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Storage and Shelf Life of PACKAGED RHUBARB

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STORAGE AND SHELF LIFE OF PACKAGED RHUBARB

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BACKGROUND

Wright, Rose, and Whiteman (*7*)[1] recommended 32° F. and 90 to 95 percent relative humidity as optimum conditions for the storage of freshly harvested rhubarb stalks. Two to three weeks was given as allowable storage time. Whiteman (*6*) listed the highest freezing points of rhubarb as 30.3° for stalks and 31.0° for leaves. Cook (*1*) also reported 32° as the optimum storage temperature for forced Michigan rhubarb. He recommended using waxed cartons and polyethylene sleeves to prevent weight and turgidity loss during 6 days' holding. A major cause of deterioriation was leaf blade breakdown. Murakishi, Potter, and Rushmore (*5*) stated that western growers of hothouse rhubarb eliminated leaf blade rot caused by *Botrytis*, by removing and discarding blades before packaging and shipping stalks to market. Hardenburg (*3*) tested five film wraps on rhubarb stalks held at 50°. Film wraps extended shelf life by 7 days mainly by reducing weight loss.

From May to August during 1961 to 1965 about 1,200 samples of Mammoth variety field-grown rhubarb were observed at Beltsville, Md., to find ways of preventing deterioration and prolonging storage and shelf life of fresh rhubarb. Generally, tests were set up in split plot experimental design, and data were processed by analysis of variance.

[1] Italic numbers in parentheses refer to Literature Cited, page 17.

PRELIMINARY TESTS AND OBSERVATIONS

In a few exploratory tests, 1-inch, 3-inch, and 6- to 12-inch pieces and whole stalks were immersed or stood in water at room temperature. After 15 minutes all cut surfaces touching water were badly split. When held in water 24 hours, uncut petioles (stalks), stalks with only intact bases in water, stalks debladed just above stalk-blade juncture, and stalks not in water did not split (fig. 1). Cut tops split most when the entire stalk base was cut off above the ocrea. The splitting force was enough to pull some of the rhubarb stalks part way out of the container.

Splitting resulted because the flesh of the cut stalk in water elongated while the epidermis did not. Flesh of 3-inch pieces lengthened about ½ inch.

When held overnight in water, stalks with intact bases developed a rupture zone similar to an abscission layer (4) about 1 inch above the original abscission. After 2 or 3 days in water the stalk base separated from the stalk as a cup-like structure (fig. 2). This defect of whole rhubarb stalks was also found during storage and holding and is discussed under "Storage and shelf-life tests."

Ultrasonic vibration at 10 kilocycles in a sonic oscillator for 1, 5, or 10 minutes had no effect on subsequent splitting, discoloration, or decay of 1-inch cut pieces of rhubarb.

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FIGURE 1.—Splitting of rhubarb stalk-ends, after 24 hours in water at 70° F. A—Top of stalk cut off, base intact. B—Top of stalk cut off, base cut off halfway up ocrea (the stipule-like structure in rhubarb). C—Top of stalk cut off, base cut off above ocrea. D—Top of stalk intact, base cut off above ocrea. E—Top of stalk intact, base intact.

RESPIRATION MEASUREMENTS

Respiration rates were measured and heat evolution calculated using CO_2 (carbon dioxide) evolved per hour per kilogram of fresh rhubarb (table 1).

Carbon dioxide evolution was measured using 300 to 800 grams of rhubarb and 50 or 100 ml. of 0.9 normal potassium hydroxide as an absorbent in sealed gallon-size glass respiration jars. Duplicate chambers for each treatment were set up in constant-temperature rooms at 70°, 60°, 50°, 40°, and 32°F. When required, time was allowed to permit the product to come to equilibrium with the temperature at which determinations were to be made. Potassium carbonate was then precipitated with barium chloride, followed by titration with hydrochloric acid to the phenolphthalein end point and then to the methyl orange end point. Respiration rates obtained by this sealed-chamber method agreed closely with those obtained using the Haller and Rose method. (*2*).

One-inch pieces of rhubarb stalks respired at the highest rate. Stalks with leaves attached respired at a slightly lower rate, and stalks without leaves respired at lowest rate, or about half the rate of 1-inch pieces or stalks with leaves. Respiration rate at 50° F. was about twice that at 32° and about half that at 70°.

TABLE 1.—*Respiration rate and heat evolution from rhubarb at 5 temperatures* [1]

Storage temperature (°F.)	Stalks without leaf blades		Stalks with attached leaf blades		Stalks cut into 1-inch pieces	
	Respiration rate	Heat evolved	Respiration rate	Heat evolved	Respiration rate	Heat evolved
	Mg. CO_2/kg./hr.	*1,000 B.t.u./ton/24 hr.*	*Mg. CO_2/kg./hr.*	*1,000 B.t.u./ton/24 hr.*	*Mg. CO_2/kg./hr.*	*1,000 B.t.u./ton/24 hr.*
70°	40–57	8.8–12.5	83–97	18.3–21.3	90–134	19.8–29.5
60°	31–48	6.8–10.6	59–80	13.0–17.6	68–106	15.0–23.3
50°	21–28	4.6–6.2	40–55	8.8–12.1	45–56	9.9–12.3
40°	11–18	2.4–4.0	23–34	5.1–7.5	21–34	4.6–7.5
32°	8–13	1.8–2.9	20–27	4.4–5.9	13–23	2.9–5.1

[1] Ranges are based on readings on 6 replications. Milligrams of carbon dioxide produced by 1 kilogram of rhubarb per hour (CO_2/kg./hr.) were multiplied by the factor 220 in converting to British thermal units per ton of rhubarb per 24 hours (B.t.u./ton/24 hr.)

