Packaging Effects on the flavor and shelf life of gamma-irradiated fresh fruits and vegetables

by

D. K. Salunkhe,

L. H. Pollard,

R. K. Gerber,

Ethelwyn B. Wilcox,

College of Agriculture,
Utah State University,
Logan, Utah,

and

Morris Simon,

Food Radiation Preservation Division
Quartermaster Food and Container Institute,
Chicago

Reprinted

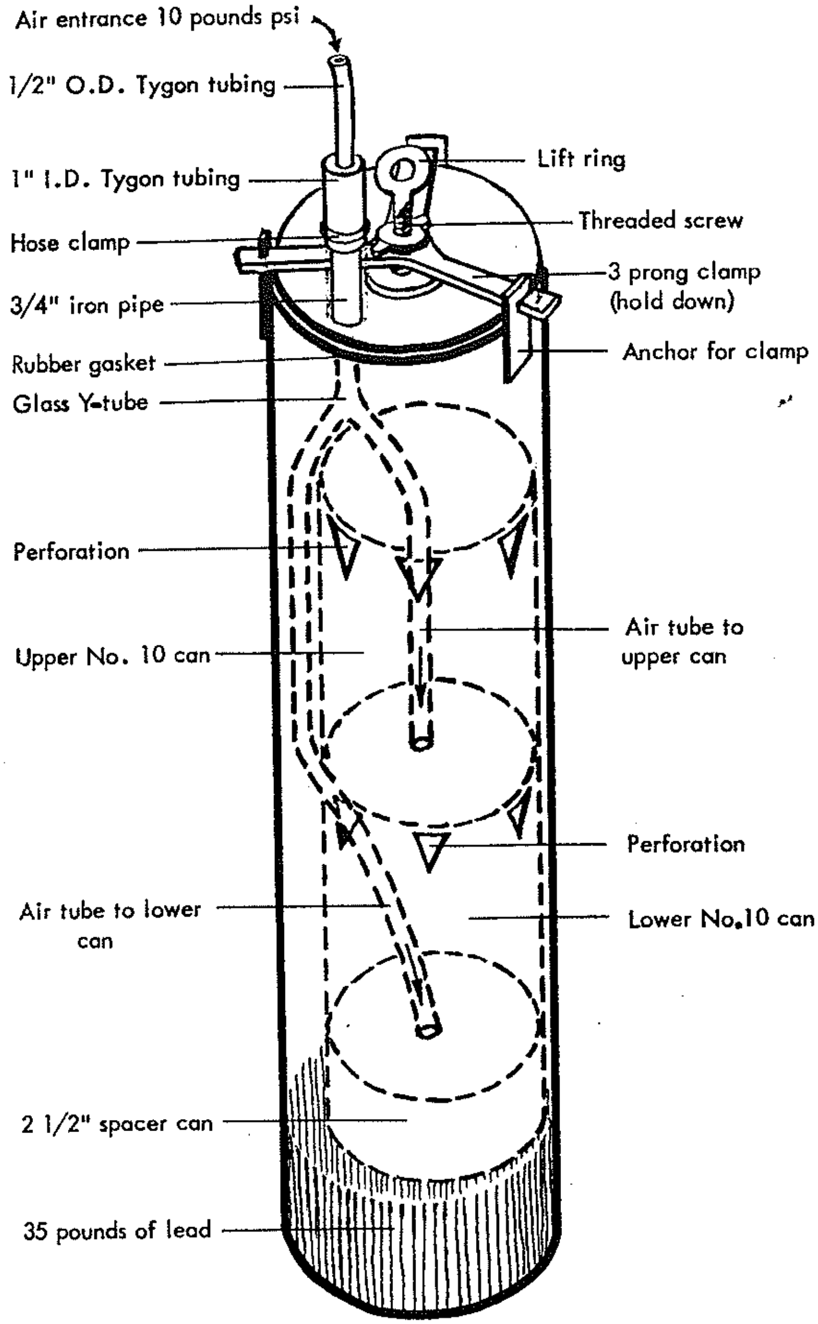
from

February, 1959,

PACKAGE ENGINEERING

Packagin
gamma-irradiat

Although the use of gamma rays for food preservation is still in the experimental stages, proper functional packaging is necessary for the success of such preservation and retaining of quality. In this study, certain fresh fruits and vegetables are packaged in various packaging materials prior to being subjected to different doses of gamma-irradiation, after which quality of the commodities is evaluated. Scored by the hedonic scale, results of the tests are reported in detail and presented in tabular form. The authors explain the experimental procedure used and the method of evaluating quality. They report the results of the effects of the can liners and the can conditions on the commodities.



