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STORAGE AND SHELF LIFE OF PACKAGED LEEKS

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PREFACE

U.S. Department of Agriculture marketing research is part of a continuing program to reduce marketing losses and to extend the marketing season of agricultural products. This study was undertaken to find improved methods for handling and packaging of leeks and to determine their storage requirements and shelf life.

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STORAGE AND SHELF LIFE OF PACKAGED LEEKS

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SUMMARY

Storage and shelf-life tests using New Jersey grown leeks (*Allium ampeloprasum* L. cv. American Flag) consisted of initial consumer-unit holding tests, crate holding tests, and post-storage holding tests. Data collected on keeping quality of leeks held at 0°, 4.4°, 10°, and 20° to 22.5° C include weight loss, appearance, and decay. In general, tests confirmed reports that leeks should keep satisfactorily for 1 to 3 months in storage at 0° C (32° F) and 90 to 100 percent relative humidity. Tests also confirmed predictions that leeks might respond favorably to holding in nonperforated (sealed) polyethylene bags.

Freshly harvested and trimmed leeks, which were consumer-unit packaged as naked (nonwrapped) bunches and in perforated and nonperforated (sealed) 1.5–mil polyethylene bags, held up well for 5, 6, and 10 weeks, respectively, at 0° C, under crushed ice; for 5, 7, and 12 days at 10°, and for 4, 3, and 6 days at 21.1°. Leeks consumer-unit packaged from nonlined wirebound wooden crates after 3 to 5 days holding at 7.2° to 10° generally had shorter shelf life at 0°, 10°, and 21.1° than leeks packaged the day after harvest.

Freshly harvested leeks remained salable in nonlined, wirebound wooden crates for 3 weeks at 0° C either with or without crushed ice, 1 week at 4.4°, and less than 1 week at 10°. Leeks remained salable in polyethylene-lined wooden crates for 4 to 6 weeks at 0°, 2 to 3 weeks at 4.4°, and 1 to 2 weeks at 10°.

Consumer-unit packaged leeks from stock that had been stored in polyethylene-lined wooden crates held up better than leeks from nonlined wooden crates. Leeks stored continuously at 0° C retained quality better than those held for a period at 4.4° or 10° before storage at 0°.

Data are presented on respiration rates of leeks compared with those of green onions at several temperatures, and on extent of leaf elongation of leeks during storage.

BACKGROUND

Leeks (*Allium ampeloprasum* L., formerly *A. porrum* L.) (*4, 9*)[2] are available all year in most urban areas from surrounding growing areas or nearby States; some are hauled longer distances. The estimated annual consumption in the United States is 10,000 metric tons (2,200 pounds per ton) for leeks, compared with 200,000 metric tons for green onions.

Optimum storage conditions and storage life for freshly harvested leeks were reported by various authors as 0° C and 100 percent relative humidity for 4 to 6 weeks (*8*); 0° to 1° and 98 to 100 percent relative humidity for 6 to 7 weeks

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[2] Italicized numbers in parentheses refer to Literature Cited, p. 19.

(*11*); 0° and 90 to 95 percent relative humidity for 1 to 3 months (*6*); −1° to −2° (some at −3°) and 70 to 80 percent relative humidity for 6 to 8 months (*7*). Holding at 0° to 4.4° to prevent yellowing and decay and the use of crushed ice to maintain freshness were recommended for leeks displayed in retail stores (*5*). Reported freezing points for leeks ranged from −0.7° to −1.4° (*12*).

Tests with leeks (*1*) and with green onions (*3*) suggested that modifying storage or package atmosphere by using nonperforated plastic packaging material may delay yellowing, curving, and rotting of leaves.

Respiration and heat-evolution rates reported for leeks (*6, 8, 10*) generally fall within ranges of rates reported for green onions (*3*) (table 1). Thus, from this measure of storage and shelf-life predictability, leeks might be expected to hold up about as well as green onions do (*3*).

The purpose of this study was to find improved methods for the handling, storing, and packaging of fresh leeks and to determine their storage and shelf life at various temperatures.

TABLE 1.—*Respiration and heat-evolution rates for leeks and green onions at 6 temperatures* [1]

Holding temperature		Respiration rates	Heat-evolution rates	
°C	°F	Mg CO_2 per kg per h	MJ per metric ton	1,000 Btu per ton per 24 h
		LEEKS		
26.7	80	107–119	27.4–30.4	23.6–26.1
21.1	70	110	28.1	24.2
15.6	60	75–117	19.2–29.9	16.5–25.7
10.0	50	50– 70	12.8–17.9	11.0–15.4
4.4	40	20– 29	5.0– 7.4	4.3– 6.4
0	32	10– 20	2.4– 5.1	2.1– 4.4
		GREEN ONIONS		
26.7	80	98–210	25.0–53.6	21.5–46.1
21.1	70	79–178	20.1–45.6	17.3–39.2
15.6	60	66–115	16.9–29.3	14.5–25.2
10.0	50	36– 62	9.2–15.9	7.9–13.7
4.4	40	17– 39	4.4– 9.9	3.8– 8.5
0	32	10– 32	2.7– 8.1	2.3– 7.0

[1] Table prepared by using or adapting published data on green onions (*3*) and leeks (*6, 8, 10*). Respiration rates as milligrams of carbon dioxide per kilogram of green onions or leeks per hour were multiplied by the factor 220 to convert to British thermal units per ton per 24 hours (*6*) (Mg CO_2 per kg per h × 220 = 1,000 Btu per ton per 24 h). Heat-evolution rates as 1,000 Btu per ton per 24 h were multiplied by the factor 1.163 to convert to megajoule (MJ) per metric ton. One MJ per metric ton equals 1 joule per gram.

METHODS AND MATERIALS

Storage and shelf-life tests of leeks were made at Beltsville, Md., from September 1975 to January 1976, using about 200 bunches of cv. American Flag leeks grown in Vineland, N.J. Following a preliminary survey of leeks available in nearby stores, tests were conducted in three phases: initial consumer-unit holding tests, crate storage tests, and post-storage consumer-unit holding tests.

The leeks were trucked from Vineland in wirebound wooden shipping-storage crates that measured 51 x 28 x 19 cm (20 x 11 x 7½ in)

inside and 56 x 29 x 20 cm (22 x 11½ x 8 in) outside. Each crate held 12 bunches of 5 leeks each. At Beltsville leeks from Vineland were placed in test within 24 hours after harvest; those purchased from a wholesale market in Washington, D.C., had spent 3 to 5 days in storage at 7.2 to 10° C before arrival at Beltsville. Initially the leeks in the 51 cm (20 in) long crates measured 66 cm (26 in) or longer and were either protruding past the partly closed lid or folded over to fit within the crate (fig. 1). At Beltsville these leeks were trimmed to 46 cm (18 in) length, to fit into the crates without folding, for use in the crate-storage tests, and then further trimmed to 30 cm (12 in) top length for consumer-unit holding tests (figs. 1, 2). Initially some leeks were left nontrimmed for comparison with trimmed leeks during storage.

During storage, crates were nonlined or each fitted with a 1.5–mil nonperforated polyethylene film liner. The liners were neither sealed nor tied shut but were folded over to limit gas exchange. Also, bunches of five leeks each were each secured by a twist-tie and either non-wrapped (naked) or placed in a perforated (eight 0.5 cm holes) polyethylene (1.5 mil) bag with a twist-tie closure or in a nonperforated polyethylene bag twist-tied to be gastight (sealed). Temperatures of 0°, 4.4°, 10°, and 20° to 22.5° C were used to test storage and shelf life of leeks. Other details of methods and materials are given under individual tests.

