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Zero Energy Overwinter Storage of Fresh Apples in Trans-Himalayan Ladakh

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Abstract: Geographical and economic constraints limit the availability of fresh fruits and vegetable during winter months in trans-Himalayan Ladakh region, thus necessitating the need to develop regionally suited cost-effective passive storage techniques. Freshly harvested fruits of three local (*Thra, Mongol, Karkechu*) and two exotic (Royal Delicious, Golden Delicious) cultivars, individually wrapped in cling foil and newspaper, were stored in an underground cellar (-2.0 to 15.6 ºC, 44.2 to 88.1% RH). Fruit quality traits and sensory evaluation were determined at 30 days interval from date of storage. *Thra* and *Mongol* do not store well and were not suitable for consumption after 60 days of storage. Fruits wrapped in cling foil stored much better as compared to newspaper-wrapped fruits. The study demonstrated that fruits of Royal Delicious and *Karkechu* can be stored for 150 days during winter seasons inside the underground cellars scoring the highest hedonic score for overall appreciation (7.2±0.8 and 7.1±1.3, respectively). The method described is easy, cost-effective, and can be a satisfactory alternative to refrigerated cold storage in trans-Himalayan region with severe winters.

Keywords: Food security, Hedonic score, Himalaya, Underground cellar.

I. Introduction

The high mountain Ladakh region is characterized by a rugged topography at an average altitude of over 3000 m. Long harsh winters reduce the cropping season to just four to five months in a year, and the region remains cut-off for over six months due to heavy snowfall. Availability of locally grown fresh fruits and vegetables is restricted to summer months and therefore, there are seasonal differences in dietary intake of food [1]. Micronutrient deficiencies are prevalent in the region. Seasonal shortfall and low dietary diversity among the local populace lead to micronutrient deficiencies, a phenomenon that has been described as 'hidden hunger' [2]. As the self-sufficiency of food is an important issue, filling the gap between the required quantity and the quantity produced locally is a difficult task in this region.

Apple (*Malus domestica* Borkh) is the most widely planted fruit tree in Ladakh after apricot. The region represents great wealth of indigenous apple germplasm that vary in colour, size, flavour and texture. The popular local cultivars, *Thra* and *Mongol*, ripe in August but do not store well. However, fruit of introduced Delicious cultivars ripe in late October and stored well for 4-5 months by traditional method of storage [3]. However, there is no standardised method for apple storage in the region. Controlled atmospheric and refrigeration storage are mostly used for apple storage in different parts of the world, where apples can be stored for 5-6 months in cold storage and 6-8 months in controlled atmospheric storage [4]. However, these facilities are cost intensive and difficult to maintain in remote places. Besides, power supply is a major constraint in the region and involves huge investment. To alleviate this problem, the present study was undertaken to develop an improved method for storage of apple without the need for external power supply.

II. Materials and Methods

A. Fruit Collection and Packaging

Two local cultivars, *Thra* and *Mongol*, were harvested on 28 August 2019, while *Karkechu* cultivar on 15 September 2019. Exotic cultivars, Royal Delicious and Golden Delicious, were harvested on 25 October 2019 from the experimental orchard (34°08.2'N; 77°34.3'E, elevation 3340 m asl) at DRDO-Defence Institute of High Altitude Research, Leh Ladakh. After sorting and grading, 800 fruits of each cultivar were equally divided into three groups. Group-I: fruits individually wrapped in cling foil (0.02 mm thickness); Group-II: fruits wrapped in newspaper; Group-III: unwrapped fruits. The fruits were then packed in plastic crates (600×400×320 mm, L×B×H) (Supreme, India).

B. Storage

The fruits were stored in an underground cellar (18'×18'×9', L×W×H) by placing the crates on three-tier iron racks. The soil surface of the cellar was kept moist by watering thrice during the

storage period. Air temperature and relative humidity inside the cellar was recorded daily at 9:00 AM with a hygro-thermometer (445702, Extech Instruments). The temperature amplitude was calculated as the difference between the maximum and minimum temperatures. Fruits of the local cultivars, *Thra* and *Mongol*, were stored for 60 days, while that of *Karkechu* and exotic cultivars for 150 days.

C. Fruit Quality Traits

Fruit quality traits such as fruit weight, firmness, TSS and acidity were determined at 30 days interval from date of storage. Ten fruits from each treatment were randomly handpicked at every fixed interval. Fruit weight was measured with an electronic balance. Total soluble solids (TSS) were measured with refractometer (ATAGO, Tokyo) and values were corrected at 20 ºC. Fruit firmness was determined using a hand penetrometer (FT-327, Effegi, Italy). Total acid (TA) percentage was determined by titration and values expressed as percent mallic acid [5].

