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Seed Quality Response of Rohida (*Tecomella undulata*) to Storage Conditions and Packaging Types

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ABSTRACT: *Tecomella undulata* (commonly known as Rohida) is a valuable tree species of arid and semi-arid regions, with significant ecological and economic importance. However, limited attention has been given to its seed storage behavior, which is critical for conservation and propagation efforts. The present study aimed to assess the effect of storage environment, storage containers and storage period on seed quality parameters of Rohida (*Tecomella undulata*) from July 2022- March 2024. Freshly harvested seeds were packed in two containers, poly bags and cloth bags, and stored in two environments, *i.e.*, controlled (at 4°C) and ambient conditions (room temperature). Polybags were more effective in preserving seed quality, with higher average germination (63.92%) compared to cloth bags (59.25%). Controlled storage conditions significantly outperformed ambient conditions in maintaining germination (65.52% vs. 57.65%) and reducing moisture fluctuations. The study underscores the importance of using appropriate storage environments and packaging materials to maintain seed quality in Rohida, with implications for large-scale propagation and afforestation programs in arid landscapes.

Keywords: *Tecomella undulata,* seed quality, storage conditions

Human civilization has long recognized the indispensable role of forests, relying on them for resources and viewing them as essential allies. The sustainability of our planet and future generations hinges on effective forest conservation and sustainable management. India, with 24.62 percent of its land under the Total Forest Tree Cover, aspires to reach the ideal 33% target set by its National Forest Policy [1,2]. Forests contribute far beyond timber, playing a critical role in climate change mitigation and supporting rural livelihoods. Seed quality is a pivotal factor in enhancing agricultural productivity, accounting for a 15–20% increase in yield [3,4]. High-quality seeds are vital for maximizing the efficiency of other agricultural inputs, making the availability of viable, vigorous seeds at planting time crucial to achieving production goals. With cultivable land shrinking due to rapid population growth, increasing agricultural productivity remains the key solution to meet food demands. Seeds exhibit peak viability and vigour at physiological maturity [5], but their quality declines over time due to ageing. Seed deterioration is an ongoing process that cannot be completely halted; however, it can be slowed down by utilizing suitable storage containers and maintaining an optimal storage environment with controlled temperature and relative humidity. Maintaining the supply of quality seeds requires effective storage methods to preserve seed integrity from one season to the next. Seed viability and vigour vary across genera and species and are influenced by numerous physical and chemical factors, including moisture content, relative humidity, temperature, initial seed quality, seed composition, gaseous exchange, storage structures, and packaging materials [6]. Over 25% of the seed inventory is lost annually due to declines in seed quality resulting from inadequate storage [7], with even greater losses likely in tropical and subtropical regions [8]. Storing seeds at low temperatures (<20°C) not only reduces physiological deterioration but also inhibits the growth and development of storage insect pests in warehouses, ultimately enhancing their shelf life [9]. Seeds, being hygroscopic, absorb moisture in humid conditions until they reach a new equilibrium. The Rohida tree (*Tecomella undulata*), an indigenous Indian species, holds immense economic and ecological significance. Known as 'Marwadi teak' for its high-quality wood, this deciduous tree is particularly suited to arid regions. However, Rohida is endangered due to its slow growth and limited regeneration. This drought-tolerant species thrives in sandy soils and endures extreme temperatures. Cultivating Rohida requires careful seed collection and nursery management. Beyond its valuable timber, the tree possesses medicinal properties, including antibacterial and antioxidant benefits. It also plays a crucial role in soil stabilization and supports wildlife in arid landscapes. Promoting sustainable practices and increasing public awareness are essential to conserving this valuable species for future generations. In light of the above, this study was designed to evaluate the impact of storage containers and storage environments on the seed quality of Rohida (*Tecomella undulata*).