Generally tests were set up in split-plot experimental design. Where appropriate, the data were processed by analysis of variance and by Duncan's multiple range test at the 5–percent level of statistical significance (*2*).

PRELIMINARY SURVEY AND OBSERVATIONS

Store Survey

Twelve bunches of leeks bought at six supermarkets near Beltsville, Md., weighed from 203 to 787 grams (g) each. Retail cost per bunch was 39 cents at 1 store and 79 cents at 5 other stores. The 39–cent leeks ranged from 15 to 16 cents per 100 g as purchased. The 79–cent leeks ranged from 10 to 39 cents per 100 g as purchased, with cost of edible portion ranging from 14 to 63 cents per 100 g. Most leeks were sold as naked bunches; others, after trimming, were placed on pulpboard trays and overwrapped with transparent film (fig. 3).

Appearance ratings of the 12 bunches of leeks as sampled in the six stores were as follows: Excellent 1, very good 2, good 4, fair 3, and poor 2. Leeks rated excellent, very good, and good were considered fully salable. To achieve salability fair and poor leeks required 20 and 26 percent trim, respectively. After trimming, all leeks were rated fresh and green, very good to excellent in appearance, and fully salable. These trimmed leeks were then placed in perforated polyethylene bags and held at 0° C. They remained salable for 3 to 9 weeks, averaging 5 weeks. At 5 weeks the leeks had slight geotropic curvature indicating that even at 0° some elongation had occurred.

Elongation Observations

Leeks initially trimmed to 30 cm (12 in) in length and stored in polyethylene-lined crates, elongated less than 1 percent per week at 0° C under crushed ice, 3 percent per week at 0° without ice, 13 percent per week at 4.4°, and 22 percent per week at 10° (table 2).

TABLE 2.—*Elongation rates for leeks held under 4 temperature-icing systems and 85 to 95 percent relative humidity in polyethylene-lined and nonlined wooden crates* [1]

Storage temperature—icing system		Length increase per week—	
°F	°C	Lined crate	Nonlined crate
		Percent	*Percent*
32	0 with crushed ice	0.8 a	10.3 b
32	0 without ice	3.0 a	10.0 b
40	4.4 do	13.0 b	41.0 d
50	10.0 do	21.7 c	(2)

[1] Each value is based on 30 leeks. Duncan's multiple range test of significance at 5–percent level; values followed by no letters in common are significantly different.

[2] Data missing because decay of leaf tips masked elongation.

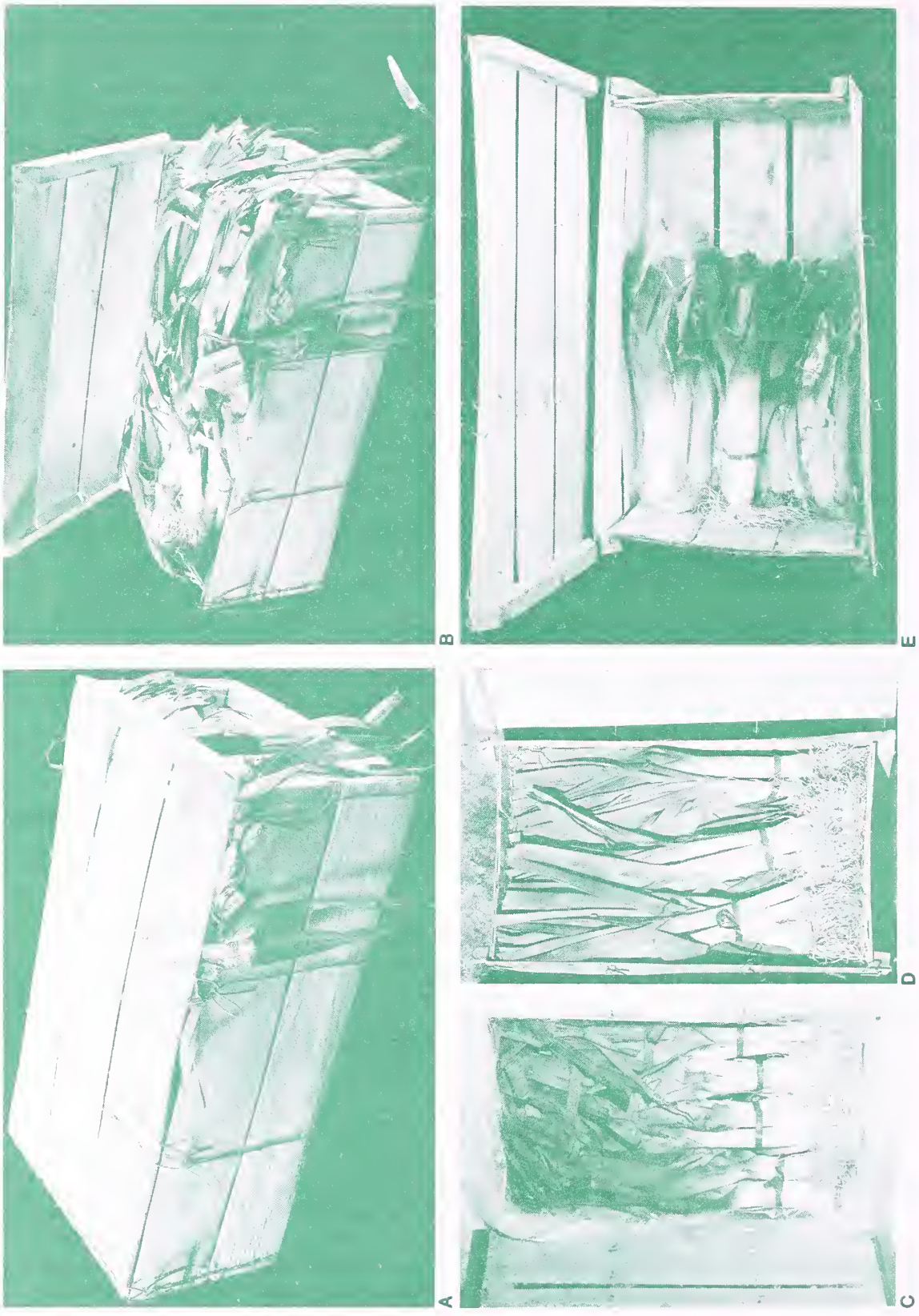

FIGURE 1.—Polyethylene—lined and nonlined, wirebound wooden crates for shipping and storing leeks: *A*, closed and *B*, open crates of nontrimmed leeks in commercial pack (note protruding tops); *C*, nontrimmed leeks folded over to fit into crate; *D*, leek tops trimmed to 46 cm (18 in) to fit crate, and *E*, leek tops trimmed to 30 cm (12 in) for packaging as consumer units (note possible saving in crate size and weight from trimming in field).

FIGURE 2.—Leeks before and after trimming to improve appearance and to allow packaging in consumer units: *Left*, leek tops on removal from crates measured over 66 cm (26 in); *right*, leeks trimmed to 30 cm (12 in).

Elongation in leeks was one-third to one-tenth as great in polyethylene-lined crates as in nonlined crates, probably because of the growth-retarding effect of the modified atmosphere within the polyethylene liners (*1, 3*). Various degrees of curvature were observed. But, data were limited, and in these observations no attempt was made to correlate curvature with elongation rate.