D. Sensory Evaluation

Fruit samples were evaluated at 30 days interval from date of storage by 12-15 members semi-trained panel (age 24-45 year) at room temperature with natural day light. Each panellist had previous experience with descriptive analysis. Panellist were presented with coded fruit samples from each cultivar. They were given water as neutralizing beverage between sample testing. The panellist were asked to rate the following sensory attributes: appearance, aroma, taste, hardness, juiciness, crispiness, sound produce and to give their overall appreciation. Each panellist rated different parameters and overall appreciation on a 1-9 scale (1 = extremely bad to 9 = extremely good).

E. Statistical Analysis

The experimental results were expressed as mean ± standard deviation (SD) using statistical analysis with SPSS. Analysis of variance (ANOVA) and post hoc analysis with 2-sided Tukey's HSD at $p \leq 0.05$ level was performed.

III. Results and Discussion

A. Environmental Condition

Temperature is the most important factor governing the maintenance of postharvest quality of apple [6]. The monthly environmental conditions of the cellar along with open field condition are presented in Table I. The temperature inside the cellar remained relatively constant during the storage period. The mean maximum and minimum temperature was 4.5 ± 1.1 and 2.9 ± 1.2 ºC, respectively. The maximum and minimum temperature difference (temperature amplitude) was 1.7 ± 1.5 ºC. In comparison, the temperature amplitude was recorded 13.9 ± 1.5 ºC outside. Apples are generally stored at 0-2 ºC [7] and freezing temperature is known to induce disorders. Therefore, temperature inside the cellar was favourable for apple storage, though not at optimal range of 0-2 ºC.

The monthly maximum and minimum relative humidity inside the cellar was recorded 77.4 ± 3.0 and 67.2 ± 4.4%, respectively. The maximum and minimum relative humidity inside the cellar remained 22.5 ± 5.8 and 42.4 ± 5.0% higher than that of natural outdoor conditions. High relative humidity inside the cellar could be a favourable factor for apple storage. Higher relative humidity maintains apple firmness and weight better than low relative humidity [8].

B. Fruit Quality Traits

i) Fruit Weight Loss

Fruit weight loss during storage is presented in Table II. Percent fruit weight loss in all the five cultivars showed increasing trend with storage duration. Similar trend was reported previously when apples were stored at room temperature for 35 days [9], and for 120 days in refrigerated condition [10]. The local cultivars, *Thra* and *Mongol*, showed significant fruit weight loss during the first two months of storage period (Table II). Therefore, these two cultivars are not suitable for storage. Low storage quality of these two cultivars could be because of thin fruit skin, and early ripening in August during which the temperature inside the cellar was significantly higher. However, the fruits of the local cultivars *Karkechu* and exotic cultivars, Royal Delicious and Golden Delicious, stored well up to 150 days. Wrapping the fruit with cling foil and newspaper significantly decrease percent fruit weight loss in all the five cultivars. After 150 days of storage fruits of *Karkechu* wrapped in cling foil showed the least fruit weight loss (4.1 ± 1.7%), while unwrapped fruits showed maximum fruit weight loss (8.0 ± 3.1%). Similar trend was observed in Royal Delicious and Golden Delicious. In comparison, 5.5-6.5% physiological weight loss in Royal Delicious apples stored at room temperature for 45 days has been reported [11]. Therefore, physiological weight loss under the present study was much slower, which could be due to constant and lower temperature. Lower physiological weight loss in fruits wrapped in cling foil could be due to reduction of both the rate of metabolism and water loss.

Table I: Weather Data of Outside and Inside the Cellar in Ladakh from September (2019) to March (2020)

