle when very dry and need careful handling to prevent cracking. Seeds be taken out from the beads and left under ambient conditions for several days prior to sowing.

What are other advantages of seed drying beads? Since the seeds are inside airtight containers, they are also protected from molds, insects and rodents. Once the seeds are dry, the

beads can be removed and re-used. So long as the seeds remain inside of the airtight container, they will remain at the same MC even after the beads are removed.

Can seed drying beads be used for other purposes? These beads can be used to dry herbs, fruits or vegetables and seeds.

Can the bead drying system be scaled up for large quantities of seeds? Based on the need, from a few grams to metric tons of seeds can be dried. For larger quantities, forced air systems have been designed that use the beads to dry the air that is circulated through the seeds.

Why not to use silica gel to dry seeds? Silica gel can and has been used to dry seeds. However, silica gel has a lower affinity for water than seed drying beads at the low humidity that we wish to obtain. Although silica gel can be regenerated by heating at a lower temperature, there is loss of water holding capacity of silica gel due to polymerization after repeated heating. There is no loss of water holding capacity of seed drying beads after repeated regeneration.

How do I know that the containers are airtight? If a small quantity of fresh silica gel placed inside an empty, sealed container changes its color within a few days, it indicates that the container is not moisture proof. Using a rubber gasket in the cap or lid helps to make an airtight seal.

Can seed drying beads help women in resource poor areas? Mostly women are involved in seed production. Traditionally, seeds have been dried under the sun, which requires constant vigilance against birds, rodents and rainfall. Women need to collect seeds in the evening and spread them out the next morning for several days. Since the seed drying beads are used inside an airtight container, women will avoid the above problems and hence save time for other activities.

What is the cost of the beads to the farmers? The cost of the beads in a particular location is uncertain, as each country may have import duties or other costs that must be considered. There is a one-time initial investment for the beads that we estimate to be approximately €10-20 (800-1200 Rs) per kg. However, as the beads can be re-used indefinitely, this cost can be spread over many years. A cooperative bead exchange program could also provide only the quantity needed, when it is needed. Good seed storage is an investment in terms of value added to seeds, time saved and loss that would normally take place from birds, insects, rodents, fungi in ambient air drying. Additionally, no pesticides are needed to combat these pests as long as the seeds are dry and in sealed containers. With extended seed storage life, growers can produce more seed in one year and save the seeds for several years, allowing the land to be used for growing other crops. This practice provides an insurance against possible natural calamities like bad weather conditions or outbreak of diseases or insects.

When the beads will be available in the market? We are currently investigating market-based systems that will provide the mechanism to make the beads available and encourage entrepreneurial enterprises to support their use. Smaller quantities are available for pilot studies or research.

How can the seed drying beads help a national agriculture system? In the short run, value-added seeds help growers produce quality crops which become the backbone of national food security system. National gene banks in resource poor areas of the globe can use the seed drying beads for germ plasm conservation, thus minimizing the seed multiplication frequency. This approach may be particularly valuable for preserving indigenous crops that contribute to stable local food systems.

Advantages of Desiccant for ultra-drying of seeds

- Provides practical method
- Can dry seeds to a specific and low MC (2-3 %)
- Protected from molds, insects and rodents
- It warns over possible seed desiccation
- Can re-use desiccants
- Real cost saver
- Seed quality is preserved for several years
- It further delays ageing by absorbing toxic gasses - Ethylene
- Used in Humid regions
- Conservation of germ plasm for longer period
- Used for the post-harvest drying and processing industry
- No need for cold storage to maintain seed viability

Disadvantages of Ultra-drying seed storage

- Investment cost is very high
- Separation of desiccants from the seeds is difficult, again it requires labour to separate
- If the colour indicators are not used for ultra-drying may cause overheating and desiccation problem will occur so that the germination percentage of seed will be decreased.
- During regeneration of desiccants, may cause lung diseases if the precautionary measures are not followed.

Case studies

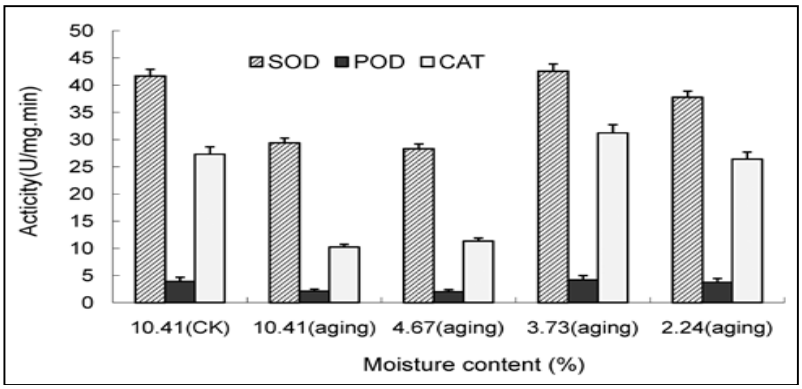
1. Germination capacity and seed vigor of the *Ammopiptanthus mongolica* seeds after storage at 25^{0}C for 12 months by three drying methods-Li and An (2006)

Month of storage	No-drying (10.41%)		Freeze-drier (4.67%)		Silica gel (3.54%)		Heating drying (2.24%)	
	G.P	S.L	G.P	S.L	G.P	S.L	G.P	S.L
0	97^A	52.5^a	98^A	55.4^a	96^A	53.7^b	93^A	52.6^a
2	95^A	51.4^a	97^A	54.3^a	96^A	55.2^a	91^A	51.4^b
4	81^B	49.2^b	91^B	51.9^b	95^A	54.1^a	88^B	49.7^d
6	70^C	41.2^c	88^B	49.0^c	91^B	52.9^c	88^B	50.1^c
8	55^D	40.2^c	89^B	51.7^b	90^B	50.3^d	89^B	50.3^c
10	40^E	38.8^d	87^C	49.2^c	92^B	51.4^c	84^C	48.2^e
12	24^F	35.1^e	86^C	48.8^b	89^C	50.7^d	84^C	47.5^f

Note: G.P means germination percent (%); S.L means seedling length (mm).
The values in a column with the same alphabetical letter are not significantly different (LSD_{test}, P=0.05).