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FIGURE 2.—Abscission of rhubarb petiole (stalk) base after 3 days in water at 70° F. or after dry storage in polyethylene overwrap for 2 weeks at 32° and 40° plus 1 day at 70°. A—Section through stalk before start of abscission, B—Abscissed cup-like stalk base, and C—Remaining thumb-shaped petiole end.

STORAGE AND SHELF-LIFE TESTS

One-Inch Pieces of Rhubarb in Polyethylene Bags

General tests

One-inch pieces were cut from freshly harvested stalks of rhubarb, and 50 pieces were packed in 1.5-mil polyethylene bags perforated with thirty-two ¼-inch holes (fig. 3). Each bag was then closed with a rubber band. The bagged rhubarb was stored 3, 5, or 7 days at 32°, 40°, or 50° F. and 85 to 95 percent relative humidity. Rhubarb was examined before and after storage and after additional holding 1, 2, or 3 days at 70°. The split plot test was replicated six times. Additional packages were included in each replicate to allow examination after longer storage as recorded in table 2.

Rhubarb held only at 70° F. developed no decay during 1 day, 4 percent developed decay during 2 days, and 23 percent in 3 days. Storing at 32° retarded decay; less than 5 percent of the 1-inch pieces decayed during 2 weeks at 32°, or during 7 days at 32° plus an additional day at 70°. Significantly more decayed pieces were found following 40° storage than following 32° storage, and still more decayed following 50° storage. The percentage of decayed pieces increased with time in storage and with time at 70° after storage.

Splitting was rated "slight" when barely visible, "moderate" when flesh but not epidermis was cracked, and "severe" when epidermis was also cracked. Data in table 2 combine moderate and severe splitting. At 70° F., cut ends of 1-inch pieces of rhubarb started to split soon after cutting. After 1 day, 83 percent were moderately to severely split. At 32°, only 8 percent split in 3 days. However, excessive

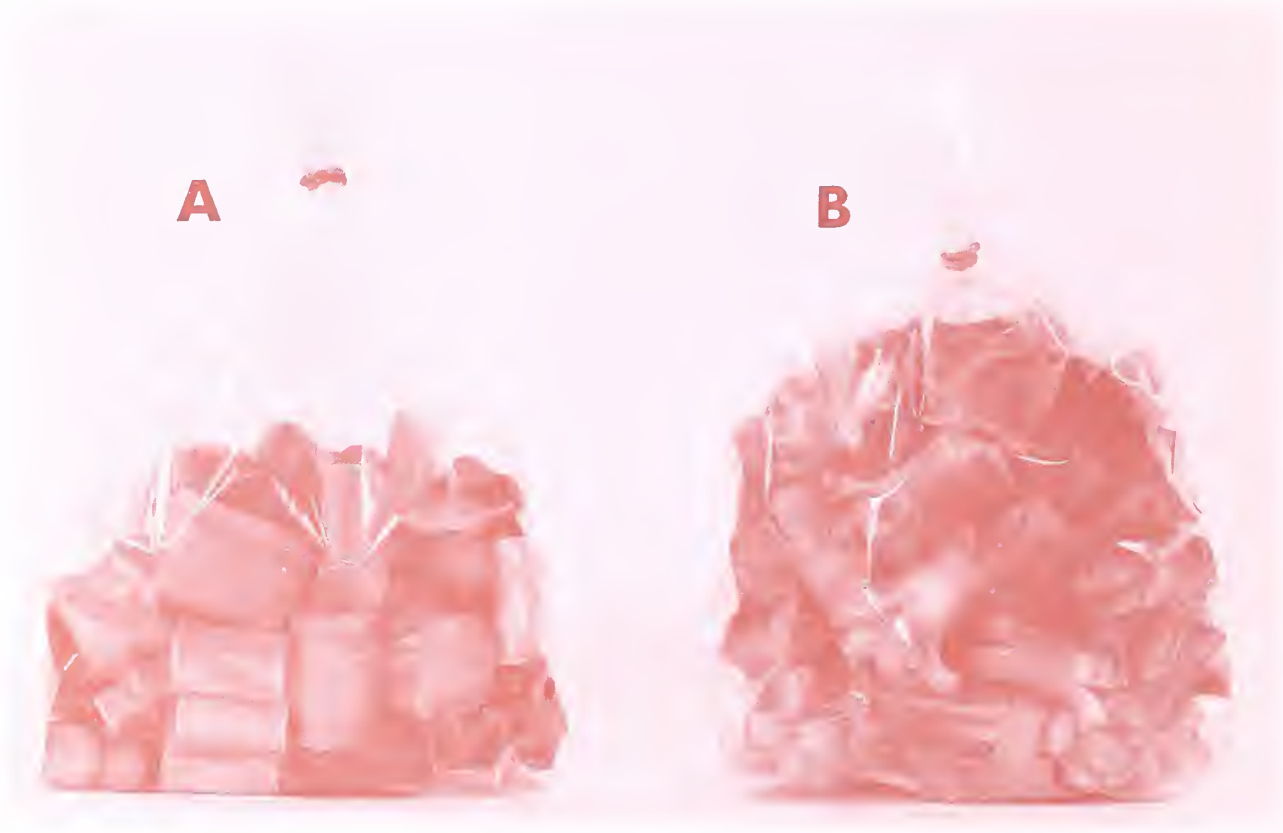

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FIGURE 3.—One-inch pieces of rhubarb bagged in perforated 10-ounce size polyethylene bags. A—Rhubarb freshly cut at time of packaging. B—Rhubarb held 1 day at 70° F. Note that splitting and curling has expanded rhubarb to fill package.