Month and Year	*Maximum Temperature (°C)*			*Minimum Temperature (°C)*			*Maximum RH (%)*			*Minimum RH (%)*		
	Outside	*Cellar*	**Difference*	*Outside*	*Cellar*	**Difference*	*Outside*	*Cellar*	**Difference*	*Outside*	*Cellar*	**Difference*
Sept 2019	22.8±2.6	15.6±1.2	7.2±1.4	7.5±3.3	10.5±1.1	3.0±2.2	40.0±5.1	62.0±2.1	22.0±3.0	14.5±8.1	44.2±2.8	29.7±5.3
Oct 2019	13.1±2.8	9.2±1.3	3.9±1.5	-1.2±2.6	7.8±1.4	9.0±1.2	45.5±11.1	66.4±1.6	20.9±9.5	18.2±16.1	54.1±3.0	35.9±13.1
Nov 2019	-1.2±2.6	5.1±1.4	6.3±1.2	-4.9±2.6	4.1±1.4	9.0±1.2	59.3±3.6	75.9±2.6	16.6±1.0	20.3±7.7	65.4±2.6	45.1±5.1
Dec 2019	0.0±2.4	0.4±1.1	0.4±1.3	-13.9±3.3	-0.5±1.2	13.4±2.1	68.9±11.9	83.9±4.1	15.0±7.7	29.5±10.5	74.9±6.1	45.3±4.4
Jan 2020	-2.8±1.1	-1.5±0.6	1.3±0.5	-14.0±6.5	-2.0±1.2	12.0±5.3	74.7±9.8	88.1±2.6	13.4±7.3	35.9±10.8	81.3±4.6	45.4±6.1
Feb 2020	3.6±3.5	0.5±0.8	3.1±2.7	-11.6±3.9	-1.3±0.8	10.3±3.1	58.3±12.1	83.1±3.9	24.8±8.2	25.5±8.1	74.9±6.8	49.4±1.3
Mar 2020	7.6±1.0	2.0±1.4	5.6±0.4	-5.6±2.3	1.6±1.1	7.3±1.2	37.7±8.1	82.7±4.5	45.0±3.6	29.7±4.4	75.7±4.9	46.0±0.6
Mean (SD)	6.2±2.27	4.5±1.1	1.7±1.2	-6.2±3.5	2.9±1.2	9.1±2.3	54.9±8.8	77.4±3.0	22.5±5.8	24.8±9.4	67.2±4.4	42.4±5.0

Values represented mean ± SD.

*Difference: temperature difference between outside and inside the cellar.

Table II: Physiological Fruit Weight Loss (%) of Five Apple Cultivars during Storage in Underground Cellar in Trans-Himalayan Region

Cultivar	*Treatment*	*Number of Days of Storage*				
		30	*60*	*90*	*120*	*150*
Royal Delicious	Cling foil	$1.3\pm0.5^{a}_{x}$	$2.0\pm0.5^{a}_{xy}$	$2.4\pm0.8^{a}_{y}$	$2.9\pm0.5^{a}_{y}$	$4.1\pm1.2^{a}_{z}$
	Newspaper	$3.1\pm1.2^{b}_{x}$	$3.4\pm0.9^{ab}_{x}$	$4.4\pm1.8^{b}_{xy}$	$4.8\pm1.1^{b}_{xy}$	$5.8\pm1.3^{b}_{y}$
	Control	$3.6\pm1.0^{b}_{x}$	$4.4\pm1.7^{b}_{xy}$	$5.1\pm0.7^{b}_{xy}$	$5.2\pm0.9^{b}_{xy}$	$5.8\pm0.6^{b}_{y}$
	Mean	2.7±1.2	3.3±1.2	4.0±1.4	4.3±1.2	5.2±1.0
Golden Delicious	Cling foil	$1.6\pm0.7^{a}_{x}$	$3.5\pm0.6^{a}_{y}$	$4.0\pm0.9^{a}_{y}$	$4.2\pm0.9^{a}_{y}$	$4.5\pm0.8^{a}_{z}$
	Newspaper	$2.5\pm0.5^{ab}_{x}$	$4.1\pm0.8^{a}_{x}$	$4.7\pm1.1^{a}_{xy}$	$5.3\pm0.6^{a}_{xy}$	$6.3\pm0.9^{b}_{y}$
	Control	$3.5\pm1.0^{b}_{w}$	$4.1\pm1.0^{a}_{x}$	$4.6\pm0.6^{a}_{x}$	$5.2\pm1.0^{a}_{y}$	$6.9\pm0.9^{b}_{z}$
	Mean	2.5±1.0	3.9±0.4	4.5±0.4	4.8±0.8	5.7±1.5
Karkechu	Cling foil	$2.3\pm1.2^{a}_{x}$	$2.7\pm1.9^{a}_{x}$	$3.6\pm1.0^{a}_{x}$	$3.7\pm1.1^{a}_{x}$	$4.1\pm1.7^{a}_{x}$
	Newspaper	$3.7\pm0.4^{a}_{x}$	$4.5\pm0.9^{ab}_{xy}$	$5.5\pm1.7^{a}_{yz}$	$5.8\pm1.1^{ab}_{yz}$	$6.7\pm1.5^{ab}_{z}$
	Control	$4.2\pm1.5^{b}_{x}$	$5.3\pm1.8^{b}_{xy}$	$7.2\pm1.6^{b}_{xy}$	$7.5\pm3.3^{b}_{xy}$	$8.0\pm3.1^{b}_{y}$
	Mean	3.4±1.0	4.1±1.3	5.5±1.8	5.7±1.9	6.3±2.0
Thra	Cling foil	$3.6\pm1.4^{a}_{x}$	$4.7\pm2.8^{a}_{x}$	-	-	-
	Newspaper	$5.8\pm3.6^{a}_{x}$	$6.4\pm2.5^{ab}_{x}$	-	-	-
	Control	$8.2\pm3.4^{b}_{x}$	$9.4\pm4.0^{b}_{x}$	-	-	-
	Mean	5.9±2.3	6.9±2.4	-	-	-
Mongol	Cling foil	$3.6\pm1.4^{a}_{x}$	$4.3\pm1.1^{a}_{x}$	-	-	-
	Newspaper	$4.7\pm3.1^{a}_{x}$	$5.3\pm2.8^{a}_{x}$	-	-	-
	Control	$5.3\pm2.4^{a}_{x}$	$6.5\pm.2.9^{a}_{x}$	-	-	-
	Mean	4.5±0.9	5.4±1.1	-	-	-

Values represented mean ± SD.