Atmospheres Within Packages

Orsat apparatus readings were made to determine carbon dioxide (CO_2) and oxygen (O_2) content of atmospheres around nonwrapped (naked) bunches of leeks and within packages of leeks enclosed in twist-tied perforated or nonperforated (sealed) polyethylene bags (table 3). Room atmospheres around naked leeks contained less than 1 percent CO_2 and over 20 percent O_2 as expected. Atmospheres within perforated packages generally had slightly more CO_2 and less O_2 than found around naked bunches. Atmospheres within nonperforated polyethylene bags had appreciably more CO_2 and less O_2 than noted in the other two package types. Most CO_2 buildup and O_2 depletion was found in nonperforated packages held at 21.1° C, less at 10°, and least at 0°. No off-odors or off-flavors caused by suboxidation, nor tissue damage from CO_2 buildup or O_2 depletion, were found in these or subsequent tests with leeks in sealed packages.

FIGURE 3.—Leeks offered for sale after trimming and packaging on pulpboard trays, *left*, overwrapped with transparent film and, *right*, unwrapped.

TABLE 3.—*Percent carbon dioxide (CO_2) and oxygen (O_2) around naked bunches and within packages of leeks in twist-tied perforated and nonperforated polyethylene bags* [1]

Holding temperature (°C), icing, and holding time	Package type and gas content					
	Naked bunches		Perforated polyethylene bags		Nonperforated (sealed) polyethylene bags	
	CO_2	O_2	CO_2	O_2	CO_2	O_2
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0° With crushed ice:						
1 day	0.1	20.4	0.3	21.0	3.2	16.4
2 days	.1	20.3	.2	20.8	3.2	17.4
3 days	.3	20.9	.3	20.9	3.5	16.4
0° Without ice:						
1 day	.1	20.1	1.5	18.7	3.5	14.6
2 days	.1	20.3	.1	20.0	3.3	16.2
3 days	.1	20.8	.1	20.8	3.3	15.8
10.0° Without ice:						
1 day	.2	20.8	.4	20.3	5.0	13.5
2 days	0	20.7	.1	20.3	4.5	12.4
3 days	0	20.7	.6	18.3	6.0	9.2
21.1° Without ice:						
1 day	.2	20.8	1.1	19.7	9.6	6.5
2 days	0	20.6	.8	20.0	7.8	6.7
3 days	0	20.7	.2	20.6	7.6	8.0

[1] Each percent is based on readings on 2 packages of each type.

STORAGE AND SHELF-LIFE TESTS

Initial Consumer-Unit Holding Tests

Test 1.—*Shelf life of leeks, from wholesale market, held after packaging in consumer-unit polyethylene bags.*—In this packaging and holding test, 24 bunches of 5 leeks each were randomly assembled from two crates of leeks, purchased from a Washington, D.C., wholesaler. Following harvest the crates of leeks had been held at the wholesale market for 3 to 5 days at 7.2° to 10° C. The bunches were either held nonwrapped (naked) or placed in perforated (eight 0.5 cm holes) polyethylene bags or nonperforated (sealed) polyethylene bags. The naked and bagged leeks were held under crushed ice at 0° or without ice at 0°, 10°, or 21.1° at about 85 to 95 percent relative humidity (fig. 4). Leeks at 0° were fresh and green, except the naked bunches held dry were severely wilted; leeks at 21.1° were not fresh and were curved slightly in nonperforated bags, and moderately curved in the naked bunches and perforated bags.

Shelf life was greater for leeks in polyethylene bags than in naked bunches (table 4). At 0° C, either with or without crushed ice, shelf life of leeks was greater in nonperforated (sealed) bags than in perforated bags. At 10° shelf life was about the same for leeks in nonperforated and perforated bags. On the average, leeks in nonperforated polyethylene bags held up best, leeks in perforated polyethylene bags next best, and leeks in naked bunches, worst.

In this shelf-life test, leeks held up well for an average of 26 days at 0° C under crushed ice, 19 days at 0° without ice, 8 days at 10°, and 3 days at 21.1°. No off-odors or off-flavors caused by suboxidation were noted. Weight loss and accompanying turgor loss were major causes of deterioration in naked leeks. Leeks under crushed ice lost no weight because of presence of free water. Without crushed ice naked leeks lost

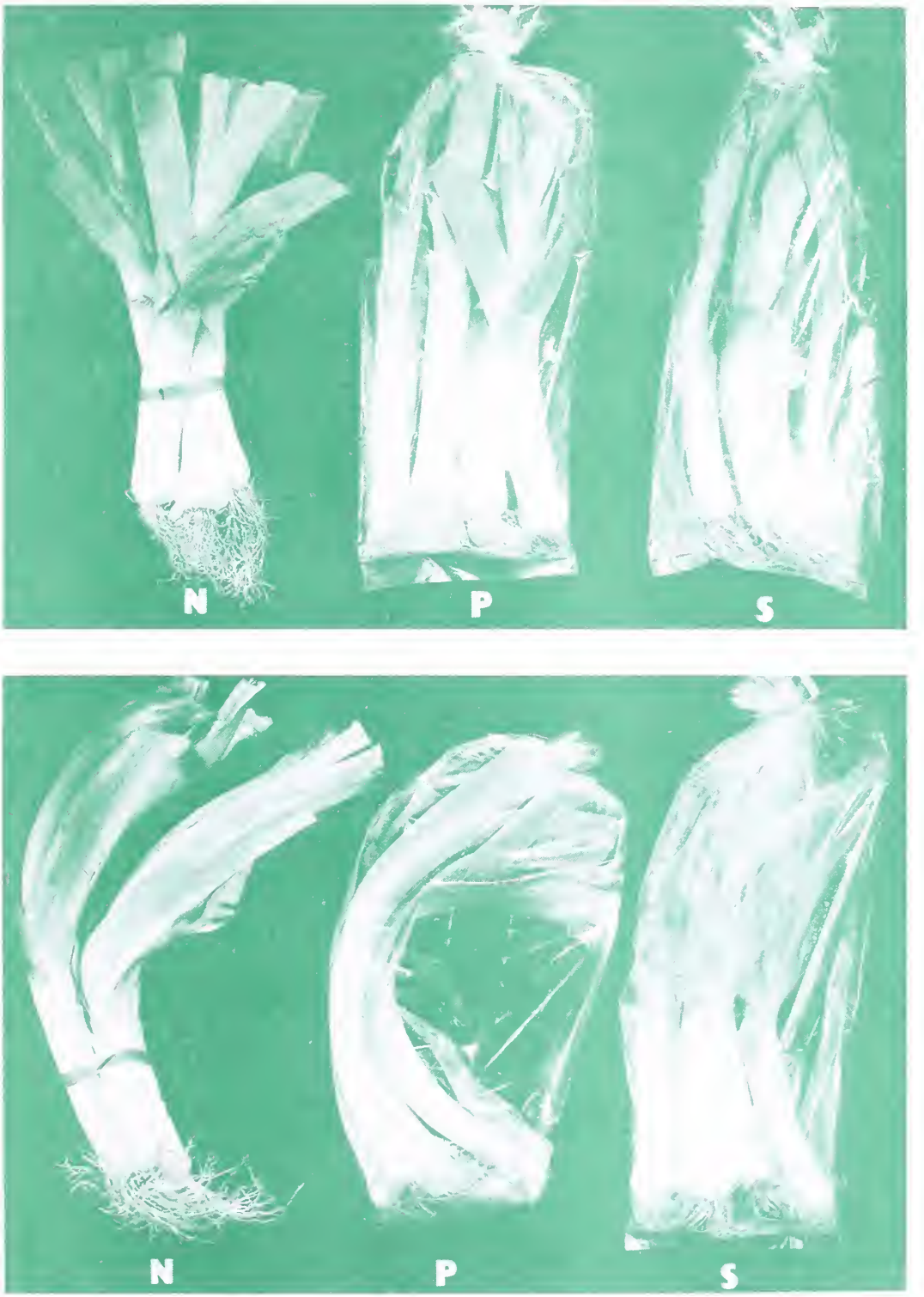

FIGURE 4.—Consumer-unit packaged leeks in nonwrapped (naked) bunches (N); perforated polyethylene bags (P); and nonperforated (sealed) polyethylene bags (S), after 6 days' holding without ice: *Above*, at 0°C, and *below*, at 21.1° C.

