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Quality and Condition of 'Delicious' Apples after Storage at 0°C and Display at Warmer Temperatures[1]

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Abstract. **Apples (*Malus domestica* Borkh.) were examined after 0, 2, 4, and 6 months' storage and after simulated retail display for 1 and 2 weeks at 4.4°, 13°, and 21°C. Apples displayed or marketed at 4.4° for 1 week developed less decay and scald than apples held at 21°, and were crisper, brighter, and about 0.55 kg (1.2 lb.) firmer. Apples softened much faster at 21° soon after harvest than after 4 or 6 months' storage at 0°C. The sonic firmness index decreased significantly with both storage time and with increases in display temp. Weight losses from bulk apples during 1 week of display at 4.4°, 13°, and 21° averaged 0.2, 0.4, and 1.8%, respectively. The greatest loss of acidity was also at the warmest display temp. Apples displayed at 13° were of a quality and condition intermediate to those held at 4.4° and 21°. Apples stored in CA for 6 months and then displayed 2 weeks at 21° were firmer and more acid, and had a lower respiration rate than those stored in air. Refrigerated display of 'Delicious' apples is strongly recommended to retard deterioration and preserve their good quality and shelf life.**

Apples are rarely adequately refrigerated in supermarkets. The dessert quality and shelf life of fruit consumers take home are greatly reduced when previous handlers have neglected refrigeration. Many investigators have studied the changes in quality of 'Delicious' apples during storage and ripening (3, 9, 12, 15, 20, 21, 22). Few studies have been done recently to compare various simulated retailing temp on apple quality maintenance. Lewis (13, 14) reported that refrigerated 'Delicious' apples retained an attractive appearance and crisp texture longer than apples held at room temp. Haut (10) and Senn and Scott (19) evaluated post-storage temp for 'Richared Delicious' and concluded that apples should be kept below 10°C if the time between storage and consumption exceeds 6-9 days.

A 1960 study (11) showed that apples displayed under simulated retail refrigeration (10°C) lost less weight and showed less decay than similar apples displayed at room temp. Scald was reduced during marketing when fruit was displayed at 10° or lower (5). Certainly both time and temp are involved in deterioration rate. Mattus et al (16, 17) surveyed the rapidity of sale of apples in Virginia supermarkets. An average of 2.7 days was required to sell 50% of the bulk or loose apples on display and 8.5 days to sell 95%. Only 25% of the bagged apples were in refrigerated displays. Recently a USDA task force studying apple marketing (4) listed many industry problems, including the holding of apples with poor keeping qualities or under poor conditions.

Chain store executives continue to ask for further information on the value of refrigeration for short retailing periods. This research was initiated to determine progressive quality changes of 'Delicious' apples during storage and during 1 and 2 weeks of subsequent display at 4.4°, 13°, and 21°C (40°, 55°, and 70°F). These temp were presumed to represent good, fair and poor retail display conditions, respectively.

Materials and Methods

Fruit source and preparation. The study was conducted in the fall and winter months of 1974-75 in experimental storage rooms at Beltsville, Md. Three lots of 'Delicious' apples were obtained from commercial orchards in Virginia, West Virginia and Pennsylvania within 6 days of harvest. All were size 100 tray packed and graded as Combination U.S. Extra Fancy and Fancy, sports 'Richared', 'Starking', and 'Red Spur' harvested at approx optimum maturity in Sept. Each lot was composited separately and dipped in 2,700 ppm ethoxyquin for scald control. Fruit was then replaced in tray-packed cartons for storage.

Storage and display. Storage was at 0°C with 85-92% relative humidity for 0, 2, 4, and 6 months in air and for 6 months in experimental CA chambers (1% O_2 with <1% CO_2) with and without the ethylene absorbent "Purafil." The initial or 0 storage examination was made when fruit had been at 0°C