For each row different subscript letters indicate significantly different at $p \leq 0.05$ as measured by Tukey's test between days of storage.

For each column, different superscript letters indicate significantly different at $p \leq 0.05$, as measured by Tukey's within a variety.

ii) Fruit Firmness

Change in fruit firmness during storage is presented in Table III. The local cultivars, *Thra and Mongol*, are soft at the time of ripening as compared to the local cultivar *Karkechu* and exotic cultivars, Royal Delicious and Golden Delicious. Therefore, *Thra* and *Mongol* showed significant decrease in fruit firmness during storage. Cling foil wrapped fruits were found to be firmer than newspaper wrapped ones. The firmness of the fruit depends on rate of evapo-transpiration and respiration rates, resulting in loss of water and solutes [12, 13].

Table III: Change in Fruit Firmness (kg/cm^2) of Five Apple Cultivars during Storage in Underground Cellar in Trans-Himalayan Region

Cultivar	*Treatment*	*Number of Days of Storage*					
		0	*30*	*60*	*90*	*120*	*150*
Royal Delicious	Cling foil	$7.7\pm0.4^{a}_{z}$	$6.0\pm0.3^{a}_{y}$	$5.5\pm0.2^{a}_{x}$	$5.5\pm0.2^{b}_{x}$	$5.4\pm0.1^{a}_{x}$	$5.3\pm0.1^{a}_{x}$
	Newspaper	$7.7\pm0.4^{a}_{z}$	$5.9\pm0.5^{a}_{xy}$	$5.4\pm0.3^{a}_{x}$	$5.4\pm0.2^{ab}_{x}$	$5.3\pm0.5^{a}_{x}$	$5.2\pm0.3^{a}_{x}$
	Control	$7.7\pm0.4^{a}_{z}$	$5.8\pm0.5^{a}_{y}$	$5.2\pm0.3^{a}_{x}$	$5.1\pm0.2^{a}_{x}$	$5.1\pm0.1^{a}_{x}$	$5.0\pm0.3^{a}_{x}$
	Mean	7.7±0.0	5.9±0.1	5.4±0.2	5.3±0.2	5.3±0.2	5.2±0.2
Golden Delicious	Cling foil	$7.5\pm0.6^{a}_{z}$	$6.6\pm0.3^{a}_{y}$	$5.6\pm0.2^{a}_{x}$	$5.5\pm0.2^{a}_{x}$	$5.5\pm0.2^{a}_{x}$	$5.3\pm0.5^{a}_{x}$
	Newspaper	$7.5\pm0.6^{a}_{z}$	$6.1\pm0.3^{a}_{xy}$	$5.5\pm0.4^{a}_{x}$	$5.5\pm0.1^{a}_{x}$	$5.4\pm0.2^{ab}_{y}$	$5.2\pm0.2^{a}_{x}$
	Control	$7.5\pm0.6^{a}_{z}$	$6.1\pm0.5^{a}_{x}$	$5.3\pm0.2^{a}_{y}$	$5.2\pm0.1^{b}_{x}$	$5.2\pm0.2^{b}_{x}$	$5.1\pm0.3^{a}_{x}$
	Mean	7.5±0.0	6.3±0.3	5.5±0.2	5.4±0.2	5.3±0.2	5.2±0.1