MATERIALS AND METHODS

Freshly harvested seeds of Rohida were collected from Ramgarh (27.37456650666622°N, 70.48510526468264°E) and Lathi (27.031684646239974°N, 71.52187479104239°E) village, District Jaisalmer, Rajasthan. The study was conducted on viable seeds only, and pseudo seeds were eliminated prior to storage (Fig. 1). The seeds were packed in two containers, *viz.*, polybags and cloth bags and stored in two environments, *i.e.* Controlled (at 4°C and 50% R.H.) in a seed bank and ambient conditions (room temperature). The study was carried out in the laboratory of the Department of Seed Science and Technology, CCS HAU Hisar, during 2022-24. The seed was assessed for various quality parameters, *viz.,* germination (%), seedling length, seedling dry weight, moisture content and vigour indices at two-month intervals up to 8 months.

Germination (%): For germination testing, 100 seeds for each of the three replications were tenderly placed between the sufficiently moistened rolled towel and incubated at 25°C in a seed germinator. Germination percentage was assessed on the 7th day using the formula:

$$\text{Germination (\%)} = \frac{\text{Number of normal seedlings}}{\text{Total number of seedlings per replication}} \times 100$$

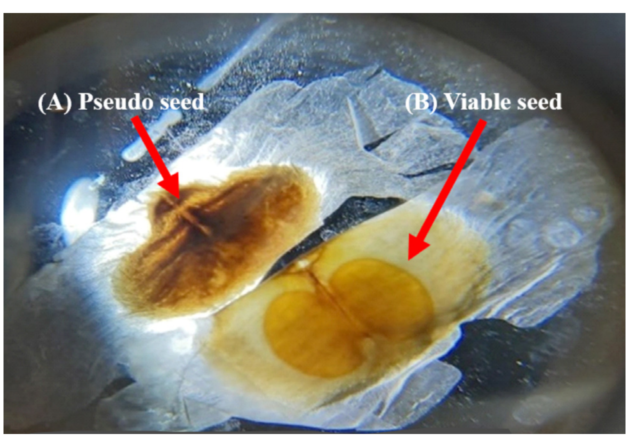

Figure 1. (A) Pseudo seed and (B) Viable seed

Only normal seedlings were considered for calculating the total germination percentage [10].

Seedling length (cm): Ten normal seedlings at the time of final count were randomly selected from each replication of all the seed treatments, and their length was measured in centimetres. The average length of these seedlings was calculated.

Seedling dry weight (mg): The same ten normal seedlings used for seedling length measurement were dried in a hot air oven at 80°C for 48 hours. After drying, they were cooled in a desiccator for 30 minutes and then weighed using an electronic balance. The average dry weight of seedlings per replication was calculated and expressed in milligrams.

Seed vigour indices: Seed vigour indices were calculated by using the formula suggested [11] as follows:

- Seed vigour Index-I = Standard germination (%) × Average seedling length (cm)
- Seed vigour Index-II = Standard germination (%) × Average seedling dry weight (mg)

Moisture content (%): The seed moisture content was estimated by the hot air oven method. The weight of the empty container was taken, along with its lid (M_1). The sample was ground and thoroughly mixed with a small spoon, and 4.5 g of the sample was weighed directly into the container (M_2). The oven was set to preheat sample at the 130°C±1°C temperature and put the sample in oven for an hour. At the end of the drying period, the lid was placed on the containers and allowed to cool for 30 to 45 minutes in a desiccator and then weighed again (M_3). The seed moisture content (M) was calculated in percentage to one decimal place by using the following formula:

$$\text{SMC (\%), M} = \frac{M_2 - M_3}{M_2 - M_1} \times 100$$

Where

M_1 = Weight of empty container with its lid.

M_2 = Weight of container with lid and seed sample before drying.

M_3 = Weight of container with lid and sample after drying and cooling.

Weather Conditions: Meteorological data during the storage period, including temperature, relative humidity, and rainfall, were obtained from the Department of Agrometeorology, CCS Haryana Agricultural University, Hisar. The location is situated at latitude 29°10′N, longitude 73°43′E, and an elevation of 210 m above mean sea level. Details of weather conditions are provided in Table 1.