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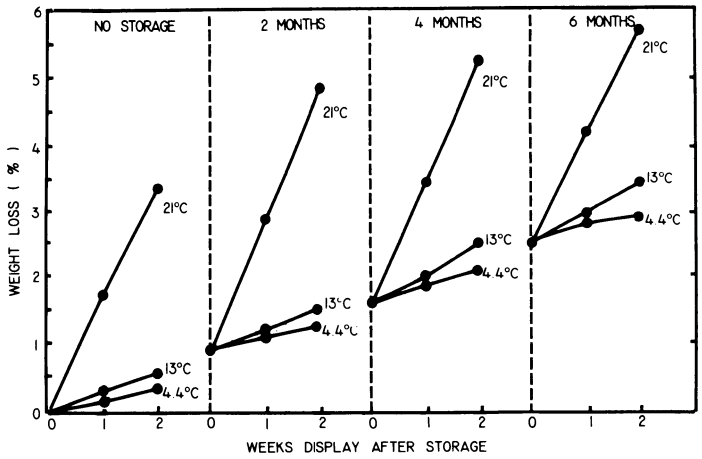

Fig. 1. Cumulative weight losses from 'Delicious' apples during storage at 0°C and during 1 and 2 weeks' display at 4.4°, 13° and 21°.

only 4-6 days. After storage for various intervals in cartons, apples were removed from the cartons and displayed on apple trays at 3 simulated retailing temp: 4.4°, 13° and 21°. Fruit was examined after 1 and 2 weeks on display. Relative humidity was 85-90% at 4.4° and 13°, and 35-40% at 21°. The CA fruit was displayed only at 21° on removal from storage.

Eighteen boxes (100 apples each) from each of the 3 orchards were stored. One box from each orchard was sampled at each examination interval. Separate boxes were examined on removal from 0°C and after holding at the 3 display temp.

Fruit evaluation. Weight losses were measured by individual weighings of 12 marked apples in each box to the nearest .01 g. Respiration measurements were made on duplicate lots of 5 apples at 21°C on removal from 0° and during the last 2 days of the first and second weeks display at 4.4°, 13°, and 21°.

Fruit firmness was measured on 2 pared sides of each of 20 apples with a Magness-Taylor pressure tester with a 10.5 mm plunger. Firmness averaged 7.1 kg (15.6 lb.) initially for the fruit from the 3 orchards. Soluble solids and titratable acidity were determined on opposite quarters of these same fruit. The quarters were ground and filtered, and duplicate 50-ml aliquots of juice were titrated with NaOH to pH 7.0. Acidity was calculated as malic acid. Soluble solids were measured by a Bausch and Lomb Abbe refractometer. Starch content was evaluated visually by the starch-iodine test.

Sonic vibration tests (1, 2, 6, 18) also were used to measure fruit firmness. Instrumentation described by Finney (7) was used in our studies. Each apple was tested over the frequency region from 200 to 2,000 Hertz (Hz). The natural resonant frequency, described by Abbott et al (1) as $f_{n=2}$, was measured and recorded for each apple. For simplicity, we dropped the subscript and refer in this report to this frequency as "f." In addition, each apple was weighed and its mass (m) was recorded. From these 2 measurements, a nondestructive "index of firmness," f^2m was calculated. The fruit was allowed approx 6 hr to reach room temp before being tested. Measurements were made on the same 10-apple samples from each orchard after storage and after 2 weeks at each display temp.

At each examination fruit was evaluated for decay and scald and given a subjective rating of general appearance, and a crispness rating based on tasting by 2 of the authors (7 tough, 5 crisp, 3 slightly mealy, 1 very mealy). For brevity, data from the 3 lots of fruit, representing 3 'Delicious' sports, are combined in the results, as the 3 sources responded similarly and served as replicates.

Results and Discussion

Weight losses. Net losses in weight from apples packed in cartons after 2, 4, and 6 months at 0°C averaged 0.9, 1.6, and 2.5%, respectively. Wt losses from bulk apples during 1 week of simulated display at 4.4°, 13°, and 21° averaged 0.2, 0.4, and 1.8%, respectively; loss for each display temp was significantly different (5% level). Thus, under these conditions, apples lost moisture 4 to 5 times faster in a non-refrigerated display than at 13°. Of course, the lower relative humidity at 21° than at 13° contributed to the magnitude of the loss. Cumulative or total wt losses during storage and display exceeded 4% for 'Delicious' apples stored 6 months at 0° plus 1 week at 21° or 2 months at 0° plus 2 weeks at 21° (Fig. 1). A weight loss of 4-5% was sufficient to cause slight shrivel in some apples. Retailing apples on refrigerated counters can significantly retard moisture loss. For example, apples stored 2 months at 0° and then displayed 2 weeks at 4.4° or 21° had weight losses of 1.2 and 4.8%, respectively.