TABLE 4.—*Condition of leeks from wholesale market held in consumer-unit polyethylene bags at various temperatures, with or without crushed ice, at about 85 to 95 percent relative humidity* [1]

Holding temperature (°C), icing, and holding time	Weight loss (cumulative)			Wilting			Curvature		
	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene
	Percent	*Percent*	*Percent*	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
0° With crushed ice:									
2 days	0	0	0	0	0	0	T	T	T
4 days	0	0	0	0	0	0	T	T	T
7 days	0	0	0	0	0	0	T	T–Sl	Sl
14 days	0	0	0	0	0	0	T–Sl	T–Sl	Sl
21 days	0	0	0	0	0	0	T–Sl	T–Sl	Sl
28 days	0	0	0	0	0	0	T–Sl	T–Sl	Sl
35 days	–	–	0	–	–	0	–	–	Sl
0° Without ice:									
2 days	5.3	.1	0	T	0	0	T	T	T
4 days	9.2	.2	0	Mod	0	0	T	T	T
7 days	13.2	.3	.1	Sv	0	0	T	T	T
14 days	20.0	.5	.1	Sv	0	0	T	T	T
21 days	–	.7	.2	–	0	0	T	T	T
28 days	–	.8	.2	–	0	0	T	T	T
35 days	–	–	.3	–	–	0	–	–	T
10° Without ice:									
2 days	7.6	.1	0	T	0	0	T	0	T
4 days	11.6	.2	.1	Sl	0	0	T	0	T
7 days	17.5	.4	.2	Sv	0	0	T	0	T
14 days	–	.8	.4	–	0	0	T	T	T
21.1° Without ice:									
2 days	6.1	.2	.0	T	0	0	Sl	Sl	T
3 days	9.1	.3	.1	Mod	0	0	Mod	Mod	T
4 days	–	.4	.2	–	0	0	–	Mod	T
6 days	–	.8	–	–	0	–	–	Sv	–

Holding temperature (°C), icing, and holding time	Yellowing			Decay			General appearance		
	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene
	Rating	*Rating*	*Rating*	*Percent*	*Percent*	*Percent*	*Rating*	*Rating*	*Rating*
0° With crushed ice:									
2 days	0	0	0	0	0	0	Ex	Ex	Ex
4 days	0	0	0	0	0	0	Ex	Ex	Ex
7 days	0	0	0	0	0	0	Ex	Ex	Ex
14 days	T	0	0	[2] 0	0	0	Ex	Ex	Ex
21 days	T	0	0	[2] 0	0	0	Ex	Ex	Ex
28 days	T	0	0	[2] 0	[3] 20 Mod	0	P	F	Ex
35 days	–	–	0	–	–	[3] 20 Sl	–	–	F
0° Without ice:									
2 days	0	0	0	0	0	0	Ex	Ex	Ex
4 days	0	0	0	0	0	0	G	Ex	Ex
7 days	0	0	0	0	0	0	F–G	Ex	Ex
14 days	0	0	0	0	0	0	F–P	Ex	Ex
21 days	–	0	0	–	[3] 30 T	0	–	F–G	Ex
28 days	–	0	0	–	[3] 30 xSv	0	–	F–P	Ex
35 days	–	–	0	–	–	[3] 30 Sl	–	–	F
10° Without ice:									
2 days	0	0	0	0	0	0	Ex	Ex	Ex
4 days	0	0	0	0	0	0	G	Ex	Ex
7 days	Mod	0	0	0	[3] 10 T	[3] 2 T	P	VG	VG
14 days	–	T	0	–	[3] 60 Mod	[3] 40 xSv	–	F–P	F–P
21.1° Without ice:									
2 days	T	0	0	[3] 10 T	0	0	G–VG	Ex	Ex
3 days	Mod	0	0	[3] 60 Mod	0	[3] 10 Mod	P	VG	G
4 days	–	0	0	–	[3] 10 T	[3] 60 Mod	–	G	F
6 days	–	Mod	–	–	[3] 60 xSv	–	–	P	–

[1] Leeks were placed in holding test at Beltsville, Md., after they had been 3 to 5 days in walk-in refrigerator at 7.2° to 10° C at Washington, D.C., wholesale market. Each value is based on 2 bunches of leeks: 0 = none, T = trace, Sl = slight, Mod = moderate, Sv = severe. xSv = extremely severe, Ex = excellent, VG = very good, G = Good, F = fair, P = poor. VP = very poor.

[2] Ice injury on some leaves.

[3] Percent leeks affected and severity or extent of decay.

about 2 to 3 percent weight per day, while bagged leeks lost 0.1 percent or less per day. Moderate wilting was noted when 9 to 14 percent weight was lost; severe, when 11 to 18 percent was lost.

Test 2.—*Shelf life of leeks, from nearby harvest area, held after packaging in consumer-unit polyethylene bags.*—Test 2 was set up the same as test 1 except that the 24 bunches of 5 leeks each randomly assembled from 2 crates of leeks were obtained at harvest at Vineland, N.J., and placed in a holding test at Beltsville, Md., within 24 hours.

As in test 1, generally, leeks in nonperforated (sealed) polyethylene bags held up best, leeks in perforated bags next best, and leeks in naked bunches, worst (table 5). In temperature comparisons, leeks held at 0° C under crushed ice held up best, those at 0° without ice next best, at 10° next best, and at 21.1°, worst. Leeks in test 2 remained salable much longer than those in test 1 because they were freshly harvested instead of being held at a city wholesale market for some time before purchase.

Thus, in test 2, leeks in bunches held naked, in perforated polyethylene bags, or in nonperforated (sealed) polyethylene bags, respectively, remained attractive and salable for 5, 6, or 10 weeks under crushed ice at 0° C, for 1.5, 4, or 10 weeks without ice at 0°, for 6, 8, or 12 days at 10°, and for 4, 3, or 6 days at 21.1°. Naked leeks lost 2 to 3 percent weight per day, while bagged leeks lost 0.1 percent or less per day. Moderate wilt was noted in some leeks when 18 to 21 percent weight was lost; severe, when 23.2 percent was lost.

Crate Storage Test

Test 3.—*Storage life of freshly harvested leeks, stored in polyethylene lined or nonlined wirebound wooden crates.*—Ten wirebound wooden crates each holding 12 five-stalk bunches of leeks were randomly filled and placed in storage at Beltsville, Md., within 24 hours after harvest at Vineland, N.J. Half of the crates were lined with nonperforated 1.5–mil polyethylene liners, which were not sealed but folded over to enclose the leeks and restrict gas exchange; half of the crates were nonlined. Paired lined and nonlined crates were stored under each one of five trimming-icing-temperature combinations (table 6).