Statistical analysis: The experimental data were analysed following the standard methods suggested [12]. Statistical analysis was conducted using the online tool OPSTAT [13].

RESULTS AND DISCUSSION

The analysis of the pooled data from 2022-23 and 2023-24 indicated significant variations in seed germination across different storage environments, storage durations, and container types. Initially, seed germination was found to be equal across all treatment combinations. The results revealed that the initial germination rate was high at 81.17%, which reduced to 73.04% after two months of storage across all treatments. The interaction between factors, time interval and type of containers resulted that seeds in polybags retained higher germination (74.08%) compared to cloth bags (72.00%). After 8 Months, the lowest germination rates were recorded, with an overall average of 33.58% and interaction between factors, time interval (after 8 months) and type of containers resulted that polybags provided better protection (38.58%) compared to cloth bags (28.58%). Controlled conditions (43.17%) showed significantly better germination than ambient conditions (24.00%). Across all intervals, controlled conditions resulted in higher germination rates (65.52%) compared to ambient conditions (57.65%). Polybags were more effective in maintaining seed viability, with an average germination of 63.92%, compared to 59.25% for cloth bags (Table 2). [14] also found in their study that polypropylene bags maintained the seed germination rates comparable to jute bags for up to 12 months, suggesting they are a cheaper, viable packaging option. The interactions between these factors (storage interval, storage environment and container type) were also statistically significant (p d” 0.05), highlighting the combined influence of these variables.

Initial seedling length was the highest, with a mean of 7.57 cm, which reduced to 6.07 cm after 8 months. The reduction in seedling length over time highlights the impact of prolonged storage on seed vigour. Seeds stored under controlled conditions exhibited a higher mean seedling length (6.75 cm) compared to seeds stored under ambient conditions (6.62 cm), indicating that controlled storage mitigates the adverse effects of environmental factors. Seeds stored in polybags had a slightly higher mean seedling length (6.76 cm) than those stored in cloth bags (6.61 cm), suggesting that polybags provide better protection during storage (Table 3). The interaction between time interval and storage environment was non-significant, indicating that the relative effect of storage environment was consistent across time intervals. Similarly, interactions between environment, storage containers, and storage period were

Table 1. Weather data during the study

Year	Month	Temperature (°C)		Relative humidity (%)	
		Maximum	Minimum	Morning	Evening
2022	July	34.7	27.1	87	70
2022	August	33.9	26.4	89	65
2022	September	34.4	25.5	88	60
2022	October	31.3	19.0	88	53
2022	November	27.8	11.9	90	53
2022	December	21.0	6.5	96	66
2023	January	17.0	5.7	97	74
2023	February	25.9	8.9	95	57
2023	March	28.9	13.9	89	57
2023	July	35.0	27.1	87	68
2023	August	35.9	26.7	82	55
2023	September	35.8	25.0	87	54
2023	October	33.4	17.7	86	39
2023	November	27.2	12.8	92	48
2023	December	22.5	7.1	96	53
2024	January	14.2	6.0	99	78
2024	February	22.3	7.5	93	49
2024	March	28.1	12.1	87	38

Table 2. Effect of containers, storage environment, and storage period on Rohida seed germination (%)

Treatments	A1: Initial			A2: After 2months			A3: After 4 months			A4: After 6 months			A5: After 8 months			B × C mean	
	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean		
C1: Polybag	81.33	81.33	81.33	74.67	73.50	74.08	73.33	67.00	70.17	57.50	53.33	55.42	44.00	33.17	38.58	66.17	61.67
C2: Cloth bag	80.67	81.33	81.00	73.67	70.33	72.00	72.33	63.00	67.67	55.33	38.67	47.00	42.33	14.83	28.58	64.87	53.63
A × B mean	81.00	81.33		74.17	71.92		72.83	65.00		56.42	46.00		43.17	24.00			

Factors	Time interval (A)					Storage environment (B)		Type of container (C)	
	Initial	After 2 months	After 4 months	After 6 months	After 8 months	Controlled	Ambient	Poly bag	Cloth bag
Means	81.17	73.04	68.92	51.21	33.58	65.52	57.65	63.92	59.25