Fruit firmness. Firmness, as measured with a pressure tester, is the most common method of recording the ripening rate or softening of apples and is closely correlated with sensory rating of crispness. In this study firmness decreased significantly during storage, during post-storage display and with increases in display temp (Fig. 2). Loss of firmness was rapid during non-refrigerated display, as expected. From an initial firmness of 7.1 kg (15.6 lb.) 'Delicious' apples softened to 5.2 kg (11.5 lb.) during 6-months storage at 0°C. The CA apples were about .9 kg (2 lb.) firmer after storage than fruit from air storage.

The benefit of refrigeration in retarding loss of firmness during 1- or 2-weeks retail display was pronounced. Apples displayed 1 week at 4.4°, 13°, and 21°C lost an average of .38, .68 and .93 kg of firmness, respectively. Thus, after 1 week

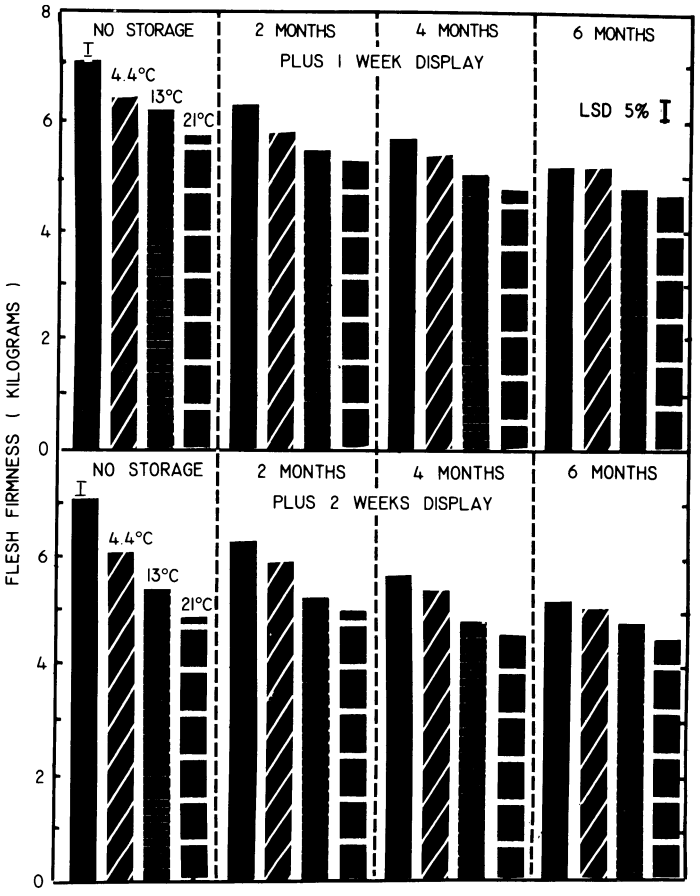

Fig. 2. Firmness of 'Delicious' apples initially (I) and after 2, 4 and 6 months storage at 0°C, and after 1 and 2 weeks' display at 4.4°, 13°, and 21°. (Values are means of measurements of fruit from 3 orchards, 20 fruit per orchard with 2 readings per apple.).

Table 1. Nondestructive firmness index, f^2m, for 'Delicious' apples after storage at 0°C and after 2 weeks display at 4.4°, 13°, and 21°C.[z]

Storage at 0°C	Firmness index, f^2m (x 10^6 Hz^2-g)			
	On removal from 0°C	After 2 weeks at:		
		4.4°C	13°C	21°C
None (initial)	220a	211a	187bcd	110g
2 months	198b	200ab	157ef	91g
4 months	202b	198abc	164def	105g
6 months	186c	176cde	147f	107g
Mean	202	196a	164b	103c

[z]Sonic vibration firmness values based on mean of measurements of fruit from 3 orchards. Mean separation by Duncan's multiple range test, 5% level.

at 4.4° apples averaged .55 kg firmer than those held at 21° (Fig. 2). Apples displayed 1 week at 13°C after storage were .25 kg firmer than those held at 21°, a significant difference. By interpolation, firmness losses during a short 4-day marketing period at 4.4°, 13°, and 21° would be about .21, .39, and .53 kg, respectively. During display at 21° for 1 week apples lost firmness at a rate about 37% faster than at 13° and 145% faster than at 4.4°.