TABLE 2.—*Decay, splitting, and weight loss during storage and holding of packaged 1-inch pieces of rhubarb* [1]

[Percentage of rhubarb pieces decayed or split and percentage of original weight lost]

Storage conditions	Decay after holding at 70°				Splitting on removal from storage (No holding)	Weight loss after holding at 70°			
	No holding	1 day	2 days	3 days		No holding	1 day	2 days	3 days
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No storage	0	0	4	23	[2] 0	0	1.0	2.3	3.2
32° F.:									
3 days	0	1	8	26	8	0	2.0	5.5	6.7
5 days	0	3	29	53	54	0	4.0	7.0	8.8
7 days	0	3	22	54	60	.3	3.7	8.3	10.5
14 days	3	26	55	79	75	1.0	4.1	7.2	8.3
21 days	14	60	81	92	74	1.6	3.4	5.6	7.1
40° F.:									
3 days	0	7	31	48	42	.2	2.0	6.0	7.0
5 days	0	8	39	56	79	.2	3.3	5.8	7.3
7 days	2	21	37	62	73	1.0	4.3	9.0	10.8
14 days	13	21	58	77	89	1.2	4.7	6.8	7.6
50° F.:									
3 days	0	21	42	74	75	.3	3.2	5.5	6.5
5 days	18	27	53	74	75	0	2.5	5.2	6.2
7 days	32	50	76	89	82	.5	3.2	5.7	6.5
Average, 3, 5, and 7 days' storage: [3]	Average				Average	Average			
32° F.	16.6 a				40.7 a	4.7 a			
40° F.	25.9 b				64.7 b	4.7 a			
50° F.	46.3 c				77.3 c	3.8 a			

[1] Packages were 10-ounce-size polyethylene bags, each perforated with 32 ¼-inch holes and each holding 50 pieces. Storage and holding was at 85 to 95 percent relative humidity. Each value within the heavy lines is based on 6 packages.

[2] 83 percent of the rhubarb held 1 day at 70° was split.

[3] Letters following averages represent Duncan Multiple Range Test values at 5% significance level. Comparable values followed by no letters in common are significantly different.

splitting was found after 5 days at 32° or 3 days at 40° or 50°.

No significant differences were found between weight losses from 1-inch pieces of rhubarb stored at 32°, 40°, or 50° F. Weight loss increased significantly with time when rhubarb was held at 70° after storage.

Chemical dips

One-inch pieces of rhubarb were packaged dry or after dipping for 1 second in chemical solutions. The rhubarb in 10-ounce-size polyethylene bags, each with two ¼-inch holes, was held at 32°, 50°, or 70° F. and high humidity and examined after 1, 2, and 5 days. Least splitting, discoloration, and decay was found in dry, undipped rhubarb held at 32° (fig. 4). These defects developed slightly during 5 days at 50°. In 2 days at 70°, dry rhubarb pieces were severely split and slightly discolored. In 5 days, they were severely decayed. Momentary dips in tap water, in 0.5-percent solutions of citric acid, ascorbic acid, sodium chloride, or hydroxyethyl cellulose, or in 10-percent solutions of sucrose increased severity of splitting, discoloration, and decay. Rhubarb pieces dipped momentarily in 0.5-percent solutions of sodium bisulfite did not split when held at any temperature tried but were bleached and odoriferous, and at 70° *Rhizopus* and *Penicillium* molds developed.

Dipping cut pieces of rhubarb in 1 molar solutions of sucrose or sodium chloride for 1, 2, 5, or 10 minutes reduced or prevented splitting but the pieces became sticky, leaky, soft, shrunken, or discolored (table 3).

Dipping whole stalks or 1-inch pieces of rhubarb in 0.5 percent CIPC (isopropyl *N* (3-chlorophenyl) carbamate), 0.5 percent DPA (diphenylamine), or a combination of the two did not reduce splitting of cut pieces. DPA alone or together with CIPC caused shrinking and bleaching near the cut ends of the pieces.

TABLE 3.—*Splitting, decay, and appearance of 1-inch pieces of rhubarb packaged after various dip treatments and held at 70°* [1]

[Percentage of rhubarb pieces]

Chemical concentration and dip time	1 day at 70° F.			2 days at 70° F.			3 days at 70° F.
	Severe split	Decay	Appearance and condition	Severe split	Decay	Appearance and condition	Appearance and condition
	Percent	*Percent*		*Percent*	*Percent*		
None (dry check)	23	0	Dry, fairly fresh	47	3	Ends gray, tan, dried out	No mold growth.
Water (distilled):							
1 minute	70	0	do	72	16	do	Do.
Average, 2, 5, 10 minutes	75	0	do	77	25	do	Do.
Glycerine, 1 molar:							
1 minute	70	0	do	75	19	do	Mold on some pieces.
Average, 2, 5, 10 minutes	71	0	do	73	26	do	Do.
Sucrose, 1 molar:							
1 minute	16	0	Sticky, leaky	43	25	Moldy, watersoaked	Mold abundant.
Average, 2, 5, 10 minutes	4	0	do	4	50	do	Do.
Sucrose, 0.5 molar:							
1 minute	28	0	do	80	47	do	Do.
Average, 2, 5, 10 minutes	13	0	do	60	46	do	Do.
Sodium chloride, 1 molar:							
1 minute	0	0	Leaky, shrunken, discolored.	0	28	Leaky, shrunken, discolored.	Do.
Average, 2, 5, 10 minutes	0	0	do	0	75	do	Do.