Aeration chamber used during the process of radiation under water.

Food preservation by gamma rays is a new method which is yet in the experimental stage. This new method of food preservation opens many new avenues and problems in the packaging methodology. For the success of food preservation and the retaining of the quality, the packaging of the product is an important factor. The packaging technics must keep up with the preservation methods.

This paper presents the investigations of different types of packaging for fresh fruits and vegetables prior to, and during, gamma-irradiation, and their effects on the subsequent quality and shelf life of the products.

EXPERIMENTAL PROCEDURE

Fruits and vegetables of prime quality, and as far as possible of uniform maturity, were selected for the experiments. Some of the products were obtained through a local wholesale dealer and others were grown on the experimental farms of the Utah State University.

*This paper reports research undertaken in cooperation with the Quartermaster Food & Container Institute for the Armed Forces, and has been assigned No. 798 in the series of papers approved for publication. The views or conclusions contained in this paper are those of authors. They are not to be construed as necessarily reflecting the views or endorsement of the Department of Defense.

†Contribution No. 68 (c) from Utah State Agricultural Experiment Station, Logan, Utah.

effects on the flavor and shelf life of

d fresh fruits and vegetables*†

Uses packaging materials of different types as can liners
Packs products inside liners
Subjects samples to gamma rays ranging in doses from 0 to 5 × 10⁵ rads
Studies effects of aeration during irradiation
Evaluates products for quality — immediately after irradiation and subsequent storage at different temperatures and lengths of time

By D. K. Salunkhe,
L. H. Pollard,
R. K. Gerber,
Ethelwyn B. Wilcox,
College of Agriculture, Utah State University, Logan, Utah,

and Morris Simon,
Food Radiation Preservation Division, Quartermaster Food and Container Institute, Chicago

Some cans perforated. Some of the samples were cushioned within a can-lining material, such as a polyethylene bag; other samples were included without such lining and cushioning material prior to sealing under vacuum; others were sealed without vacuum in No. 10 tin cans. Some of the cans for certain treatments were perforated after sealing. If the fruits and vegetables were of such nature that they might be easily bruised or crushed, paperboard dividers were used to divide the can into three or four compartments along its length.

Each can was labeled indicating the dose and rate of gamma rays to be given. The cans, thus prepared for irradiation, were transported under refrigeration, 40° F. (4.4° C.) either to the Material Testing Reactor Station near Arco, Idaho, or to the Dugway Proving Ground, Dugway, Utah.

Use Special Aeration Chamber

During the process of irradiation at the Arco facility, air was forced into the perforated cans. However, air was not circulated in the perforated cans when irradiated at the Dugway facility. A special chamber, as illustrated, was constructed for this purpose from a 2-ft. section of 7-in. diameter aluminum portable irrigation pipe with a thickness of 0.083 in.

An aluminum bottom was welded on one end, then the cylindrical tank was weighted with 35 lb. of lead. A maneuverable aluminum lid was designed to fit the other end and was made water tight with a rubber gasket. A 6-in. piece of 3/4-in. iron pipe was fastened with a gasket into the lid to which was clamped a 25-ft. length of 1-in. inner diameter Tygon tubing. A 25-ft. length of 1/2-in. outer diameter Tygon tubing was threaded through the larger piece of Tygon tubing.

Two perforated No. 10 cans of fruits or vegetables were placed in the chamber and air under 10 lb/sq. in. pressure was forced down the small tube. Within the chamber, the air was divided with a glass Y-tube and taken by auxiliary tubes to each perforated can of the product.

The exhaust air escaped from the chamber through the space between the small tube and the wall of the large tube. During radiation, the chamber was lowered in water to the bottom of the 18-ft. UIA‡ column in the radiation facility at M.T.R. Station near Arco, Idaho. The Tygon tubing connected the chamber to the surface of the water in the UIA column and also allowed several feet for handling in the room.