Freshly harvested leeks remained in better condition and salable much longer when stored in polyethylene-lined than in nonlined crates (table 6). In lined crates stored at 0° C under crushed ice, trimmed leeks remained in excellent condition 1 week longer than nontrimmed leeks. Leeks under crushed ice remained in excellent condition and salable longer than leeks without ice. Leeks held up best at 0°, next best at 4.4°, and worst at 10°. From data not directly shown in table 6, no weight loss due to moisture loss was noted in leeks with ice because free water was present on leek surfaces. Leeks without ice stored at 0°, 4.4°, and 10° in lined crates lost 0.5, 0.7, and 1.4 percent weight per week, respectively; while in nonlined crates they lost 2.5, 4.6, and 6.0 percent per week, respectively. Thus, leeks stored in nonlined crates remained salable for less than 1 week at 10.0°, 8 days at 4.4°, and 3 weeks at 0° (with or without ice). In lined crates leeks kept well for 13 days at 10°, over 2 weeks at 4.4°, 4 weeks at 0° without ice, and 5 to 6 weeks at 0° under crushed ice (fig. 5). Moderate yellowing, which detracted from general appearance, was found only in leeks held at 10° for 1 week in nonlined crates or for 2 weeks in lined crates. When, after 1 to 7 weeks' storage at 0°, 4.4°, or 10°, the appearance of the leeks in each nonlined or lined crate deteriorated and the leeks became unsalable, they were trimmed for salability. Each crate was then lined or relined and the freshened leeks recrated and placed at 0° without ice. At 5 weeks after harvest, half (six bunches) of the leeks from each storage crate were lightly trimmed for salability, packaged in bunches, and held at 20° or 22.5° either naked or in perforated polyethylene bags, or nonperforated (sealed) polyethylene bags to determine shelf life after storage. The remaining leeks, recrated in the 10 lined wooden crates, were reexamined after 16 weeks' total storage including initial storage at 0°, 4.4°, or 10° and subsequent storage at 0° only (table 7). At the 16–week examination, leeks in all crates were unsalable. However, by moderate trimming 83 percent of the leeks from originally lined crates and 67 percent from originally nonlined crates were made salable. The remaining 25 percent required removal of

all roots in addition to moderate leaf trimming to make them attractive. Following the 16-week examination the remaining salable leeks from each lined storage crate were consumer-unit packaged and held at 20° or 22.5° for shelf-life test 5.

Post-Storage Consumer-Unit Holding Tests

Test 4.—*Shelf life of leeks consumer-unit packaged after 5 weeks of crate storage.*—Following 5 weeks' storage in originally lined or nonlined crates—at 0° C only for the entire 5 weeks (six crates); 1 and 3 weeks at 4.4°, plus 4 and 2 weeks at 0° (two crates); 1 and 2 weeks at 10°, plus 4 and 3 weeks at 0° (two crates)—six bunches of leeks from each of 10 crates from test 3 (table 6) were trimmed for salability and held 3 days at about 20° and 95 percent relative humidity, or 22.5° and 35 percent relative humidity as naked bunches or packaged in perforated or nonperforated (sealed) polyethylene consumer-unit bags.

During 3 days' holding, leeks consumer-unit packaged after 5 weeks' storage in lined crates held up slightly better than leeks from nonlined crates, averaging good versus fair to good in general appearance. Leeks from continuous 0° C storage held up better than leeks initially at 4.4° or 10° and subsequently at 0°. Leeks at 20° and 95 percent relative humidity held up better than leeks at 22.5° and 35 percent relative humidity (table 8). Consumer-unit packaged leeks held up best in nonperforated polyethylene bags and averaged very good in general appearance over the 3 days.

Leeks remained salable at 20° to 22.5° C, after consumer-unit packaging, for 1 day in naked bunches, 2 days in perforated polyethylene bags, and 4 to 5 days in nonperforated bags. After an additional day in any of the three package types,

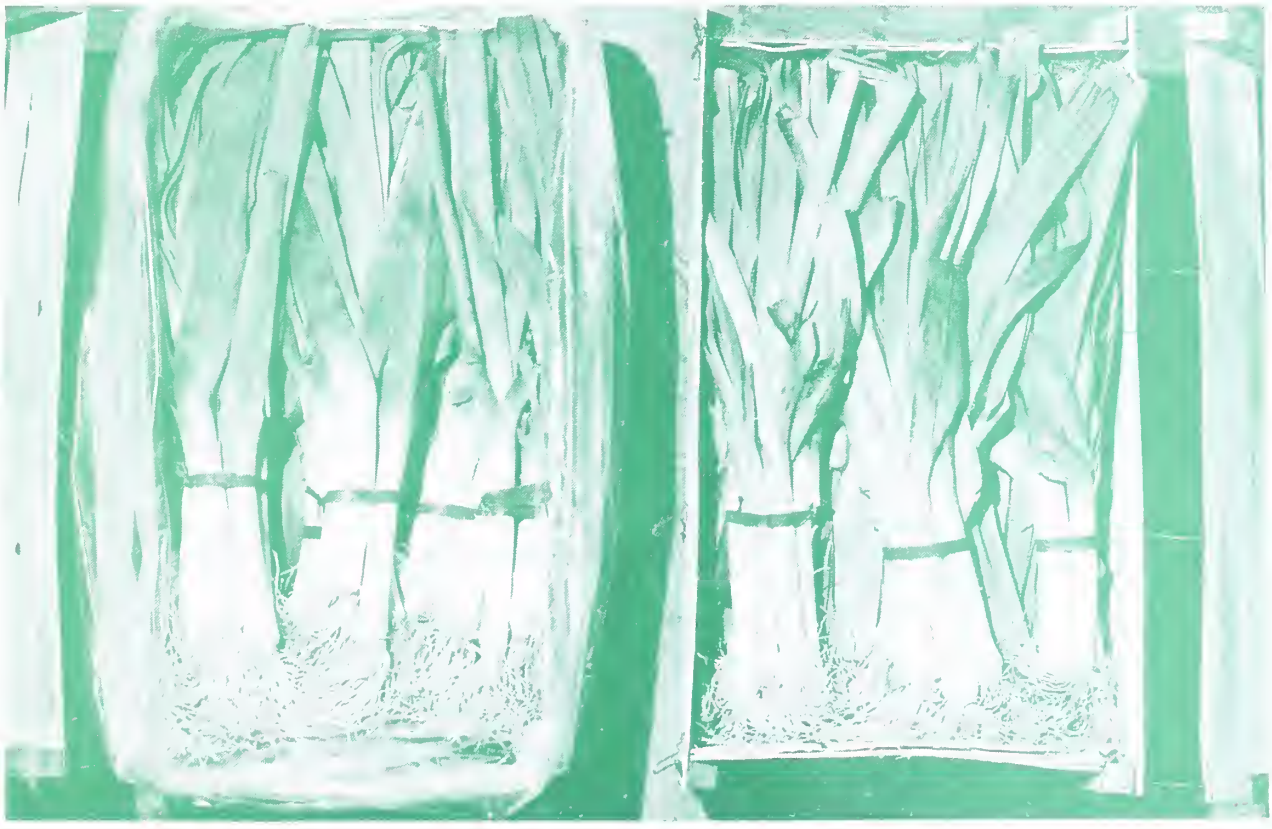

FIGURE 5.—Leeks in wirebound wooden shipping-storage crate after 1 week at 10.0° C: *Left*, leeks in polyethylene-lined crate rated very good and salable; *right*, leeks in nonlined crate rated very poor and unsalable because of yellowing and decay.