[1] Rhubarb pieces were packaged 50 per bag in 10-ounce size polyethylene bags each with two ¼-inch holes. Observations were made on 2 packages of rhubarb for each chemical concentration and dip time. Readings for 2, 5, and 10 minutes were averaged. Molds on pieces included *Aspergillus*, *Botrytis*, *Penicillium* and *Rhizopus*.

FIGURE 4.—Chemically treated rhubarb pieces after 5 days' holding at 32°, 50°, or 70° F. in perforated polyethylene bags. D—Dry, untreated check pieces. T—Pieces dipped in tap water, or solutions of citric acid, ascorbic acid, sodium chloride, sucrose, or cellosize. SB—Pieces dipped in sodium bisulfite solution.

Hot water treatment

One-inch pieces of rhubarb were cut from untreated whole rhubarb stalks or from stalks immersed for 2 minutes in 125° F. water and then wiped dry. Pieces cut from the top half or bottom half of the stalk were packaged in 10-ounce-size polyethylene bags perforated with two or thirty-two ¼-inch holes, stored at 32°, 40°, and 50° and then held at 70° (tables 4 and 5).

Decay and splitting developed in fewer rhubarb pieces: (1) From hot-water-treated stalks than from nontreated stalks, (2) from stalk bottoms than from stalk tops, and (3) in bags perforated with 32 holes than with 2 holes. Decay developed in the least number of pieces stored at 32° F. and in the greatest number stored at 50°. Splitting was not consistently affected by storage temperature in these tests. However, this may be due to the overshadowing effect of holding the rhubarb at 70° following removal from storage. Percent of decayed and split pieces increased with holding time at 70° and was not consistently affected by time in 32° storage.

Decay was adequately controlled for 7 days by storage at 32° F., and rhubarb pieces were practically free of decay for an additional day at 70° after removal from 32° (table 5). In packages perforated with 32 holes, hot-water treated rhubarb was practically decay-free for 2 days at 70° after removal from 32°.

Splitting was not satisfactorily controlled by any combination of treatments.

As expected, weight loss during storage and holding was greater in rhubarb pieces packaged in bags with 32 holes (average 4.4 percent loss) than in bags with 2 holes (average less than 1 percent loss). No difference in weight loss or shriveling was attributable to hot water treatment.

TABLE 4.—*Decay and splitting during storage and holding of packaged 1-inch pieces of rhubarb, cut from debladed whole stalks, as influenced by hot water treatment* [1]

[Percentage of rhubarb pieces]

Treatment, and section of stalk	Decay at indicated storage temperature					Splitting at indicated storage temperature				
	32° F.	40° F.	50° F.	Average	Dip-time effect, average	32° F.	40° F.	50° F.	Average	Dip-time effect, average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2 minutes in 125° F. water:										
Bottom	2	8	22	10.7 a		42	46	40	42 a	
Top	2	10	22	11.3 ab		66	64	62	64 c	
Average	2 a	9 bc	22 d		11.0 a	54 ab	55 ab	51 a		53 a
No hot water treatment:										
Bottom	4	10	24	12.7 b		46	51	48	48 b	
Top	7	15	35	19.0 c		66	64	68	66 c	
Average	5 ab	13 c	30 e		16.0 b	56 ab	58 b	58 b		57 b
Temperature effect, average	4 a	11 b	26 c			55 a	56 a	54 a		

[1] Rhubarb pieces (50 per bag) were packaged in 10-ounce-size polyethylene bags each perforated with two ¼-inch holes. Each value within the heavy lines is based on 12 observations after 0, 3, 5, and 7 days' storage and 0, 1, and 2 days' holding at 70°, all at 85 to 95 percent relative humidity. Letters following averages indicate Duncan Multiple Range Test values at 5% significance level. Comparable averages followed by no letter in common are significantly different.

TABLE 5.—*Decay and splitting during storage and holding of 1-inch pieces of rhubarb cut from debladed whole stalks as influenced by hot water treatment and polyethylene-bag perforation* [1]

[Percentage of rhubarb pieces decayed or split, and percentage of original weight lost]

Type of deterioration, treatment, and holding period	Bags with 32 ¼-inch holes, stored at 32° F.					Bags with 2 ¼-inch holes, stored at 32° F.					Average dip-time effect
	No storage	3 days	5 days	7 days	Average	No storage	3 days	5 days	7 days	Average	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
DECAY											
2 minutes in 125° F. water:											
No holding	0	0	0	0	0	0	0	0	0	0	---
Held 1 day at 70°	0	0	0	0	0	4	0	0	0	1	---
Held 2 days at 70°	0	2	0	2	1	8	6	18	9	10	---
Average	0	0.7	0	0.7	0.3 a	4	2	6	3	3.8 b	2.0 a
No hot water treatment:											
No holding	0	0	0	0	0	0	0	0	0	0	---
Held 1 day at 70°	0	0	0	0	0	0	0	0	0	0	---
Held 2 days at 70°	15	22	8	20	16	37	55	48	36	44	---
Average	5	7	3	7	5.4 b	12	18	16	12	14.6 c	10.0 b
Average perforation effect	---	---	---	---	2.8 a	---	---	---	---	9.2 b	---
SPLITTING											
2 minutes in 125° F. water:											
No holding	9	20	40	60	32	10	20	66	74	42	---
Held 1 day at 70°	86	90	86	88	88	98	95	96	98	97	---
Held 2 days at 70°	86	90	88	88	88	98	95	97	98	97	---
Average	60	67	71	79	69.2 a	69	70	86	90	78.8 ab	74.0 a
No hot water treatment:											
No holding	40	13	62	65	45	56	17	78	78	57	---
Held 1 day at 70°	92	93	86	91	91	96	99	96	96	96	---
Held 2 days at 70°	92	93	87	92	91	96	99	97	97	97	---
Average	75	66	78	83	75.5 ab	83	72	90	90	83.3 b	79.4 b
Average perforation effect	---	---	---	---	72.4 a	---	---	---	---	81.0 b	---

[1] Rhubarb pieces were packaged 50 per bag in 10-ounce-size polyethylene bags. Storage and holding was at 85 to 95 percent relative humidity. Each value within the heavy lines is based on 4 packages.