Evaluate Quality

Subsequent to irradiation, the cans were returned to the research laboratories of the Department of Horticulture and the Department of Foods and Nutrition. Here the irradiated products, along with non-irradiated control products, were evaluated for quality appraisal as well as for certain microbiological changes immediately after irradiation, and after storing the irradiated products for different lengths of time and at various temperatures.

Scored by hedonic scale. Quality of the irradiated fruits and vegetables was evaluated by a trained panel consisting of ten judges. Each irradiated product, along with the appropriate non-irradiated samples, was scored according to the hedonic scale (2) ranging from 1 to 9 (1—extreme dislike; 5—neither like nor dislike; and 9—extreme like). Some of the products were judged raw, and others were cooked prior to evaluation. Where possible, the data were analyzed statistically (*1*).

RESULTS

Effects Of Can Liners

Tomatoes. Pink tomatoes were placed in the following inner containers—can liners—and were irradiated to a dose of 4.65 × 10^5

‡Named after University of Idaho, Aberdeen.

ABOUT THE AUTHORS:

D. K. Salunkhe, assistant professor of horticulture, received his B. S. degree from Poona University in India, and his M. S. and Ph. D. degrees from Michigan State University. He has authored more than 25 scientific publications on food preservation and food chemistry. He is a member of American Association for the Advancement of Science and Institute of Food Technologists.

L. H. Pollard, professor and head of department of horticulture, received his B. S. and M. S. degrees from Utah State University, and his Ph. D. from University of California. Currently, he is chief of the Plant Science Division, Karadj Agricultural College, Tehran, Iran, under the International Cooperation Administration Programme. He is a member of American Society for Horticultural Science, American Association for the Advancement of Science, and Sigma Xi.

R. K. Gerber, assistant professor of horticulture, attended Utah State University where he received his B. S. and M. S. degrees. He holds membership in American Society for Horticultural Science, American Association for the Advancement of Science, and Phi Kappa Phi.

Ethelwyn B. Wilcox, professor of foods and nutrition, received her B. S., M. S., and Ph. D. degrees from Iowa State College. She is a member of American Chemical Society, American Home Economics Association, American Dietetic Association, Institute of Food Technologists, Sigma Xi, and Phi Upsilon Omicron.

Morris Simon, chief, technical plans and program, received his B. A. degree from Brooklyn College and his M. S. degree from New York University. He has pursued additional graduate work in chemistry at Northwestern University. In 1956, he received the Research Director's Award of the Quartermaster Research and Development Organization in recognition of achievement in the field of potato dehydration. A member of the Institute of Food Technologists, he has authored a number of technical papers on dehydration and radiation preservation of foods.

TABLE I

Effect of Can Liner on the Flavor of Irradiated (4.65 $\times$ 10^5 Rads) Tomatoes

Can liner	Flavor score	Judges who disliked (%)
No radiation (control)	5.8	16
No "can liner" (control)	4.3	50
Saran, Dow Code No. 120	3.7	66
Aluminum foil, heavy duty, 0.001 in. thick	3.7	83
Glassine, 0.0015 in. thick	3.0	83
32-lb. parchment (unglazed)	3.0	83
27-lb. parchment (glazed)	2.8	100
Poly x 200	2.5	100
Polyethylene, 0.0015 in. thick	2.5	100
30-lb. unbleached kraft paper bag	2.5	100
Poly x 300	2.0	100
L.S.R. @ 0.05: Individual	2.0-1.7	

rads§ at the rate of 0.93 $\times$ 10^6 rads/hr.

1. Aluminum foil, heavy duty, 0.001 in. thick
2. 30-lb. unbleached kraft paper bag
3. Saran, Dow code No. 120
4. Polyethylene, 0.0015 in. thick
5. Glassine, 0.0015 in. thick
6. Poly x 200
7. Poly x 300
8. 32-lb. parchment (unglazed)
9. 27-lb. parchment (glazed)
10. No inner container (control)

All cans were perforated. A non-irradiated tomato sample was included in the experiment for comparison. The non-irradiated tomatoes were scored the highest. The remaining treatments were scored in descending order of acceptability as follows: No inner container, saran, aluminum foil, glassine, parchment (glazed and unglazed), kraft paper bag, poly x 200, polyethylene, and poly x 300. (See Table I)

Yellow sweet corn. Ears of sweet corn with and without husks (variety—Golden Cross Bantam) were placed in the following inner containers (can liners) prior to sealing and irradiation. These were irradiated at the doses of 0, 1, 3, and 5 $\times$ 10^5 rads at the rate of 1 $\times$ 10^6 rads/hr.