We assigned the ripeness terms (hard, firm, firm ripe, and ripe) used in U.S. Standards for Apples as defined by Haller et al (9) to our firmness data. The apples were firm initially, firm ripe after 1 week at 21°C, and ripe after 2 weeks at 21°. After 4 months at 0°, fruit was firm ripe on removal and ripe after 1-week display at 21°. Apples should be sold to consumers before the fruit ripens below the limit of the firm-ripe stage (5 kg). Refrigerated handling in stores is highly desirable, particularly for fruit previously stored more than 2-3 months. In these tests many apples became mealy during display at 21° with a firmness of 4.1-4.8 kg. Wright and Whiteman (22) reported that in some seasons 'Delicious' apples stored 4 to 6 months at 0° plus 1 week at 21° were overripe and mealy and had only fair flavor when they still had a firmness of 5.4-5.9 kg.

Sonic firmness index. Initial (at harvest) values of the nondestructive firmness index, f^2m, averaged 220 x 10^6 Hz^2-g and were comparable to values reported earlier (6). The firmness index decreased significantly both with storage time and increases in display temp (Table 1). During 6 months at 0°C, f^2m decreased by 15%, a significant difference from the other storage periods. The most dramatic changes, however, occurred during the 2-week display period at 21°. The firmness index

Table 2. Respiration rate, acidity, decay and scald of 'Delicious' apples after storage at 0°C and after display at 4.4°, 13°, and 21°C.[z]

Type examination and storage period at 0°C	On removal from 0°C	After 1 week at:			After 2 weeks at:			Mean
		4.4°C	13°C	21°C	4.4°C	13°C	21°C	
Respiration rate[y] (mg CO_2/kg-hr)								
None (initial)	23.8	4.7	9.0	19.5	4.7	9.2	16.9	12.5b
2 months	25.9	5.0	13.6	21.8	5.0	11.9	17.6	14.4a
4 months	26.2	4.8	12.6	23.6	4.9	13.9	18.7	15.0a
6 months	25.1	4.8	13.8	24.0	5.1	12.4	19.8	15.0a
6 months CA	15.1	–	–	14.7	–	–	15.3	
6 months CA + Purafil	14.8	–	–	14.2	–	–	15.2	
Mean	25.3a	4.8e	12.3d	22.2b	4.9e	11.9d	18.3c	
Titratable acidity (mg/100 g juice)								
None (initial)	240	222	226	204	227	221	194	219a
2 months	225	204	200	199	204	203	173	201b
4 months	199	186	182	165	172	159	156	174c
6 months	160	153	147	144	137	133	140	145d
6 months CA	207	–	–	206	–	–	172	
6 months CA + Purafil	206	–	–	192	–	–	179	
Mean	206a	191b	189b	178bc	185b	179b	166c	
Decay (%)								
None (initial)	0	0	0.7	1.1	0	1.6	2.9	0.9a
2 months	0.6	0	2.4	1.0	1.2	3.3	3.8	1.8a
4 months	1.9	1.7	3.0	4.0	2.1	3.8	6.7	3.3a
6 months	1.8	1.3	2.3	2.8	1.8	2.8	7.2	2.9a
6 months CA	4.6	–	–	6.4	–	–	9.5	
6 months CA + Purafil	2.1	–	–	3.2	–	–	5.4	
Mean	1.1ab	0.8a	2.1bcd	2.2cd	1.3abc	2.9d	5.2e	
Scald[x] (%)								
None (initial)	0	0	0	0	0	0	0	0a
2 months	0	0	1	10	0	10	31	7.4ab
4 months	13	15	17	38	17	25	49	24.9bc
6 months	26	29	36	36	26	36	46	33.6c
6 months CA	2	–	–	2	–	–	8	
6 months CA + Purafil	3	–	–	2	–	–	10	
Mean	10a	11a	14ab	21c	11a	18bc	32d	

[z]Values in body of table are means of analyses of fruit from 3 orchards, 300 fruit for decay and scald. CA data not included in means. Mean separation by Duncan's multiple range test, 5% level.