Cultivar	*Treatment*	*Number of Days of Storage*					
		0	*30*	*60*	*90*	*120*	*150*
Karkechu	Cling foil	$7.6\pm0.9^{a}_{y}$	$6.0\pm0.6^{a}_{x}$	$6.0\pm0.4^{a}_{x}$	$5.8\pm0.3^{a}_{x}$	$5.7\pm0.2^{a}_{x}$	$5.6\pm0.4^{a}_{x}$
	Newspaper	$7.6\pm0.9^{a}_{y}$	$5.9\pm0.5^{a}_{x}$	$5.9\pm0.3^{a}_{x}$	$5.7\pm0.4^{a}_{x}$	$5.6\pm0.6^{a}_{x}$	$5.4\pm0.6^{ab}_{x}$
	Control	$7.6\pm0.9^{a}_{z}$	$5.9\pm0.5^{a}_{y}$	$5.7\pm0.6^{a}_{xy}$	$5.4\pm0.3^{a}_{xy}$	$5.3\pm0.2^{a}_{xy}$	$4.9\pm0.4^{b}_{x}$
	Mean	7.6±0.9	6.0±0.1	5.8±0.2	5.6±0.2	5.5±0.2	5.3±0.4
Thra	Cling foil	$6.7\pm0.5^{a}_{y}$	$5.7\pm1.6^{a}_{y}$	$5.2\pm0.2^{a}_{x}$	-	-	-
	Newspaper	$6.7\pm0.5^{a}_{y}$	$5.3\pm0.4^{a}_{x}$	$5.2\pm0.5^{a}_{x}$	-	-	-
	Control	$6.7\pm0.5^{a}_{x}$	$4.9\pm0.6^{a}_{x}$	$4.8\pm0.5^{a}_{x}$	-	-	-
	Mean	6.7±0.5	5.3±0.4	5.1±0.2	-	-	-
Mongol	Cling foil	$5.6\pm0.5^{a}_{z}$	$4.0\pm0.2^{a}_{y}$	$3.5\pm0.2^{a}_{x}$	-	-	-
	Newspaper	$5.6\pm0.5^{a}_{y}$	$3.9\pm0.1^{a}_{x}$	$3.3\pm0.5^{ab}_{x}$	-	-	-
	Control	$5.6\pm0.5^{a}_{y}$	$3.3\pm0.3^{b}_{x}$	$3.1\pm0.4^{b}_{x}$	-	-	-
	Mean	5.6±0.5	3.7±0.4	3.3±0.2	-	-	-

Values represented mean ± SD.
For each row different subscript letters indicate significantly different at $p \leq 0.05$ as measured by Tukey's test between days of storage.
For each column, different superscript letters indicate significantly different at $p \leq 0.05$, as measured by Tukey's within a variety.

iii) Fruit TSS

Change in fruit TSS during storage is presented in Table IV. Fruit TSS showed increasing trend with storage duration and then a declining trend on prolong storage (120-150 days). The increase in TSS may be due to conversion of starch into monosaccharide [14]. The exhibited trends were in consensus with earlier reports [15, 16]. TSS of cling foil wrapped fruits was higher at the end of storage period followed by the newspaper wrapped fruits in all the five cultivars.

Table IV: Change in Fruit TSS (°brix) of Five Apple Cultivars during Storage in Underground Cellar in Trans-Himalayan Region