1. Polyethylene, 0.0015 in. thick
2. DuPont's experimental film No. 322
3. Mylar polyester film, type C, 0.0005 in. thick
4. Cellophane, 450 MSAD-84
5. Mylar, 0.001 in. thick, coated with 0.002 in. polyethylene
6. Cellophane, 450 K-202
7. Cellophane, 450 MSD (Oneida Ful-lok)
8. Saran, Dow code No. 120
9. 27-lb. parchment (glazed)
10. 32-lb. parchment, white (unglazed)
11. 32-lb. parchment, gray (unglazed)
12. 30-lb. unbleached kraft paper bag
13. Polyethylene, perforated
14. No inner container (control)

All cans were perforated and the sweet corn was evaluated for qual-

§A rad is a measure of radiation absorbed and is equal to 100 ergs/gm. of material being irradiated.

TABLE II

Effect of Radiation Dose and Can Liners on the Flavor of Yellow Sweet Corn Irradiated With and Without Husks when Evaluated 24-48 Hours After Irradiation

Can liner	Flavor score Dose $\times$ 10^5 rads				can liner mean	Judges who disliked (%) Dose $\times$ 10^5 rads				Flavor score Dose $\times$ 10^5 rads				can liner mean	Judges who disliked (%) Dose $\times$ 10^5 rads			
	0	1	3	5		0	1	3	5	0	1	3	5		0	1	3	5
Polyethylene, 0.0015 in. thick	7.4	6.1	6.9	7.0	6.9	0	20	10	10	7.4	7.5	6.6	7.4	7.2	10	0	10	0
DuPont No. 322	6.3	8.1	7.3	6.2	7.0	30	0	0	30	7.2	7.9	7.0	6.3	7.1	0	0	0	30
Mylar, polyester film, type C, 0.0005 in. thick	7.6	7.3	6.8	6.2	7.0	0	0	10	30	7.1	6.6	7.2	5.7	6.7	10	10	0	40
Cellophane, 450 MSAD-84	7.0	7.0	7.3	6.6	7.0	10	0	0	20	6.9	8.3	6.5	7.1	7.2	20	0	10	0
Mylar, 0.001 in. thick, coated with 0.002 in. polyethylene	7.3	8.0	7.9	6.2	7.4	10	0	0	30	7.0	6.7	5.6	6.2	6.4	10	10	40	30
Cellophane, 450 K-202	7.6	6.8	6.6	7.7	7.2	0	20	10	0	7.1	7.4	7.7	7.2	7.4	10	0	0	0
Cellophane, 450 MSD, (Ful-lok)	7.8	7.0	7.7	6.7	7.3	0	0	0	10	7.8	7.9	7.2	6.0	7.2	0	0	0	30
Saran, Dow code No. 120	8.1	6.5	7.8	7.1	7.4	0	10	0	10	7.5	7.1	6.1	7.5	7.1	10	0	30	0
27-lb. parchment (glazed)	8.0	8.1	7.7	5.8	7.4	0	0	10	40	6.8	7.3	6.7	6.4	6.8	20	0	20	20
32-lb. parchment, white (unglazed)	6.2	7.6	6.5	7.0	6.8	20	0	10	10	7.9	7.2	7.1	6.2	7.1	0	0	0	30
32-lb. parchment, gray (unglazed)	7.5	7.0	6.2	6.3	6.8	0	0	10	0	7.7	7.5	7.1	6.0	7.1	10	0	0	30
30-lb. unbleached kraft paper bag	6.8	7.0	6.4	6.2	6.6	0	10	20	20	7.2	7.2	6.8	5.7	6.7	10	0	10	30
Polyethylene, perforated	7.6	6.6	6.7	5.5	6.6	10	10	10	30	6.4	6.8	6.2	6.5	6.5	30	10	10	30
No "can liner" — sealed cans (control)	6.0	7.4	6.7	7.0	6.8	40	10	10	0	6.4	7.4	5.1	6.3	6.3	20	10	50	10
No "can liner" — perforated cans (control)	6.8	6.4	7.7	5.3	6.6	10	20	0	50	6.6	7.7	5.8	5.0	6.3	20	0	20	50
Dose mean	7.2	7.1	7.1	6.5	...	...	...	...	...	7.1	7.4	6.6	6.4	...	...	...	...	...
L.S.R. @ 0.05:																		
Individual	0.7-0.6									0.6-0.5								
Dose mean	0.2-0.1									0.1								
Can liner mean	0.3									0.3-0.2								