Letters following averages indicate Duncan Multiple Range Test values at 5% significance level. Comparable averages followed by no letters in common are significantly different.

Ten-Inch Pieces of Rhubarb in Heat-Shrinkable Polyvinyl Chloride Film

Ten-inch pieces of rhubarb were cut from stalks, grouped in bunches of 10, and sleeve-wrapped or completely wrapped in heat-shrinkable polyvinyl chloride film perforated with $\frac{3}{64}$-inch holes $\frac{1}{2}$ inch apart. Film was shrunk (to form a stretch-wrap over the rhubarb) by hot air blast from a portable hair dryer. Debladed whole stalks approximately 10 inches long were also sleeve-wrapped in the film (fig. 5). The packaged rhubarb was stored 2 weeks at 32° F. and held 3 days at 70° after storage.

Practically no splitting was found in these tests. No difference in splitting attributable to wrap coverage was noted.

Nonwrapped rhubarb lost the most weight (table 6). Sleeve-wrapped rhubarb lost intermediate amounts, and completely wrapped rhubarb lost very little weight. Shriveling due to weight loss detracted from appearance when weight loss approached 10 percent.

No decay developed in 10-inch pieces of packaged rhubarb during 2 weeks' storage at 32° F., and only a trace of decay was found on a few pieces after 1 day at 70° following storage. After 2 or 3 days at 70° following storage, decay developed in most packaged rhubarb.

The complete wrap seems to be the most practical of the package types tested for 10-inch rhubarb pieces. Pieces stayed in good condition for 2 weeks at 32° and an additional day at 70° with little weight loss, and only a few pieces showed trace decay. The complete wrap also prevented pieces from slipping from the package.

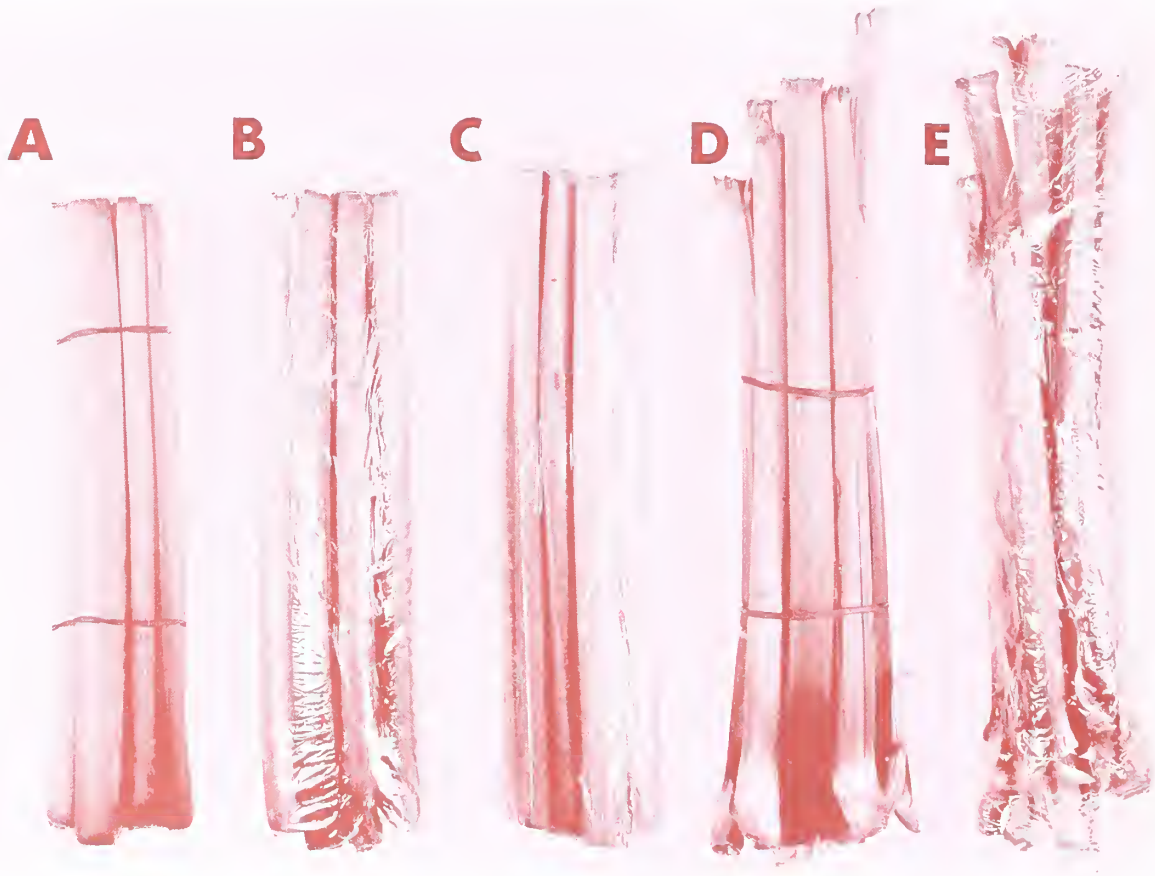

FIGURE 5.—Ten-inch pieces of rhubarb and short whole stalks unwrapped or stretch-wrapped in heat shrinkable perforated polyvinyl chloride film. A—unwrapped 10-inch pieces secured by rubber bands, B—Sleeve-wrapped 10-inch pieces, C—Completely overwrapped 10-inch pieces, D—Unwrapped whole stalks, E—Sleeve-wrapped whole stalks.