TABLE 5.—*Condition of leeks freshly harvested before packaging in consumer-unit polyethylene bags at various temperatures, with or without crushed ice, at about 85 to 95 percent relative humidity* [1]

Holding temperature (°C), icing, and holding time	Weight loss (cumulative)			Wilting			Curvature		
	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene
	Percent	*Percent*	*Percent*	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*	*Rating*
0° With crushed ice:									
4 weeks	0	0	0	0	0	0	0	0	0
5 weeks	0	0	0	0	0	0	0	0	0
6 weeks	0	0	0	0	0	0	0	0	0
7 weeks	–	0	0	–	0	0	–	0	0
8 weeks	–	–	0	–	–	0	–	–	0
10 weeks	–	–	0	–	–	0	–	–	0
11 weeks	–	–	0	–	–	0	–	–	0
0° Without ice:									
1 week	16.4	.6	.2	T–Mod	0	0	T	T	T
2 weeks	24.2	1.0	.3	Mod–Sv	0	0	T	T	T
4 weeks	–	2.2	.5	–	0	0	–	T	T
5 weeks	–	2.4	.6	–	0	0	–	T	T
10 weeks	–	–	.9	–	–	0	–	–	T
11 weeks	–	–	1.0	–	–	0	–	–	T
10° Without ice:									
5 days	15.9	.7	.1	T–Sl	0	0	T	Sl	Sl
7 days	20.4	.8	.2	Sl–Mod	0	0	T	Sl	Sl
10 days	–	1.0	.3	–	0	0	–	Mod	Sl
14 days	–	–	.4	–	–	0	–	–	Mod
21.1° Without ice:									
3 days	8.2	.4	.1	0	0	0	Sl–Mod	Sl	Sl
4 days	11.4	1.0	.2	T	0	0	Sl-Mod	Mod	Sl–Mod
5 days	13.5	–	.3	T	–	0	Mod	–	Mod
7 days	–	–	.3	–	–	0	–	–	Sv

Holding temperature (°C), icing, and holding time	Yellowing			Decay			General appearance		
	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene	Naked	Perforated polyethylene	Non-perforated (sealed) polyethylene
	Rating	*Rating*	*Rating*	*Percent*	*Percent*	*Percent*	*Rating*	*Rating*	*Rating*
0° With crushed ice:									
4 weeks	0	0	0	0	0	0	Ex	Ex	Ex
5 weeks	T	0	0	[3] 20 T	[2] 20 T	0	G	VG	Ex
6 weeks	Sl	0	0	[2] 100 Mod	[2] 30 T	0	F–P	G	Ex
7 weeks	–	Sl	0	–	[2] 100 Mod	0	–	P	Ex
8 weeks	–	–	0	–	–	0	–	–	Ex
10 weeks	–	–	0	–	–	[2] 10 T	–	–	VG
11 weeks	–	–	T	–	–	[2] 50 Mod	–	–	P
0° Without ice:									
1 week	0	0	0	0	0	0	VG	Ex	Ex
2 weeks	0	0	0	[2] 50 Mod	[2] 20 T	0	F–P	Ex	Ex
4 weeks	–	0	0	–	[2] 50 T	0	–	Ex	Ex
5 weeks	–	–	0	–	[2] 50 Mod	0	–	P	Ex
10 weeks	–	–	0	–	–	0	–	–	F
11 weeks	–	–	0	–	–	[2] 70 Mod	–	–	P
10° Without ice:									
5 days	0	0	0	0	0	0	G	Ex	Ex
7 days	Sl	0	0	0	[2] 20 T	0	P	VG	Ex
10 days	–	Sl	0	–	[2] 100 Mod	0	–	P	Ex
14 days	–	–	0	–	–	[2] 20 Mod	–	–	P
21.1° Without ice:									
3 days	T	T	0	0	0	0	G	G	Ex
4 days	Sl	Sl	0	0	0	0	F	P	Ex
5 days	Sl	–	0	0	–	0	P	–	Ex
7 days	–	–	Sl	–	–	[2] 50 Mod	–	–	P

[1] Leeks were placed in holding test at Beltsville, Md., within 24 h after harvest in Vineland, N.J. Each value is based on 2 bunches of leeks: 0 = none, T = trace, Sl = slight, Mod = moderate, Sv = severe, xSv = extremely severe, Ex = excellent, VG = very good, G = good, F = fair, P = poor, VP = very poor.

[2] Percent leeks affected and severity or extent of decay.

TABLE 6.—*Condition of leeks after storage in polyethylene-lined and nonlined, wirebound wooden crates at 0°, 4.4°, or 10° C and 85 to 95 percent relative humidity* [1]

Storage temperature (°C), icing, trimming, and holding time	Bunches with decay		Appearance [2]		Post-storage trim weight		Total shrink weight [3]	
	Lined crates	Nonlined crates	Lined crates	Nonlined crates	Lined crates	Non-lined crates	Lined crates	Non-lined crates
	Number	*Number*	*Rating*	*Rating*	*Percent*	*Percent*	*Percent*	*Percent*
0° With crushed ice, trimmed:								
1 week	6 T	6 T	Ex	Ex	–	–	–	–
2 weeks	6 T	12 T	Ex	Ex	–	–	–	–
3 weeks	6 T	12 T	Ex	VG	–	–	–	–
4 weeks	6 T	12 Sl–Sv	Ex	P	–	29.5	–	38.2
5 weeks	6 T	–	Ex	–	–	–	–	–
6 weeks	6 T	–	Ex	–	–	–	–	–
7 weeks	9 T–Mod	–	F–P	–	33.7	–	42.4	–
0° With crushed ice, nontrimmed:								
1 week	0	0	Ex	Ex	–	–	–	–
2 weeks	6 T	10 T	Ex	VG [4]	–	–	–	–
3 weeks	6 T	10 T	Ex	VG [4]	–	–	–	–
4 weeks	8 T	10 Mod	Ex	P [4]	–	37.8	–	37.8
5 weeks	8 T	–	Ex	–	–	–	–	–
6 weeks	12 T–Mod	–	P	–	37.3	–	37.3	–
0° Without ice, trimmed:								
1 week	0	0	Ex	Ex	–	–	–	–
2 weeks	3 T	6 T	Ex	VG	–	–	–	–
3 weeks	3 T	6 T	Ex	G	–	–	–	–
4 weeks	8 T	12 T-Sv	VG	P	–	25.0	–	43.7
5 weeks	10 T–Mod	–	P	–	35.0	–	46.2	–
4.4° Without ice, trimmed:								
0.4 week [5]	0	0	Ex	VG	–	–	–	–
1 week	2 T	3 T	Ex	G	–	–	–	–
1.4 weeks [5]	4 T	12 T-Sv	Ex	VP	–	23.8	–	39.5
2 weeks	8 T	–	VG	–	–	–	–	–
3 weeks	12 T–Sv	–	P	–	16.3	–	27.2	–
10.0° Without ice, trimmed:								
0.4 week [5]	8 T	6 T	Ex	VG	–	–	–	
1 week	8 T	12 Mod	VG	VP [6]	–	38.5	–	[6] 53.2
1.4 weeks [5]	9 T–Sl	–	G	–	–	–	–	–
2 weeks	12 T–Mod	–	P	–	22.0	–	33.4	–

[1] Ratings based on 12 bunches of leeks per crate: 0 = none, T = trace, Sl = slight, Mod = moderate, Sv = severe, xSv = extremely severe, Ex = excellent, VG = very good, G = good, F = fair, P = poor, VP = very poor.

[2] Except for iced crates, all leeks in nonlined crates appeared less fresh than in lined crates.

[3] Total shrink included loss in weight caused by: (1) Initial trimming to fit into crates without folding, (2) transpired water lost during storage, and (3) post-storage trimming required for consumer-unit packaging and salability. Note that post-storage and post-trim data were collected 1 to 3 weeks later for lined than for nonlined crates of leeks.

[4] Ice marks on some leaves.

[5] Three days are about 0.4 week; 10 days are about 1.4 weeks.

[6] Leeks from nonlined crates stored 1 week at 10° C required excessive trimming to become only barely salable. All other leeks were fully salable after moderate trim.