TABLE III

Effect of Radiation Dose and Can Liners on the Flavor of Yellow Sweet Corn Irradiated With and Without Husks when Evaluated 10 Days (Storage at 40°F.) After Irradiation

Can liner	Flavor score Dose × 10^5 rads				can liner mean	Judges who disliked (%) Dose × 10^5 rads				Flavor score Dose × 10^5 rads				can liner mean	Judges who disliked (%) Dose × 10^5 rads			
	0	1	3	5		0	1	3	5	0	1	3	5		0	1	3	5
Polyethylene, 0.0015 in. thick	6.4	6.7	6.7	3.9	5.9	20	10	10	90	7.6	6.5	5.4	4.1	5.9	0	0	50	70
DuPont No. 322	7.5	7.1	6.4	4.7	6.4	10	0	10	60	7.6	5.9	6.5	2.9	5.7	10	30	10	90
Mylar, polyester film, type C, 0.0005 in. thick	5.8	5.6	5.9	4.0	5.3	40	30	20	70	7.1	5.2	5.8	5.5	5.9	10	30	20	30
Cellophane, 450 MSAD-84	6.2	6.4	5.9	3.6	5.5	10	20	30	60	6.8	5.9	6.1	3.8	5.7	0	30	10	70
Mylar, 0.001 in. thick, coated with 0.002 in. polyethylene	6.1	6.3	6.1	3.9	5.6	10	10	20	80	6.7	5.3	5.9	6.3	6.1	10	30	30	10
Cellophane, 450 K-202	6.4	6.8	6.8	5.5	6.4	10	0	0	30	6.8	6.6	5.5	4.5	5.9	0	0	30	60
Cellophane, 450 MSD, (Ful-lok)	6.7	6.2	5.3	4.0	5.6	10	20	40	70	6.5	6.5	7.2	5.4	6.4	0	10	0	40
Saran, Dow code No. 120	6.8	6.9	6.8	4.1	6.2	0	20	0	80	7.1	6.6	6.3	4.3	6.1	0	10	0	50
27-lb. parchment (glazed)	6.0	6.2	4.5	3.0	4.9	20	30	50	90	6.6	5.2	6.5	4.8	5.8	10	40	0	60
32-lb. parchment, white (unglazed)	6.0	5.2	6.4	4.4	5.5	30	30	10	50	6.4	6.1	5.4	4.6	5.6	10	0	20	60
32-lb. parchment, gray (unglazed)	6.9	5.6	6.9	4.0	5.9	0	40	0	70	5.6	5.7	4.7	3.7	4.9	30	30	40	90
30-lb. unbleached kraft paper bag	6.6	6.0	6.5	4.5	5.9	10	20	10	60	7.0	5.3	5.5	4.0	5.5	0	40	50	70
Polyethylene, perforated	5.6	6.1	5.6	3.8	5.3	30	30	40	60	6.4	6.4	5.7	4.6	5.8	20	20	20	60
No "can liner" — sealed cans (control)	7.3	6.3	5.4	2.6	5.4	0	0	30	90	5.7	5.9	3.9	4.0	4.9	30	30	70	80
No "can liner" — perforated cans (control)	6.1	6.2	5.0	4.4	5.4	20	10	40	70	5.8	5.8	4.7	5.8	5.5	10	20	60	30
Dose mean	6.4	6.2	6.0	4.0	...	...	...	...	...	6.6	5.9	5.6	4.5	...	...	...	...	...

L.S.R. @ 0.05:
Individual .... 0.6-0.5 .... 0.7-0.6
Dose mean .... 0.1 .... 0.2
Can liner mean .... 0.1 .... 0.4-0.3

ity within 24 hr. after irradiation. Can liners had no significant effect on the quality of sweet corn. However, only a slight difference in the quality of sweet corn irradiated to 5 × 10^5 rads was evidenced. This difference was more pronounced after 10 days' storage at 40° F. (4.4° C.)—i.e., the sweet corn irradiated to 3 and 5 × 10^5 rads had marked off flavor.