TABLE 6.—*Weight loss and decay during storage and holding in bunches of 10-inch cut pieces and whole stalks of rhubarb wrapped in heat-shrinkable polyvinyl chloride film* [1]

[Percentage of original weight lost and percentage of pieces decayed]

Stalks, type of wrap, and length of storage at 32° F.	Weight loss after holding at 70° F.					Decay after holding at 70° F.				
	No holding	1 day	2 days	3 days	Average	No holding	1 day	2 days	3 days	Average
10-INCH CUT PIECES	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Complete overwrap:										
No storage	0	0.9	1.4	1.6	---	0	0	15	15	---
1 week	0.4	0.8	1.3	1.8	---	0	[2] 5	45	65	---
2 weeks	1.0	1.4	1.8	1.8	---	0	[2] 5	70	80	---
Average	---	---	---	---	1.4 a	---	---	---	---	25.0 c
Sleeve wrap:										
No storage	0	3.0	4.9	6.8	---	0	0	0	10	---
1 week	2.8	4.4	6.4	8.2	---	0	0	15	15	---
2 weeks	5.8	7.1	8.2	9.2	---	0	0	20	20	---
Average	---	---	---	---	5.4 b	---	---	---	---	6.7 b
No wrap:										
No storage	0	4.0	6.8	10.0	---	0	0	0	0	---
1 week	4.2	7.1	9.1	11.5	---	0	[2] 5	10	10	---
2 weeks	8.4	10.6	12.4	13.9	---	0	0	15	15	---
Average	---	---	---	---	8.1 c	---	---	---	---	4.6 b
10-INCH (APPROX.) WHOLE STALKS										
Sleeve wrap:										
No storage	0	2.7	4.3	6.4	---	0	0	0	0	---
1 week	1.6	3.3	4.7	6.0	---	0	0	15	15	---
2 weeks	4.4	5.6	6.6	7.6	---	0	0	5	5	---
Average	---	---	---	---	4.5 b	---	---	---	---	3.3 ab
No wrap:										
No storage	0	3.8	6.6	9.6	---	0	0	0	0	---
1 week	5.2	8.1	12.0	13.8	---	0	0	0	0	---
2 weeks	9.8	12.2	14.6	16.6	---	0	0	0	0	---
Average	---	---	---	---	9.4 c	---	---	---	---	0 a

[1] Film perforations were 3/64 inch in diameter and spaced ½ inch by ½ inch. Storage and holding was at 85 to 95 percent relative humidity. Each value within the heavy lines is based on 2 bunches of 10 pieces or stalks each. Letters following averages indicate Duncan Multiple Range Test values at 5% significance level. Comparable figures followed by no letters in common are significantly different.

[2] This was trace decay on 1 out of 20 pieces.

Whole Stalks of Rhubarb Packaged and Stored in Polyethylene Film Wraps

Bunched (10 stalks per bunch) whole rhubarb stalks, with leaf blade attached or removed at about ¼-inch above the top of the stalk and with or without polyethylene film wrap, were compared. The film wrap for each package was perforated with two ¼-inch holes. Observations were made before and after storage and holding. Storage was for 3, 5, 7, or 14 days at 32°, 40°, or 50° F.; holding after storage was 1, 2, and 3 days at 70°. Data up to 14 days at 32° and 3 days at 70° are summarized in table 7. Additional bunches were stored at 32° and 40° to allow observations over longer storage. These observations are included in following paragraphs but not in table 7.

When displayed in a single layer, nonwrapped bunches of rhubarb stalks with attached leaf blades remained acceptable for less than 1 day at 70° F. and for less than 3 days at 32°, 40°, and 50°. The main cause of deterioration was moisture loss accompanied by wilting and shriveling. Polyethylene-wrapped, debladed rhubarb stalks were acceptable after 4 weeks at 32° plus 1 day at 70°, 2 weeks at 40° plus 1 day at 70°, or 1 week at 50° plus 1 day at 70°. At 32°, wrapped rhubarb with attached leaf blades remained acceptable almost as long as wrapped debladed rhubarb. Rhubarb stalks free of waste leaf blades require one-third less packaging materials and should cost less to transport since weight is also reduced one-third.

Weight loss

Polyethylene-wrapped, bunched rhubarb with or without attached leaf blades averaged less than 1 percent weight loss during storage at 32°, 40°, or 50° F. and holding at 70°. Nonwrapped debladed rhubarb averaged about half as much weight loss as nonwrapped rhubarb with attached leaf blades during 2 weeks' storage and 3 days' holding. Weight loss was slightly lower at 40° than at 32° or 50°. This may be due to slightly higher humidity in 40° storage than in 32° or 50° storage although all three rooms were within the 85 to 95 percent relative humidity range.