No particular difference in longevity and maintained good seed quality when seeds are dried by either exposure to silica gel, freeze drying or heating to 50^0C compared to nondrying.

2. Changes of the activities of CAT, SOD and POD of ultra-dried *Ammopiptanthus mongolica*seeds after accelerated ageing at 50°C for 1 month-----Li *et al.* (2010)



The ultra-drying treatment of *A. mongolica* seeds has not only caused less injury, it has strongly enhanced their ageing resistant capability and storability. Ultra-dry storage at ambient temperature will be potentially useful for the preservation of *A. Mongolica* germplasm.

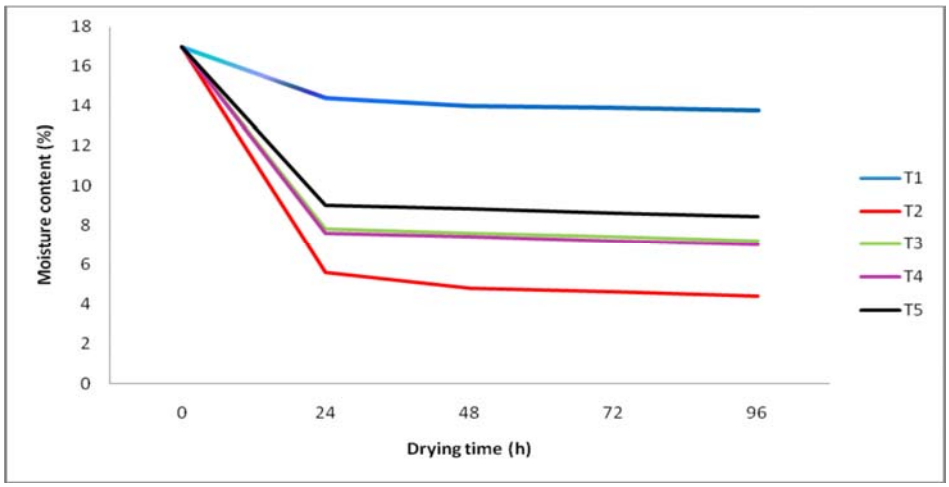
3. The impact of ultra-dry storage on the germination percentage of *Elymusdahuricus*seeds for 12 months---Zhi-hong*et al*. (2011).

Moisture content (%)	Germination percentage (%)			
	-4 (℃)	4(℃)	Room temperature	45(℃)
1.26	94^{a}	88^{ab}	86^{ab}	84^{a}
2.58	90^{abc}	90^{ab}	80^{bc}	86^{a}
3.83	88^{abc}	90^{ab}	88^{ab}	86^{a}
4.47	88^{abc}	86^{ab}	92^{a}	88^{a}
4.97	84^{c}	86^{ab}	90^{a}	84^{a}
6.10	92^{ab}	90^{ab}	92^{a}	80^{a}
7.69	86^{bc}	90^{ab}	90^{a}	80^{a}
9.03 (CK)	86^{bc}	82^{b}	78^{c}	0b

Different small letters in the same column mean significance at $P < 0.05$.

The ultra-dried seeds are stored at room temperature is an effective way for the storage of *Elymus* germ plasm resources, thereby reducing the cost of conservation needed for storage at low temperature.

4. Effect of drying treatments on extent and speed of seed drying on moisture content of tomato seed----Nassari *et al*. (2014) [5].



T1: Sun drying (control), **T2**: Airtight container + Zeolite beads 1:1, **T3**: Air tight container + silica gel (1:1), **T4**: Airtight container + zeolite beads (0.5:1), **T5**: Airtight container + silica gel (0.5:1)

The zeolite desiccant beads at 1:1 and 0.5:1 bead to seed ratio were more effective in tomato seed drying to ultra-low moisture level for storage in air tight container followed by silica gel.

5. Effects of different ultra-drying methods on seed quality of sorghum---Manish *et al.* (2015) [4].

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		

All the drying methods improved the seed quality parameters except acid drying. Lithium chloride drying recorded the highest drying rate and the quality of seeds followed by silica gel.

Conclusion

Ultra-dry seed storage technology is the one of an ideal method to store seeds for longer period by using desiccants in an air tight container without seed quality reduction. Hence, it is a suitable technology to low volume seeds, seed companies and seed banks to store precious seed material for a longer period.

Future line of Work

- Further work is required to determine a protocol for calculating bead to seed ratios to reliably dry seeds to target moisture contents.
- Appropriate MC for better storability for each crop should be examined using ultra drying.
- This method can be used for all cereals, pulses, oil seeds and vegetable seeds storage.
- Newly available desiccants can be replaced by old ones.
- Can also be used for the germplasm conservation and conservation studies.

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