Some beneficial effect of can liners such as saran, parchment, cellophane, DuPont's experimental film No. 322, and Mylar on the flavor of sweet corn was found. In addition, they can be used as cushioning material. In general, the quality of yellow sweet corn was maintained when irradiated with husks on. (See Tables II and III) Similar packaging effects were noticed when tomatoes and strawberries were irradiated using various can liners.

Effects Of Can Conditions

Yellow sweet corn. For this study, yellow sweet corn (variety—Golden Cross Bantam) with and without husks was irradiated in sealed and perforated cans at 0.93, 1.86, 3.72, and 4.65 × 10^5 rads at the rate of 0.93 × 10^6 rads/hr. The samples were evaluated for quality imme-

TABLE IV

Effect of Radiation Dose, Condition of Can, and Storage Period on the Flavor of Irradiated Sweet Corn With or Without Husks

Dose × 10^5 rads	Sample	Condition of can	Evaluated 24-48 hr. after irradiation: Flavor score	Evaluated 24-48 hr. after irradiation: Judges who disliked (%)	Evaluated 10 days after irradiation: Flavor score	Evaluated 10 days after irradiation: Judges who disliked (%)
0	With husks	Perforated	7.9	0	5.3	30
		Sealed	6.4	20	5.4	40
	Without husks	Perforated	7.8	10	6.4	20
		Sealed	5.6	40	5.7	30
		Mean	6.9	...	5.7	...
1	With husks	Perforated	6.6	20	6.7	10
		Sealed	6.8	0	5.6	30
	Without husks	Perforated	7.9	0	6.6	10
		Sealed	6.6	10	5.3	30
		Mean	6.9	...	6.0	...
3	With husks	Perforated	6.0	20	5.5	20
		Sealed	6.9	20	5.6	40
	Without husks	Perforated	7.0	0	5.0	50
		Sealed	3.6	80	5.3	40
		Mean	5.8	...	5.3	...
5	With husks	Perforated	6.4	10	5.0	30
		Sealed	4.7	50	4.9	40
	Without husks	Perforated	5.4	30	4.3	70
		Sealed	3.8	80	5.2	40
		Mean	5.1	...	4.8	...
Can condition mean		Perforated	6.8	...	5.6	...
		Sealed	5.5	...	5.3	...
Husk mean		With husks	6.4	...	5.5	...
		Without husks	5.9	...	5.4	...

L.S.R. @ 0.05 Individual .... 1.5-1.3 .... 1.7-1.4
Dose mean .... 1.0-0.9 .... 1.1-1.0
Can condition mean .... 1.0-0.9 .... 1.1-1.0
Husk mean .... 0.7 .... 0.7

TABLE V

Effect of Radiation Dose, Condition of Can, and Storage Period on the Flavor of Peaches

Doses $\times 10^5$ rads	Condition of can	Evaluated 24-48 hr. after irradiation: Flavor score	Evaluated 24-48 hr. after irradiation: Judges who disliked (%)	Evaluated 10 days after irradiation: Flavor score	Evaluated 10 days after irradiation: Judges who disliked (%)
0	Perforated	6.3	10	7.8	0
	Sealed	4.4	50	*	*
	Mean	5.4	....	—	....
1	Perforated	6.9	10	7.4	0
	Sealed	4.0	60	*	*
	Mean	5.5	....	—	....
3	Perforated	6.5	10	6.8	10
	Sealed	1.9	100	*	*
	Mean	4.2	....	—	....
5	Perforated	4.4	70	4.0	70
	Sealed	1.5	100	*	*
	Mean	3.0	....	—	....
Can condition mean	Perforated	6.0	....	—	....
	Sealed	3.0	....	—	....

L.S.R. @ 0.05:

Individual	1.4-1.3	1.3-1.2
Dose mean	1.0-0.9	—
Can condition mean	0.6	—

*Samples were disintegrated and rotten.