Statistics	SE(m)±	CD(p=0.05)
Factor(A): Time interval	0.97	2.77
Factor(B): Storage environment	0.61	1.75
Interaction A × B	1.37	3.92
Factor(C): Type of container	0.61	1.75
Interaction A × C	1.37	3.92
Interaction B × C	0.87	2.48
Interaction A × B × C	1.94	5.54

Table 3. Effect of containers, storage environment, and storage period on seedling length (cm) of Rohida seeds

Treatments	A1: Initial			A2: After 2months			A3: After 4 months			A4: After 6 months			A5: After 8 months			B × C mean	
	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean		
C1: Polybag	7.57	7.56	7.57	7.02	6.90	6.96	6.69	6.50	6.59	6.57	6.37	6.47	6.29	6.08	6.19	6.83	6.68
C2: Cloth bag	7.58	7.57	7.58	6.91	6.82	6.86	6.46	6.30	6.38	6.35	6.24	6.30	6.03	5.88	5.96	6.67	6.56
A × B mean	7.58	7.57		6.97	6.86		6.58	6.40		6.46	6.30		6.16	5.98			

Factors	Time interval (A)					Storage environment (B)		Type of container (C)	
	Initial	After 2 months	After 4 months	After 6 months	After 8 months	Controlled	Ambient	Poly bag	Cloth bag
Means	7.57	6.91	6.49	6.38	6.07	6.75	6.62	6.76	6.61

Statistics	SE(m)±	CD(p=0.05)
Factor(A): Time interval	0.05	0.15
Factor(B): Storage environment	0.03	0.09
Interaction A × B	0.07	NS
Factor(C): Type of container	0.03	0.09
Interaction A × C	0.07	NS
Interaction B × C	0.05	NS
Interaction A × B × C	0.10	NS

also found to be non-significant, demonstrating that individual factors influenced seedling length independently. The initial seedling dry weight was 0.064 mg, which decreased steadily over time, with the lowest value recorded after 8 months (0.047 mg), indicating a decline in seed quality with prolonged storage. Seeds stored under controlled conditions showed a higher mean dry weight (0.056 mg) compared to those stored under ambient conditions (0.054 mg), emphasizing the benefits of controlled storage for maintaining seed vigour. Seeds stored in polybags exhibited slightly higher mean dry weight (0.056 mg) compared to those stored in cloth bags (0.054 mg), suggesting that polybags provide better protection for seeds during storage. The interaction between storage period and storage environment was not significant, indicating that the effect of storage environment was consistent over time. The interactions among storage containers, environments and storage period were also not significant, implying that the main factors influenced seedling dry weight independently (Table 4). The initial moisture content was 10.16% which gradually fluctuated over storage period peaking after 6 months (10.37%) and slightly decreasing after 8 months (10.18%). The increase was more pronounced in cloth bags under ambient conditions compared to polybags and controlled conditions. Seeds stored under controlled conditions maintained a stable moisture content (10.16%) throughout the storage period. Ambient conditions led to higher moisture fluctuations, with a mean value of 10.33%, indicating greater susceptibility to environmental factors like temperature and humidity. Polybags maintained a more stable moisture content (10.16%) due to better insulation from external environmental changes. Cloth bags showed significant moisture variation, with a higher mean moisture content of 10.34%, especially under ambient conditions. The interaction between storage period and storage environment was significant, indicating that moisture content dynamics varied over time between controlled and ambient conditions (Table 5). The Initial Vigour Index-I was 613.85, which reduced to 205.70 after 8 months of storage highlighting the negative impact of prolonged storage on seed vigour. Seeds stored under controlled conditions exhibited a significantly higher mean Vigour Index-I (448.12) compared to those stored under ambient conditions (392.16), emphasizing the advantages of controlled storage for maintaining seed vigour. Seeds stored in polybags retained a higher Vigour Index-I (438.64) compared to those stored in cloth bags (401.64), indicating better protection and preservation in polybags. The interaction between the storage period and environment was found to be significant, but the interaction among these three factors was not significant (Table 6). The initial Vigour Index-II was 5.17, which decreased significantly over time, reaching 4.26 after 2 months, 3.73 after 4 months, 2.65 after 6 months, and 1.58 after 8 months. The decline in vigour was more pronounced under ambient conditions compared to controlled storage. Seeds stored under controlled conditions had a higher mean Vigour Index-II (3.71) compared to those stored under ambient conditions (3.25). Controlled conditions were more effective in minimizing the loss of seed vigour over time. Seeds stored in polybags exhibited a higher mean Vigour Index-II (3.65) compared to cloth bags (3.31). Polybags were more effective in retaining seed vigour, especially under controlled conditions. Significant interactions were observed between storage period and storage environment and storage environment and container type, indicating that the impact of storage conditions on vigour varied over time and between containers. The interaction between storage period and container type and the three-way interaction were not significant (Table 7). The type of storage container had a significant impact on seedling length, seedling dry weight, and seed vigour indices (I and II) over the storage period. Fresh seeds exhibited the highest seedling length, while seeds stored for eight months showed the lowest seedling length and dry weight. Seeds stored in polythene bags demonstrated greater seedling length, dry weight, and vigour indices compared to those stored in cloth bags, likely due to a higher rate of seed deterioration in the latter. This deterioration in cloth bags was attributed to fluctuations in seed moisture content, which corresponded to the relative humidity of the storage environment. In contrast, seed moisture content remained stable in polythene bags. Frequent moisture fluctuations during storage are detrimental, as they increase respiration rates, accelerating deterioration and reducing seedling growth and vigour attributes. The results found here were consistent with those observed in okra [15], fenugreek [16], turnip [17], and rice [18]. Additionally, seedling length, dry weight, and vigour indices declined more rapidly in two-year-old coriander seeds [19]. Similar trends were reported in wheat [20] and in barley [21,22].