Cultivar	*Treatment*	*Number of Days of Storage*					
		0	*30*	*60*	*90*	*120*	*150*
Royal Delicious	Cling foil	$14.0\pm0.4^{a}_{x}$	$14.7\pm0.7^{a}_{xy}$	$15.0\pm0.2^{a}_{y}$	$15.1\pm0.4^{a}_{y}$	$15.2\pm0.7^{a}_{y}$	$14.8\pm1.0^{ab}_{y}$
	Newspaper	$14.0\pm0.4^{a}_{x}$	$14.6\pm0.6^{a}_{xy}$	$14.9\pm0.8^{a}_{y}$	$15.0\pm0.4^{a}_{y}$	$14.7\pm0.7^{a}_{xy}$	$14.6\pm0.4^{a}_{xy}$
	Control	$14.0\pm0.4^{a}_{x}$	$14.6\pm0.4^{ab}_{xy}$	$14.6\pm0.6^{a}_{y}$	$14.9\pm0.6^{a}_{xy}$	$14.5\pm0.6^{a}_{xy}$	$14.4\pm0.3^{a}_{xy}$
	Mean	14.0±0.4	14.7±0.1	14.9±0.2	15.0±0.1	14.8±0.4	14.6±0.2
Golden Delicious	Cling foil	$14.0\pm0.3^{a}_{xy}$	$14.4\pm0.7^{a}_{y}$	$14.4\pm0.6^{a}_{y}$	$14.4\pm0.1^{a}_{xy}$	$14.5\pm0.7^{a}_{x}$	$13.5\pm0.7^{a}_{xy}$
	Newspaper	$14.0\pm0.3^{a}_{xy}$	$14.1\pm0.6^{a}_{y}$	$14.2\pm0.8^{a}_{x}$	$14.3\pm0.3^{a}_{y}$	$14.2\pm0.3^{a}_{xy}$	$13.4\pm0.4^{a}_{xy}$
	Control	$14.0\pm0.3^{a}_{y}$	$14.0\pm0.4^{a}_{y}$	$14.1\pm0.3^{a}_{y}$	$14.1\pm0.4^{a}_{y}$	$14.1\pm0.6^{a}_{y}$	$13.2\pm0.7^{a}_{x}$
	Mean	14.0±0.3	14.3±0.2	14.3±0.2	14.4±0.2	13.3±0.1	13.3±0.1
Karkechu	Cling foil	$14.0\pm0.6^{a}_{x}$	$14.9\pm0.5^{a}_{y}$	$15.2\pm0.3^{a}_{y}$	$15.3\pm0.5^{a}_{y}$	$15.4\pm0.4^{a}_{y}$	$14.8\pm0.6^{a}_{y}$
	Newspaper	$14.0\pm0.6^{a}_{x}$	$14.1\pm0.6^{ab}_{xy}$	$14.7\pm0.4^{a}_{y}$	$14.8\pm0.4^{a}_{y}$	$14.9\pm0.2^{a}_{y}$	$14.6\pm0.5^{a}_{y}$
	Control	$14.0\pm0.6^{a}_{x}$	$14.4\pm0.4^{b}_{x}$	$14.6\pm0.5^{a}_{x}$	$14.8\pm0.2^{a}_{x}$	$14.9\pm1.1^{a}_{x}$	$14.4\pm1.5^{a}_{x}$
	Mean	14.0±0.6	14.5±0.4	14.7±0.5	14.9±0.3	15.0±0.4	14.6±0.4
Thra	Cling foil	$13.4\pm1.5^{a}_{y}$	$13.6\pm0.3^{a}_{xy}$	$13.8\pm0.3^{a}_{x}$	-	-	-
	Newspaper	$13.4\pm1.5^{a}_{y}$	$13.6\pm0.8^{a}_{x}$	$13.7\pm0.8^{a}_{x}$	-	-	-
	Control	$13.4\pm1.5^{a}_{x}$	$13.5\pm0.4^{a}_{y}$	$13.6\pm0.4^{a}_{y}$	-	-	-
	Mean	13.4±1.5	13.6±0.1	13.7±0.1	-	-	-
Mongol	Cling foil	$11.3\pm1.3^{a}_{x}$	$11.4\pm0.8^{a}_{x}$	$11.6\pm0.4^{a}_{x}$	-	-	-
	Newspaper	$11.3\pm1.3^{a}_{x}$	$11.4\pm0.7^{a}_{x}$	$11.5\pm0.6^{a}_{x}$	-	-	-
	Control	$11.3\pm1.3^{a}_{x}$	$11.3\pm1.0^{a}_{x}$	$11.4\pm1.0^{a}_{x}$	-	-	-
	Mean	11.3±1.3	11.4±0.0	11.5±0.1	-	-	-

Values represented mean ± SD.
For each row different subscript letters indicate significantly different at $p \leq 0.05$ as measured by Tukey's test between days of storage.
For each column, different superscript letters indicate significantly different at $p \leq 0.05$, as measured by Tukey's within a variety.

Table V: Change in Fruit Acidity (% Malic Acid) of Five Apple Cultivars during Storage in Underground Cellar in Trans-Himalayan Region