[y]Respiration on removal from 0°C was at 21°.

[x]All fruit dipped in 2700 ppm ethoxyquin before storage.

Table 3. Condition and crispness of 'Delicious' apples after storage at 0°C and after display at 4.4°, 13°, and 21°.

Storage at 0°C	On removal from 0°C	After 1 week at:			After 2 weeks at:		
		4.4°C	13°C	21°C	4.4°C	13°C	21°C
Fruit condition[z]:				*Rating*			
None (initial)	VG	VG	VG	G-VG	G-VG	G-VG	G-F
2 months	G-VG	VG	G-VG	G-F	G	G-F	F-P
4 months	G-F	G-F	F-G	F	G-F	F	F-P
6 months	G-P	G-P	F-P	P	G-P	F-P	P
6 months CA	G-VG	–	–	G-F	–	–	G-F
6 months CA + Purafil	G-VG	–	–	G-F	–	–	G-F
Fruit crispness[y]:				*Rating*			
None (initial)	–	5.3	5.0	4.3	5.2	4.6	4.0
2 months	–	5.2	4.5	4.2	4.5	3.4	3.2
4 months	–	4.3	3.9	3.3	4.3	2.9	2.7
6 months	–	3.3	3.3	2.2	2.7	1.9	2.2
6 months CA	–	–	–	3.8	–	–	3.3
6 months CA + Purafil	–	–	–	2.8	–	–	3.1

[z]Evaluation based on fruit from 3 orchards. Condition and appearance rating: VG = very good, G = good, F = fair, P = poor. Main defects were decay, scald, mealiness, shrivel and skin dullness.

[y]Crispness rating 7-1: 7 = tough, 5 = crisp, 3 = slightly mealy, 1 = very mealy.

decreased by about 50%, from a mean of 202 x 10^6 to 103 x 10^6 Hz^2-g, showing the importance of low temp to retain firmness. At 4.4°, for example, firmness decreased only 2-5% in 2 weeks. At 13°, the firmness decreased about 20%.

The sonic firmness indices (Table 1) reflect a trend similar to the pressure test firmness measurements in Fig. 2. A linear correlation coefficient of 0.76 was calculated from 72 paired measurements on the same apples. The f^2m firmness index tended to reflect larger changes in fruit held 2 weeks at 13° or 21°C than did the pressure test. At harvest, for example, pressure test readings for apples held 2 weeks at 21° changed from 7.1 to 4.9 kg, a 31% decrease. The firmness index, f^2m, changed from 220 to 110 x 10^6 Hz^2-g, a 50% decrease. Similar results were observed after the 2-, 4- and 6-months storage. Pressure test readings after storage plus 2 weeks' display at 21° generally decreased 14-21%, whereas f^2m declined 42-54%. These results suggest that the nondestructive sonic index of firmness may be more sensitive than the pressure test to ripeness changes in apples held at high temp.

Respiration. Fruit respiration rate at 21°C initially and on removal from storage averaged 25 mg CO_2/kg-hr. During subsequent display for 1 and 2 weeks at 21° respiration decreased significantly to an average of 22 and 18 mg CO_2/kg-hr, respectively (Table 2). Apples displayed for sale at 21° respired 4-5 times faster than at 4.4° and 1.8 times faster than at 13°.

'Delicious' apples removed from CA after 6 months at 0°C respired 40% slower at 21° than did fruit stored in air. After 1 week display at 21° the CA apples still respired about 40% slower than did air-stored apples. The presence of "Purafil" to absorb ethylene in the CA chamber did not affect post-storage respiration.

Starch, soluble solids and acidity. The starch-iodine test, sometimes recommended as a maturity index for some cultivars, can also be used to register the change of starch to sugar or the advance of ripening of 'Delicious' apples after harvest (8). Using a 7-1 rating (7 = very extensive starch, 1 = no starch) and 10-apple samples, starch content was recorded after 2-weeks display at the temp shown in the tabulation:

	2 wk 4.4°C	2 wk 13°C	2 wk 21°C
No storage	5.7	4.3	2.3
2 months 0°C	3.8	2.4	1.6
4 months 0°C	1.6	1.2	1.1

Starch conversion was more rapid in apples displayed at room temp than in those displayed with refrigeration. After 4-months storage at 0°C most of the starch had disappeared, as indicated by the starch-iodine test.