Wilting

Polyethylene-wrapped debladed stalks, stalks with leaf blades attached, and the attached leaf blades remained turgid throughout 2 to 5 weeks'

TABLE 7.—*Weight loss and decay during storage and holding of wrapped and nonwrapped bunches of whole stalks of rhubarb* [1]

[Percentage of original weight lost and percentage of pieces decayed]

Type of deterioration and storage temperature	Polyethylene-wrapped		Nonwrapped		Average
	Debladed stalks	Stalks with attached leaf blades	Debladed stalks	Stalks with attached leaf blades	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Weight loss:					
32°	0.3 a	0.4 a	6.8 b	15.7 d	5.8 b
40°	0.3 a	0.3 a	5.2 b	10.9 c	4.2 a
50°	0.3 a	0.5 a	7.0 b	13.5 cd	5.3 b
Average	0.3 a	0.4 a	6.3 b	13.4 c	
Decay:					
32°	4.5 b	7.2 bc	0.8 a	10.2 cd	5.7 a
40°	10.8 de	19.9 f	0.5 a	13.8 e	11.2 b
50°	18.5 f	38.6 h	0 a	28.8 g	21.5 c
Average	11.3 b	21.9 c	0.4 a	17.6 c	

[1] Each film wrap was perforated with two ¼-inch holes.

Data summarize 0,3,5,7,14 days in storage and 0,1,2,3 days at 70°, all at 85 to 95 percent humidity. Two packages of 10 stalks each were observed at each removal. Thus, each value within the heavy lines is based on 40 package observations.

Letters following numbers indicate Duncan Multiple Range Test values at 5% significance level. Comparable numbers followed by no letters in common are significantly different.

storage at 32°, 40°, or 50° F. and 3 days' holding at 70° (fig. 6).

Nonwrapped rhubarb wilted badly. When weight loss was 5 to 10 percent, wilting seriously detracted from appearance (fig. 6). Attached leaf blades wilted more rapidly than attached or debladed stalks. Stalks with leaf blades attached wilted more rapidly than debladed stalks. Attached leaf blades wilted some during 1 day at 70°; most were limp by 2 days. All attached leaf blades were extremely limp after 1 week at 32°, 40°, or 50°; by 2 weeks, they were wrinkled and dried stiff. No detached leaf blades were held in these tests. Debladed stalks wilted some and became limp during 1 to 3 days at 70°. They were limp after 2 or 3 weeks in storage and extremely limp and wrinkled after 3 to 5 weeks. Nontrimmed stalks were also limp after 2 or 3 days at 70°; after 1 week in storage (32°, 40°, and 50°) they were extremely limp, and after 2 to 3 weeks in storage they were badly wrinkled.

Decay

No decay occurred in attached leaf blades or attached or debladed stalks of wrapped or nonwrapped rhubarb during 3 days at 70° F. only. No decay occurred during 4 weeks at 32° plus 1 day at 70° or 2 weeks at 40° plus 1 day at 70°; some decay occurred during 1 week at 50° and 1 day at 70°. Subsequently, decay developed and increased with time in storage and during 2 or 3 days at 70°. After 2 weeks in storage and 3 days at 70°, decay was lowest in rhubarb from 32° storage and highest in rhubarb from 50° storage. Decay was lower in debladed stalks than in rhubarb with leaf blades attached and was lower in nonwrapped than in polyethylene-wrapped rhubarb. Most of the decay noted was

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FIGURE 6.—Whole stalks of rhubarb with and without leaf blades, stored with and without film wraps for 5 weeks at 32° F. and 85 to 95 percent relative humidity. The two outer bunches were stored without film wraps. The two inner bunches were completely overwrapped with perforated polyethylene film. Appearance was similar at 3- and 4-week withdrawal from 32° storage.

in leaf blades or at cut ends starting in remnants of leaf blade left adhering to stalk. After longer storage, the onset of decay was dramatically sudden. Thus, in packages of wrapped rhubarb held 5 weeks at 32° most leaves looked fresh and green with only trace of decay spots found on a few leaves on removal (fig. 6). After only 1 day at 70° most of the leaves were completely broken down with decay.

Whole Stalks of Rhubarb Bulk-Stored in Polyethylene Film-Lined Crates

Rhubarb was debladed, banded in bunches of 10 stalks each, packed 10 bunches per crate in wirebound wood crates 22 by 11.5 by 8 inches with polyethylene liner and stored at 32° or 40° F. (fig. 7). On removal from storage, five bunches from each crate were individually wrapped in polyethylene film perforated with two ¼-inch holes and five were not wrapped before placing at 70°.

Weight loss

Weight loss averaged 0.1 percent during 4 weeks at 32° F. or 2 weeks at 40° while bunched, debladed rhubarb was in polyethylene-lined wirebound wood crates. During 3 days' holding at 70° following storage, weight loss averaged 0.3 percent per day in polyethylene-wrapped bunches of rhubarb and 3.2 percent per day in nonwrapped bunches of rhubarb.

Wilting

Rhubarb stalks remained turgid while stored or held in polyethylene film. Nonwrapped rhubarb wilted readily. After 3 days' holding at 70° most stalks were limp and some were wrinkled.

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FIGURE 7.—Debladed rhubarb in polyethylene-lined wirebound crate with outside dimensions of 22 by 11.5 by 8 inches.

Decay

No decay was found in rhubarb stalks held in 10-stalk packages during 3 days at 70° F. or bulk stored in polyethylene-lined wirebound crates during 4 weeks at 32° or 2 weeks at 40°. Decay was found in only 1 percent or less of the stalks after: (1) 2 weeks at 32° plus 3 days at 70°, (2) 4 weeks at 32° plus 1 day at 70°, (3) 1 week at 40° plus 2 days at 70°, or (4) 2 weeks at 40° plus 1 day at 70°. Beyond these time limits, decay became excessive.