Cultivar	*Treatment*	*Number of Days of Storage*					
		0	*30*	*60*	*90*	*120*	*150*
Royal Delicious	Cling foil	$0.31\pm0.04^{a}_{x}$	$0.28\pm0.04^{a}_{x}$	$0.26\pm0.00^{a}_{x}$	$0.25\pm0.01^{a}_{x}$	$0.24\pm0.04^{a}_{x}$	$0.22\pm0.08^{a}_{x}$
	Newspaper	$0.31\pm0.04^{a}_{x}$	$0.28\pm0.04^{a}_{x}$	$0.23\pm0.05^{a}_{x}$	$0.24\pm0.04^{a}_{x}$	$0.21\pm0.04^{a}_{x}$	$0.21\pm0.04^{a}_{x}$
	Control	$0.31\pm0.04^{a}_{x}$	$0.21\pm0.04^{a/x}$	$0.23\pm0.05^{a}_{x}$	$0.19\pm0.08^{a}_{x}$	$0.21\pm0.04^{a}_{x}$	$0.19\pm0.0^{a}_{x}$
	Mean	0.31±0.0	0.26±0.04	0.24±0.02	0.23±0.03	0.22±0.02	0.21±0.02
Golden Delicious	Cling foil	$0.40\pm0.0^{a}_{y}$	$0.31\pm0.04^{a}_{xy}$	$0.30\pm0.05^{a}_{xy}$	$0.26\pm0.07^{a}_{x}$	$0.24\pm0.04^{a}_{x}$	$0.24\pm0.04^{ab}_{x}$
	Newspaper	$0.40\pm0.0^{a}_{y}$	$0.28\pm0.04^{a}_{x}$	$0.26\pm0.00^{a}_{x}$	$0.24\pm0.04^{a}_{x}$	$0.21\pm0.04^{a}_{x}$	$0.21\pm0.04^{ab}_{x}$
	Control	$0.40\pm0.0^{a}_{z}$	$0.26\pm0.00^{a}_{xy}$	$0.23\pm0.03^{a}_{xy}$	$0.21\pm0.04^{a}_{xy}$	$0.21\pm0.03^{a}_{xy}$	$0.19\pm0.0^{b}_{x}$
	Mean	0.40±0.0	0.28±0.03	0.26±0.04	0.24±0.03	0.22±0.02	0.21±0.02
Karkechu	Cling foil	$0.31\pm0.04^{a}_{x}$	$0.24\pm0.04^{a}_{y}$	$0.26\pm0.0^{a}_{y}$	$0.24\pm0.04^{a}_{z}$	$0.21\pm0.04^{a}_{z}$	$0.21\pm0.04^{a}_{z}$
	Newspaper	$0.31\pm0.04^{a}_{y}$	$0.28\pm0.04^{a}_{xy}$	$0.26\pm0.07^{a}_{xy}$	$0.19\pm0.07^{a}_{x}$	$0.21\pm0.04^{a}_{x}$	$0.19\pm0.0^{a}_{x}$
	Control	$0.31\pm0.04^{a}_{y}$	$0.26\pm0.00^{a}_{xy}$	$0.24\pm0.04^{a}_{xy}$	$0.21\pm0.04^{a}_{xy}$	$0.19\pm0.0^{a}_{x}$	$0.19\pm0.0^{a}_{x}$
	Mean	0.31±0.0	0.26±0.02	0.25±0.01	0.21±0.03	0.20±0.01	0.20±0.01
Thra	Cling foil	$0.28\pm0.04^{a}_{x}$	$0.27\pm0.02^{b}_{x}$	$0.24\pm0.0^{ab}_{x}$	-	-	-
	Newspaper	$0.28\pm0.04^{a}_{x}$	$0.26\pm0.00^{b}_{x}$	$0.24\pm0.04^{ab}_{x}$	-	-	-
	Control	$0.28\pm0.04^{a}_{y}$	$0.19\pm0.0^{ab}_{xy}$	$0.19\pm0.0^{a}_{x}$	-	-	-
	Mean	0.28±0.0	0.24±0.04	0.22±0.03	-	-	-
Mongol	Cling foil	$0.31\pm0.04^{a}_{x}$	$0.26\pm0.0^{a}_{x}$	$0.24\pm0.04^{a}_{x}$	-	-	-
	Newspaper	$0.31\pm0.04^{a}_{x}$	$0.24\pm0.04^{a}_{x}$	$0.23\pm0.04^{a}_{x}$	-	-	-
	Control	$0.31\pm0.04^{a}_{x}$	$0.22\pm0.04^{a}_{y}$	$0.21\pm0.04^{a}_{y}$	-	-	-
	Mean	0.31±0.0	0.24±0.02	0.23±0.02	-	-	-

Values represented mean ± SD.

For each row different subscript letters indicate significantly different at $p \leq 0.05$ as measured by Tukey's test between days of storage.

For each column, different superscript letters indicate significantly different at $p \leq 0.05$, as measured by Tukey's within a variety.

iv) Fruit Acidity

Fruit acidity decreased with increasing storage duration with few exceptions (Table V). The decrease in fruit acidity in all cultivars could be due to metabolic reactions occurring in the fruit [11]. At the end of the storage studies, the acidity was highest in fruits wrapped in cling foil followed by newspaper. Higher fruit acidity in wrapped fruit could be due to slow metabolism. Different coating treatments can often delay fruit metabolism, as higher CO_2 and lower O_2 rates in the coated fruits are retained [17].

Table VI: Three-Way Anova Showing the Relationship of Cultivar, Treatments and Storage Duration and Their Interaction with Fruit Weight Loss, Firmness, TSS and Acidity

Source	*Moisture Loss %*		*TSS*		*Acidity*		*Firmness*	
	df	*F*	*df*	*F*	*df*	*F*	*df*	*F*
Cultivar	4	29.925***	4	235.911***	4	15.054***	4	366.257***
Treatment	2	52.123***	2	2.953	2	7.096***	2	13.555***
Days	2	122.328***	2	6.968***	2	83.708***	2	453.476***
Cultivar × Treatment	8	20.769***	8	0.285	8	0.722	8	1.559
Cultivar × Days	8	7.995***	8	6.612***	8	3.118**	8	17.991***
Treatment × Days	4	13.221***	4	0.889	4	1.921	4	4.048**
Cultivar × Treatment × Days	16	5.653***	16	0.138	16	0.662	16	0.699