Soluble solids averaged 11% in the apples at harvest. This is an adequate level for 'Delicious' apples, indicating acceptable maturity, for fruit with a firmness averaging 7.1 kg (15.6 lb.) at harvest. After storage for 2 to 6 months at 0°C and during simulated display, soluble solids ranged from 11.9 to 12.5%. There were no significant changes in soluble solids with time in storage or during display at the different temp, other than an increase from 11.0% at harvest to 12% or over soon afterwards during storage or display (data not shown).

Titratable acidity of the juice was highest at harvest and decreased continuously during 6-months storage (Table 2). Apples stored in CA for 6 months were more acid on removal than fruit from regular storage, and remained more acid during 1- or 2-weeks display at 21°C. Acidity decreased significantly during post-storage holding at 4.4°, 13°, and 21°. The greatest loss of acidity was at the warmest display temp. Apples displayed 2 weeks at 21° after storage were less acid than fruit displayed with refrigeration.

Decay and scald. Most of the decay after storage and display was due to *Penicillium expansum* (Lk.) Thom. Decay during storage at 0°C did not increase significantly with time (Table 2). Apples displayed 1 week at 21° after storage developed slightly more decay than did apples displayed at 4.4°. During post-storage holding for 1 or 2 weeks, 'Delicious' apples held at 4.4° had less decay than fruit held at 13° or 21°.

The apples stored in CA had the most decay after 6-months and after display. The fruit in the CA with "Purafil" had less decay than fruit stored without the ethylene absorbent. There have been previous reports that ethylene absorbents reduced decay of citrus fruit. In this case further testing is needed to clarify this effect with apples.

Although all of these apples were dipped in ethoxyquin before storage, appreciable scald developed, especially after 4- and 6-months storage (Table 2). Scald was largely controlled on 'Delicious' apples by storage in CA. The extent of scald on fruit at removal from storage did not become more extensive during 1- or 2-weeks display at 4.4°C. Refrigeration helped control scald during marketing. More moderate to severe scald developed on apples displayed at 21°C than on fruit at 13° or 4.4°. The most scald occurred on fruit displayed 2 weeks at 21° after 4- or 6-months storage.

Appearance and condition. Following storage and after 1-

and 2-weeks display the apples were given an overall subjective rating for appearance and condition (Table 3). Freshly harvested 'Delicious' apples could be displayed 1 week at 21°C or 2 weeks at 13° and remained in good to very good condition. With increasing time in storage before marketing, the importance of refrigeration during display to maintain quality became more important. Apples stored 4 months and then displayed 1 week at 21°C had only fair appearance and condition. Apples stored 6 months and then displayed a week at 21° were generally in poor condition. Apples refrigerated during display were in better condition with less wt loss, softening, decay, scald, and a brighter skin luster. Apples stored 4 months and then displayed 1 week at either 13° or 21° were noticeably duller than those displayed at 4.4°.

The apples stored 6 months in CA were in better condition, except for decay, than fruit from air storage on removal and they maintained better condition during 1 week at 21°. The CA fruit was more acid, firmer, brighter, and had less scald than air-stored fruit.

A gradual decline in crispness with increasing mealiness occurred with time in storage or on display (Table 3). Loss of crispness was more rapid at 21°C, as expected. Some mealiness was apparent in apples with as little as 2-months storage, if they were subsequently held or displayed 2 weeks at 13° or 21°.

Conclusion

Holding 'Delicious' apples 2 weeks non-refrigerated after storage is obviously too long and seriously damages quality. Two weeks is longer than apples normally remain in retail stores. However, apples are subjected to warm temp at other points in marketing as in transit, wholesaling or in the ultimate buyer's home. Hopefully, apples will still be crisp and not soft when finally purchased by the consumer. These data showing the ripening and deterioration rates for apples displayed 1 or 2 weeks at 3 temp following storage should be useful in estimating changes in other lots. A refrigerated display at 4.4°C was much superior to 13°. Display of apples at 21° hastened softening and loss of quality, and could possibly be justified only for firm fruit to be marketed within 4 to 5 days. Refrigerated display of 'Delicious' apples in retail stores is strongly recommended to preserve good quality and shelf life.

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