Petiole (stalk) base abscission

Petiole (stalk) base abscission described earlier in this report and elsewhere (4) was found in rhubarb stored 2 weeks or longer at 32° or 40° F. in film-lined crates and then held 1 day or longer at 70° (table 8). Polyethylene-wrapped stalks abscissed more readily than non-wrapped stalks. Stalks previously stored at 40° abscissed more than those previously stored at 32°.

Appearance

Appearance of rhubarb in polyethylene-lined wirebound crates was excellent after 5 weeks at 32° F. or 2 weeks at 40°. Appearance of polyethylene-wrapped bunches was excellent for 3 days at 70°, for 2 days at 70° after 2 weeks at 32° and for 1 day at 70° after 4 weeks at 32° or 2 weeks at 40°.

TABLE 8.—*Petiole-base abscission in bunched, debladed whole stalks of rhubarb stored in polyethylene-lined wirebound wood crates and then wrapped in polyethylene and held at 70° F.* [1]

[Percentage of stalks]

Storage temperature and time	Polyethylene-wrapped—held at 70° F.				Nonwrapped—held at 70° F.			
	No holding	1 day	2 days	3 days	No holding	1 day	2 days	3 days
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No storage	0	0	0	0	0	0	0	0
32°:								
1 week	0	0	0	0	0	0	0	0
2 weeks	0	1 T	1	1	0	0	0	0
3 weeks	0	2 T	16	21	0	4 T	6	10
4 weeks	3 T	20 T	29	33	5 T	13 T	28	33
5 weeks	16 T	57	---	---	8 T	32	---	---
40°:								
1 week	0	0	0	0	0	0	0	0
2 weeks	0	2	9	11	0	0	1	1
3 weeks	32	---	---	---	36	---	---	---
4 weeks	83	---	---	---	83	---	---	---
5 weeks	100	---	---	---	100	---	---	---

[1] Film liner was folded shut but not sealed tight. Each wrapped package was perforated with two ¼-inch holes. Each figure is based on 100 stalks of rhubarb (10 bunches).

T indicates stalks showed only a trace of cracking in the abscission zone.

SUMMARY AND CONCLUSIONS

Fresh rhubarb wilts, shrivels, and decays rapidly. However, its storage and shelf life can be extended by proper handling, packaging, and refrigeration.

For best quality maintenance, rhubarb should be kept at 32° F. and high relative humidity (90 percent or above) throughout storage and marketing. In addition, rhubarb should be protected from moisture loss by storing in crates lined with moisture-proof film. Following storage, rhubarb should be packaged in moisture-proof film to maintain freshness during retailing and home storage.

Removing and discarding leaf blades at harvest is desirable as it not only reduces the possibility of decay and weight loss, but also reduces shipping weight and package size by one-third. Debladed rhubarb respired and produced half as much heat as rhubarb stalks with leaves attached and thus required one-half as much refrigeration.

Rhubarb in unwrapped bunches of whole stalks with leaf blades attached remained acceptable for less than 1 day at 70° F. and 85 to 95 percent relative humidity and less than 3 days at 32°. However, bunched, debladed rhubarb stalks in polyethylene-lined crates or in polyethylene-film bunch wraps remained acceptable at 32° F. for 4 weeks plus 1 day at 70°. They were acceptable at 40° for 2 weeks plus 1 day at 70° and at 50° for 1 week plus 1 day at 70°. Rhubarb could be held an extra week at 32° or 40° with no additional time at 70° and still be acceptable. Polyethylene crate liners or bunch wraps maintained freshness in rhubarb by keeping weight loss below 1 percent during 4 or 5 weeks' storage at 32°.

Ten-inch pieces of rhubarb packaged in stretch-wrap heat-shrinkable polyvinyl chloride film were attractive in appearance. This method of packaging rhubarb could have commercial value. In complete wraps, 10-inch pieces were acceptable about half as long as whole stalks, or for 2 weeks at 32° F. plus an additional day at 70°.

One-inch pieces were also attractive in appearance and should have good sales appeal. However, 1-inch pieces of rhubarb in 10-ounce-size perforated polyethylene bags were more perishable than wrapped 10-inch pieces or whole stalks due to the greater number of cut surfaces. Bagged 1-inch pieces were acceptable for 1 week at 32° F. plus an additional day at 70°.

Various chemical dips and ultrasonic vibration did not improve shelf life of fresh cut rhubarb pieces, and chemical dips often damaged the rhubarb. Sucrose dips made pieces sticky, and mold grew on the surfaces. Sodium chloride dips caused water loss and shriveling. Sodium bisulfite caused leaking, bleaching, off odor, and mold growth. Dry untreated rhubarb pieces held in polyethylene bags at 32° F. looked better and developed less decay than pieces treated with any of the chemicals.

Splitting of cut ends and curling was common in 1-inch pieces of rhubarb in film bags, especially when held at 70° F. Treatments did not adequately check splitting but some reduced it. When decay was not a factor, splitting and curling did not detract from appearance and some observers felt it improved appearance.

Decay of cut pieces of rhubarb was greatly reduced and shelf life was increased by immersing debladed whole stalks for 2 minutes in water at 125° F. before cutting and packaging in adequately perforated (32 holes per 10-ounce-size) film bags. Thus handled, rhubarb pieces remained nearly decay-free for 2 days at 70° following 1 week's storage at 32°.

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