CONCLUSION

It is concluded from the study that germination as well as seed quality parameters can be preserved for a longer

Table 4. Effect of containers, storage environment and storage period on seedling dry weight (mg) of Rohida seeds

Treatments	A1: Initial			A2: After 2 months			A3: After 4 months			A4: After 6 months			A5: After 8 months			B × C mean	
	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean		
C1: Polybag	0.063	0.064	0.064	0.059	0.059	0.059	0.056	0.054	0.055	0.054	0.052	0.053	0.049	0.047	0.048	0.056	0.055
C2: Cloth bag	0.064	0.064	0.064	0.058	0.057	0.058	0.053	0.052	0.053	0.052	0.050	0.051	0.047	0.044	0.046	0.055	0.053
A × B mean	0.064	0.064		0.059	0.058		0.055	0.053		0.053	0.051		0.048	0.046			

Factors	Time interval (A)					Storage environment (B)		Type of container (C)	
	Initial	After 2 months	After 4 months	After 6 months	After 8 months	Controlled	Ambient	Poly bag	Cloth bag
Means	0.064	0.058	0.054	0.052	0.047	0.056	0.054	0.056	0.054

Statistics	SE(m)±	CD(p=0.05)
Factor(A): Time interval	0.001	0.002
Factor(B): Storage environment	0.000	0.001
Interaction A × B	0.001	NS
Factor(C): Type of container	0.000	0.001
Interaction A × C	0.001	NS
Interaction B × C	0.001	NS
Interaction A × B × C	0.001	NS

Table 5. Effect of containers, storage environment and storage period on moisture (%) of Rohida seed

Treatments	A1: Initial			A2: After 2months			A3: After 4 months			A4: After 6 months			A5: After 8 months			B × C mean	
	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean		
C1: Polybag	10.16	10.16	10.16	10.16	10.16	10.16	10.16	10.14	10.15	10.16	10.16	10.16	10.16	10.13	10.15	10.16	10.15
C2: Cloth bag	10.16	10.17	10.17	10.16	10.21	10.19	10.16	10.95	10.55	10.16	10.99	10.58	10.16	10.26	10.21	10.16	10.51
A × B mean	10.16	10.17		10.16	10.18		10.16	10.55		10.16	10.57		10.16	10.20			