TABLE 7.—*Condition of leeks after 16 weeks' total storage with initial storage in polyethylene-lined or nonlined crates for 1 to 3 weeks at 10° or 4.4° C or 4 to 7 weeks at 0° and subsequent storage all in polyethylene-lined crates at 0° and 85 to 95 percent relative humidity*

Initial storage temperature (°C), storage icing, and trim before storage	Initial storage time	Ratings after 16 weeks' storage: Pretrim [1] General appearance	Pretrim [1] Salability	Post-storage trim	Post-trim [1] General appearance	Post-trim [1] Salable bunches
	Weeks	*Rating*	*Rating*	*Percent*	*Rating*	*Percent*
INITIALLY STORED IN POLYETHYLENE-LINED CRATES						
0°, With crushed ice, trimmed	7	Poor-very poor	No	16	Very good-poor	83
0°, With crushed ice, nontrimmed	6	do	do	28	do	83
0°, Without ice, trimmed	5	do	do	18	Very good	100
4.4°, Without ice, trimmed	3	Very poor	do	33	Good-poor	83
10.0°, Without ice, trimmed	2	do	do	44	do	67
Average	–			28		[2] 83
INITIALLY STORED IN NONLINED CRATES						
0°, With crushed ice, trimmed	4	Very poor	No	56	Good-poor	67
0°, With crushed ice, nontrimmed	4	do	do	47	Poor	0
0°, Without ice, trimmed	4	do	do	33	Good-poor	83
4.4°, Without ice, trimmed	1.5	do	do	28	Good	100
10.0°, Without ice, trimmed	1	Poor	do	35	Good-poor	83
Average	–			40		[2] 67

[1] Ratings based on 6 bunches of leeks per crate.

[2] Overall an average of 75 percent of the bunches of leeks were salable after trimming; while 25 percent required removal of all roots and moderate trimming for salability.

over 50 percent of the bunches had deteriorated seriously. Weight loss of leeks in naked bunches was four times as great at 35 percent relative humidity as at 95 percent relative humidity (table 8). Combined weight and trim losses per day for naked, perforated polyethylene, and nonperforated (sealed) polyethylene packages were about 17 percent, 10 percent, and 7 percent, respectively.

Test 5.—*Shelf life of leeks consumer-unit packaged after 16 weeks of crate storage.*—Leeks that were consumer-unit packaged from test 3 were used. Leeks were taken from polyethylene-lined crates after 16 weeks' storage, which consisted of initial storage in lined or nonlined crates for 1 to 3 weeks at 10° or 4.4° C, or 4 to 7 weeks at 0°, and subsequently in lined or relined crates at 0°. Five bunches of leeks from each of 10 crates were trimmed for salability and held 3 days at about 20° and 95 percent relative humidity or 22.5° and 35 percent relative humidity as naked bunches or in bunches in perforated or nonperforated (sealed) polyethylene consumer-unit bags.

Consumer-unit packaged leeks held at 20° C and 95 percent relative humidity lost much less weight and wilted less than those held at 22.5° and 35 percent relative humidity (table 9). However, packaging caused greater differences than those attributable to holding room relative humidity. After 1 day's holding, naked leeks lost 4.7 percent weight and developed a trace of wilting at 20° and 95 percent relative humidity, while those at 22.5° and 35 percent relative humidity lost 18.5 percent weight and developed moderate to severe wilting. Polyethylene bags kept weight loss under 2 percent over the 3 days. Only 50 percent of the bunches of naked leeks remained salable for 1 day and none was salable at 2 days. All leeks in polyethylene bags were salable for 1 day and 67 percent of them remained salable for 2 days. The main symptoms of deterioration were wilting, yellowing, and curvature. Leeks which were consumer-unit packaged from originally lined crates stored only at 0° held up better than leeks from originally nonlined crates stored initially at 4.4° or 10.0° and subsequently at 0°.

TABLE 8.—*Condition of leeks packaged, from initially polyethylene-lined or nonlined crates after 5 weeks combined 10°, 4.4°, and 0° C storage, and held after packaging at 22.5° and 35 percent relative humidity, or 20° and 95 percent relative humidity* [1]

Package type and holding condition (°C)	Holding time			Average
	1 day	2 days	3 days	
GENERAL APPEARANCE (RATING) [2]				
Naked and held at—				
20°, 95 percent relative humidity	8.9 ef	6.2 c	4.7 b	6.6 b
22.5°, 35 percent relative humidity	7.3 d	5.0 b	3.6 a	5.3 a
Average	8.1 c	5.6 b	4.2 a	5.9 a
Perforated polyethylene bagged and held at—				
20°, 95 percent relative humidity	9.4 f	8.8 ef	6.0 c	8.1 c
22.5°, 35 percent relative humidity	9.2 ef	8.4 e	6.1 c	7.9 c
Average	9.3 e	8.6 cd	6.0 b	8.0 b
Nonperforated polyethylene bagged and held at—				
20°, 95 percent relative humidity	9.5 f	9.4 f	9.1 ef	9.3 d
22.5°, 35 percent relative humidity	8.9 ef	8.5 e	7.3 d	8.2 c
Average	9.2 e	9.0 de	8.2 c	8.8 c
WEIGHT LOSS (PERCENT)				
Naked and held at—				
20°, 95 percent relative humidity	3.2 d	6.6 e	9.9 f	6.6 b
22.5°, 35 percent relative humidity	14.8 g	22.3 h	29.3 i	22.1 c
Average	9.0 c	14.5 d	19.6 e	14.4 b
Perforated polyethylene bagged and held at—				
20°, 95 percent relative humidity	.1 a	.3 a	.5 a	.3 a
22.5°, 35 percent relative humidity	.6 a	1.4 b	2.2 c	1.4 a
Average	.4 a	.8 b	1.3 b	.8 a
Nonperforated polyethylene bagged and held at—				
20°, 95 percent relative humidity	.1 a	.1 a	.2 a	.1 a
22.5°, 35 percent relative humidity	.1 a	.4 a	.6 a	.4 a
Average	.1 a	.3 a	.4 a	.2 a

See footnotes at end of table.

TABLE 8.—*Condition of leeks packaged, from initially polyethylene-lined or nonlined crates after 5 weeks combined 10°, 4.4°, and 0° C storage, and held after packaging at 22.5° and 35 percent relative humidity, or 20° and 95 percent relative humidity* [1]—Continued

Package type and holding condition (°C)	Holding time			
	1 day	2 days	3 days	Average
	CURVATURE (RATING)[3]			
Naked and held at—				
20°, 95 percent relative humidity	1.7 a	2.0 abc	3.6 ef	2.4 a
22.5°, 35 percent relative humidity	1.9 abc	2.4 cde	2.8 cde	2.4 a
Average	1.8 a	2.2 abc	3.2 de	2.4 a
Perforated polyethylene bagged and held at—				
20°, 95 percent relative humidity	1.7 a	3.2 de	5.0 g	3.2 ab
22.5°, 35 percent relative humidity	2.2 a–d	4.4 fg	6.2 h	4.2 b
Average	1.9 ab	3.8 e	5.6 f	3.6 b
Nonperforated polyethylene bagged and held at—				
20°, 95 percent relative humidity	1.7 a	2.4 a–d	2.6 b–e	2.2 a
22.5°, 35 percent relative humidity	1.8 ab	2.4 a–d	3.2 de	2.4 a
Average	1.8 a	2.4 bc	2.8 cd	2.4 a

[1] Simple data for consumer-unit packaged types are based on 10 bunches for each value. Averages are based on multiples of 10 bunches for each value. Duncan's multiple range test of significance at 5-percent level; comparable values followed by no letters in common are significantly different.