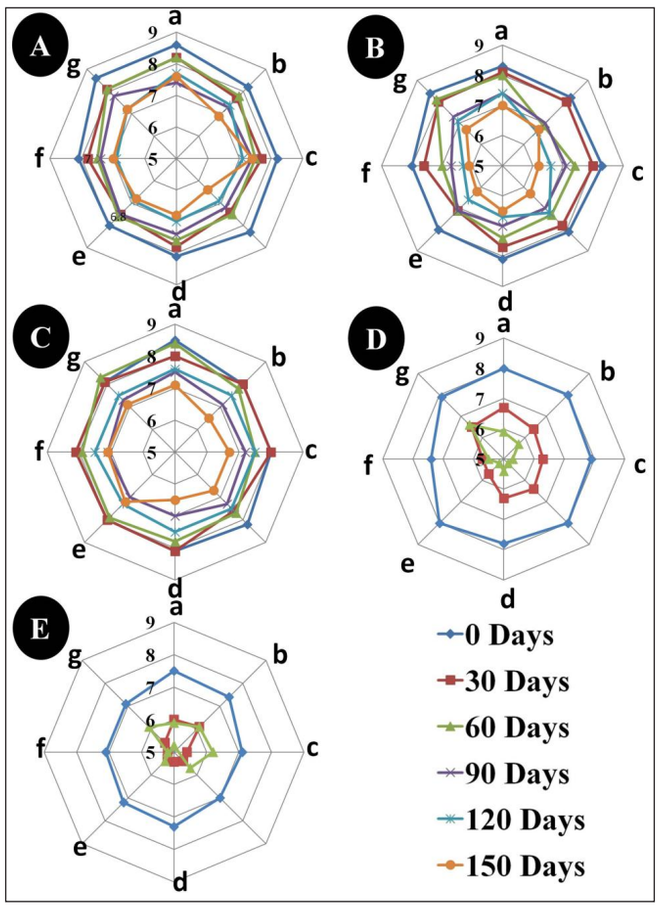
df – Degrees of freedom; *F* – F ratio; **Significant at $p \leq 0.01$; ***Significant at $p \leq 0.001$.

v) Three-Way ANOVA

Three-way ANOVA was done to determine the relationship of cultivar, treatments and storage duration and their interaction with fruit weight loss, firmness, TSS and acidity (Table VI). Wrapping the fruit for different durations irrespective of cultivar showed significant effect on fruit weight loss, firmness but no effect on change in fruit TSS and acidity during storage. The fruit weight loss varied significantly as a result of interactive effect of cultivars and fruit wrapping within cultivar but no significant effect on change in fruit TSS, acidity and firmness was found during storage. On the other hand interaction effect of storage duration and cultivars was found to have significantly varied for all character studied. The interaction effect of cultivar, fruit wrapping and storage duration showed significant variation in fruit weight loss but no significant variation on change in fruit TSS, acidity and firmness during the storage studies.

C. Sensory Evaluation

Sensory evaluation of stored apples at 30 days interval in terms of fruit appearance, aroma, taste, hardness, juiciness, crispiness, sound produced, and overall acceptability are shown in Fig. 1. At the time of harvest Royal Delicious ranked first in terms of overall acceptability, while the local cultivar *Mongol* ranked the lowest. Significant decline in overall acceptability was recorded for *Thra* and *Mongol* at 60 days of storage. The mean overall acceptability score drop to less than 7 on a nine-point scale. A mean liking score of 7 or higher on a nine-point scale is usually indicative of highly acceptable sensory quality [18]. The method of storage showed significant effect on sensory attributes of stored apples. After 90 days of storage, unwrapped fruits of Golden Delicious and *Karkechu* score less than 7, which was below the acceptable value. Wrapping the fruits with cling foil significantly improved the sensory attributes and overall acceptability in all the cultivars studied and at every stages of evaluation. It has also been that wrapped fruit had better sensory score over unwrapped ones when stored at ambient condition for 42 days [19]. After 150 days of storage the fruits of Royal Delicious and *Karkechu* wrapped in cling foil scored more than 7 on a nine-point scale. It is, therefore, concluded that fruits of Royal Delicious and *Karkechu* wrapped in cling foil can be effectively stored for 150 days in underground cellars.



a: appearance; b: aroma; c: taste; d: hardness; e: juiciness; f: crispiness; g: sound produced; h: overall acceptability
A: Royal Delicious; B: Golden Delicious; C: *Karkechu*; D: *Thra*; E: *Mongol*

Fig. 1: Spider Plot for Sensory Scores of Stored Apples in Underground Cellar

IV. Conclusions

Underground cellars are commonly used in Ladakh for storage of vegetable. However, we found that the structure can be effectively used for overwinter storage of apple. Fruits of Royal Delicious and *Karkechu* wrapped in cling foil can be effectively stored for 150 days in underground cellars. The method described is easy, cost-effective and can be an alternative to refrigerated cold storage in trans-Himalayan region.

Conflict of Interest: None

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