Factors	Time interval (A)					Storage environment (B)		Type of container (C)	
	Initial	After 2 months	After 4 months	After 6 months	After 8 months	Controlled	Ambient	Poly bag	Cloth bag
Means	10.16	10.17	10.35	10.37	10.18	10.16	10.33	10.16	10.34

Statistics	SE(m)±	CD(p=0.05)
Factor(A): Time interval	0.03	0.08
Factor(B): Storage environment	0.02	0.05
Interaction A × B	0.04	0.11
Factor(C): Type of container	0.02	0.05
Interaction A × C	0.04	0.11
Interaction B × C	0.02	0.07
Interaction A × B × C	0.05	0.15

Table 6. Effect of containers, storage environment and storage period on Vigour Index-I of Rohida seeds

Treatments	A1: Initial			A2: After 2months			A3: After 4 months			A4: After 6 months			A5: After 8 months			B × C mean	
	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean		
C1: Polybag	614.97	614.39	614.68	524.93	507.53	516.23	490.83	435.65	463.24	377.81	340.65	359.23	277.13	202.52	239.83	457.14	420.15
C2: Cloth bag	610.81	615.21	613.01	509.14	479.98	494.56	467.76	397.16	432.46	351.91	241.29	296.60	255.92	87.23	171.57	439.11	364.17
A × B mean	612.89	614.80		517.04	493.76		479.29	416.41		364.86	290.97		266.53	144.87			

Factors	Time interval (A)					Storage environment (B)		Type of container (C)	
	Initial	After 2 months	After 4 months	After 6 months	After 8 months	Controlled	Ambient	Poly bag	Cloth bag
Means	613.85	505.40	447.85	327.91	205.70	448.12	392.16	438.64	401.64

Statistics	SE(m)±	CD(p=0.05)
Factor(A): Time interval	5.54	15.85
Factor(B): Storage environment	3.51	10.02
Interaction A × B	7.84	22.41
Factor(C): Type of container	3.51	10.02
Interaction A × C	7.84	22.41
Interaction B × C	4.96	14.18
Interaction A × B × C	11.09	31.70

Table 7. Effect of containers, storage environment and storage period on Vigour Index-II of Rohida seeds

Treatments	A1: Initial			A2: After 2months			A3: After 4 months			A4: After 6 months			A5: After 8 months			B × C mean	
	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean	B1: Control cond.	B2: Ambient cond.	A × C mean		
C1: Polybag	5.18	5.17	5.17	4.45	4.31	4.38	4.13	3.67	3.90	3.07	2.77	2.92	2.16	1.55	1.86	3.80	3.49
C2: Cloth bag	5.14	5.18	5.16	4.26	4.01	4.13	3.85	3.26	3.56	2.86	1.92	2.39	1.97	0.64	1.31	3.62	3.00
A × B mean	5.16	5.18		4.36	4.16		3.99	3.46		2.97	2.34		2.07	1.10			

Factors	Time interval (A)					Storage environment (B)		Type of container (C)	
	Initial	After 2 months	After 4 months	After 6 months	After 8 months	Controlled	Ambient	Poly bag	Cloth bag
Means	5.17	4.26	3.73	2.65	1.58	3.71	3.25	3.65	3.31

Statistics	SE(m)±	CD(p=0.05)
Factor(A): Time interval	0.07	0.21
Factor(B): Storage environment	0.05	0.13
Interaction A × B	0.10	0.29
Factor(C): Type of container	0.05	0.13
Interaction A × C	0.10	NS
Interaction B × C	0.07	0.18
Interaction A × B × C	0.14	NS

duration in Polybags as compared to cloth bags. Controlled storage conditions significantly outperformed ambient.

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