[2] General appearance rating scale: Excellent = 10, good = 8, fair = 6, poor = 4, very poor = 2, garbage = 0; (6 (fair) = barely salable, over 6 = salable, under 6 = not salable).

[3] Curvature rating scale: None = 0, trace = 2, slight = 4, moderate = 6, severe = 8, extremely severe = 10.

TABLE 9.—*Condition of consumer-unit packaged leeks held after packaging at 22.5° C and 35 percent relative humidity or 20° and 95 percent relative humidity* [1]

Holding conditions and consumer wrap	Weight loss	Wilting [2]	Curvature [2]	Yellowing [2]	General appearance [3]	
					Ex–G	F
	Percent	*Rating*	*Rating*	*Rating*	*Percent*	*Percent*
1 day, 22.5° C, 35 percent relative humidity:						
Naked	18.5 e	Mod–Sv	Sl–Mod	T	50	30
Perforated polyethylene bags	.6 ab	0	Sl +	T	100	
Nonperforated polyethylene bags	.2 a	0	Sl	0–T	100	
1 day, 20°, 95 percent relative humidity:						
Naked	4.7 c	T	Mod	T	50	40
Nonperforated polyethylene bags	.1 a	0	Sl	0–T	100	
2 days, 22.5°, 35 percent relative humidity:						
Naked	29.7 f	Sv–xSv	Mod	Sv	0	
Perforated polyethylene bags	1.1 ab	T	Sl–Mod	T	60	40
Nonperforated polyethylene bags	.4 a	T	Sl	0–T	90	
2 days, 20°, 95 percent relative humidity:						
Naked	9.4 d	Mod–Sv	Mod–Sv	Sv	0	
Nonperforated polyethylene bags	.2 a	T	Mod	T	50	20
3 days, 22.5°, 35 percent relative humidity:						
Naked	(4)	---	---	---	---	---
Perforated polyethylene bags	1.9 ab	Sl	Sv	Mod	20	
Nonperforated polyethylene bags	.7 ab	T–Sl	Sl–Mod	T	40	
3 days, 20°, 95 percent relative humidity:						
Naked	(4)	---	---	---	---	---
Nonperforated polyethylene bags	.2 a	Sl	Mod–Sv	Sl	0	20

[1] Leeks were from polyethylene-lined crates after 16 weeks' storage, initially 1 to 3 weeks at 10° or 4.4° C or 4 to 7 weeks at 0°, and all subsequently at 0°. Data based on 10 bunches of leeks for each value. Duncan's multiple range test for significance at 5-percent level; values followed by no letters in common are significantly different (*2*).

[2] Ratings for wilt, curve, and yellowing: 0 = none, T = trace, Sl = slight, Mod = moderate, Sv = severe, xSv = extremely severe.

[3] General appearance ratings: Ex–G = excellent to good, F = fair.

[4] Packages discarded after 2 days' inspection.

DISCUSSION AND CONCLUSIONS

The storage and shelf life of fresh green leeks can be maintained by proper handling, packaging, and refrigeration. For best quality maintenance, leeks should be kept at 0° C (32° F) and high relative humidity (95 percent or above) throughout storage and marketing. During transit and storage, leeks may be protected from moisture loss, temperature rise, and accompanying deterioration by using polyethylene film crate liners and crushed ice over the shipping crates. During retailing and home storage, leeks need the protection afforded by packaging in moisture-retentive film, and refrigeration.

Leeks lose weight, and wilt to about the same degree as fresh green onions do (*3*). Moderate wilting was noted in some leeks when an average of about 15 percent weight was lost; severe wilting, when about 20 percent weight was lost. Packaging of leeks in perforated or nonperforated moisture-retentive polyethylene bags can prevent wilting by greatly reducing weight losses.

At the growing area trimming the long, field-grown leeks to fit a 51 cm (20 in) wirebound wooden crate or shorter 39 cm waxed carton can reduce shipping weight and package size by about 10 to 30 percent.

At 21.1° C (70° F) leeks respire and produce heat at about 28,000 megajoules per metric ton (24,000 Btu per ton) per day, which is about eight times the rate for leeks held at 0° (32°). This difference in respiration rates partly explains why leeks held at higher temperatures deteriorate faster than leeks held at 0°.

Appearance of leeks in supermarkets ranged from excellent to poor. With more attention given to improved packaging and refrigeration, more leeks offered for sale would be in excellent condition.

Leeks stored in polyethylene-lined crates elongated less than 1 percent per week at 0° C under crushed ice and 22 percent per week at 10°. Without polyethylene crate liners, elongation rates for leeks were 3 to 10 times as great. The difference is probably due to the modified atmospheres generated within the polyethylene liners. No off-odors, off-flavors, or tissue injury due to suboxidation in leeks in nonperforated (sealed) polyethylene bags were noted throughout these tests.

In shelf-life tests, leeks consumer-unit packaged in nonperforated (sealed) polyethylene bags held up best, those in perforated polyethylene bags next best, and those in naked bunches, worst. The slightly greater curvature in leeks noted in perforated polyethylene bags over that in naked leeks was probably caused by enhancement of elongation from higher relative humidity. But, curvature affected appearance far less than the wilting found mainly in naked leeks.

The residual benefit, noted during shelf-life tests, of initial storage of leeks at 0° C in polyethylene-lined crates, over initial storage at 4.4° or 10.0° in nonlined crates, points to the need for prompt refrigeration and storage at 0° with high relative humidity (95 percent or above).

LITERATURE CITED

(1) Food Investigation Board.
1959. Gas storage of vegetables. [Gt. Brit.] Food Invest. Bd. Rpt. 1958: 29–30.

(2) Hruschka, H. W.
1973. Systematic application of Duncan's multiple range test to biological research data. U.S. Dept. Agr., Agr. Res. Serv. ARS–NE–6, 13 pp.

(3) ———
1974. Storage and shelf life of packaged green onions. U.S. Dept. Agr. Market. Res. Rpt. 1015, 21 pp.

(4) Jones, H. A., and Mann, L. K.
1963. Onions and their allies. 286 pp. Leonard Hill Books Ltd., London, and Interscience Publications, Inc., New York.

(5) Lewis, W. E.
1957. Maintaining produce quality in retail stores. U.S. Dept. Agr., Agr. Handb. 117, 30 pp.

(6) Lutz, J. M., and Hardenburg, R. E.
1968. The commercial storage of fruits, vegetables, and florists and nursery stocks. U.S. Dept. Agr., Agr. Handb. 66, 94 pp.

(7) Rassmusson, L.
1930. La conservation des legumes en frigorifique. [Refrigerated storage of vegetables.] *In* 5th Internatl. Cong. Refrig. Proc. 9–15 April 1928, pp. 504–542. Rome, Italy.

(8) Robinson, J. E., Browne, K. M., and Burton, W. G.
1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol. 81: 399–408.

(9) Smith, P. G., and Welch, J. E.
1964. Nomenclature of vegetables and condiment herbs grown in the United States. Amer. Soc. Hort. Sci. Proc. 84: 535–548.

(10) Smith, W. H.
1957. The production of carbon dioxide and metabolic heat by horticulture produce. Modern Refrig. 6: 493–496.

(11) van den Berg, L., and Lentz, C. P.
1974. High humidity storage of some vegetables. Canad. Inst. Food Sci. Technol. Jour. 7(4): 260–262.

(12) Whiteman, T. M.
1957. Freezing point of fruits, vegetables and florists stocks. U.S. Dept. Agr. Market. Res. Rpt. 196, 32 pp.

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