TABLE VI

Effect of Radiation Dose, Condition of Can, and Storage Period on the Flavor of Lindalicious Strawberries

Dose $\times 10^5$ rads	Condition of can	Evaluated 24-48 hr. after irradiation: Flavor score	Evaluated 24-48 hr. after irradiation: Judges who disliked (%)	Evaluated 10 days after irradiation: Flavor score	Evaluated 10 days after irradiation: Judges who disliked (%)
0	Perforated and aerated	7.6	0	7.5	0
	Sealed	7.2	0	7.5	0
	Vacuumed	7.3	10	2.7	90
	Mean	7.4	....	5.9	....
0.93	Perforated and aerated	7.5	0	7.2	10
	Sealed	6.5	20	3.3	70
	Vacuumed	5.9	20	3.0	80
	Mean	6.6	....	4.5	....
2.79	Perforated and aerated	5.5	40	4.8	40
	Sealed	3.8	60	3.5	80
	Vacuumed	3.2	70	2.7	90
	Mean	4.1	....	3.7	....
4.65	Perforated and aerated	3.6	70	3.0	20
	Sealed	3.6	70	2.8	80
	Vacuumed	3.1	70	2.8	100
	Mean	3.4	....	2.9	....
Can condition mean	Perforated and aerated	6.1	....	5.6	....
	Sealed	5.3	....	4.3	....
	Vacuumed	4.9	....	2.8	....

L.S.R. @ 0.05:

Individual	1.5-1.2	1.3-1.1
Dose mean	0.7	0.7-0.6
Can condition mean	0.6	0.6-0.5

diately after irradiation. Sweet corn with the husks, in perforated cans, was scored slightly higher than that without husks in sealed cans.

No significant difference in the quality of sweet corn, with and without husk, was evidenced at that time. However, after 10 days' storage at 40° F. (4.4° C), the difference was pronounced, i.e., the sweet corn with husks was scored higher than the sweet corn without husks, regardless of the container condition. The increase in radiation dose progressively lowered the quality of sweet corn both in sealed and perforated cans. (See Table IV)

After 10 days at 40° F. (4.4° C.), a large amount of gas developed in non-irradiated cans. A small amount of gas was also observed in the sealed cans irradiated at 0.93×10^5 rads, but no gas was evident in the cans irradiated at 3.72 and 4.65×10^5 rads. However, after 45 days' storage, a moderate amount of bulging was seen in the cans which were irradiated at 3.72 and 4.65×10^5 rads.

Peaches. When Elberta peaches were irradiated at 0, 1, 3, and 5×10^5 rads, at the rate of 1×10^6 rads/hr. in sealed cans, an unacceptable product was developed. Hence, it was not evaluated. The samples which were aerated during the process of irradiation were somewhat acceptable. The results indicated that there was no significant difference in the quality of peaches which were non-irradiated samples after the end of 10 days' storage at 70° F. (21.1° C.). (See Table V)

Strawberries. Strawberries (variety—Lindalicious) were placed in No. 10 cans. Some of the cans were sealed, some were evacuated, and others were perforated. They were irradiated at 0, 0.93, 2.79, and 4.65×10^5 rads at the rate of 0.93×10^6 rads/hr.

In general, it may be said that as the radiation dose advanced, the quality of strawberries declined. Strawberries, when sealed under vacuum, deteriorated in quality more than those either sealed or perforated and stored for 10 days under refrigeration, 40° F. (4.4° C.). (See Table VI) The true red color of strawberries was faded when sealed under vacuum and irradiated. It was found that the quality of strawberries was better in most cases when irradiated in perforated cans rather than in sealed cans. As the radiation dose advanced, a progressive decline in quality was evidenced.

String beans. String beans (variety—Blue Lake) were sealed in No. 10 cans. Some of the cans were sealed under vacuum and some were perforated. In perforated cans, no air was circulated during the process of irradiation. The cans were irradiated at 0.93, 2.79, and 4.65 × 10^5 rads at the approximate rate of 0.93 × 10^6 rads/hr.

The taste panel evaluated the irradiated and non-irradiated string beans after cooking. It was noticed that the quality of the irradiated products seemed to be improved when stored for 10 days at 40° F. (4.4° C.). The string beans when irradiated in evacuated cans, were of inferior quality. (See Table VII) They developed a rubber-like texture and were much more shriveled than the green beans in sealed cans or in perforated cans.

Asparagus. Approximately 2½ lb. of 6-in. asparagus spears were sealed in No. 10 cans without can liners. Some of the cans were perforated. The cans, thus prepared, were irradiated at 0, 0.93, 2.79, and 4.65 × 10^5 rads at the rate of 0.93 × 10^6 rads/hr. The asparagus was judged more acceptable after being irradiated with aeration through perforations of the can than irradiated in sealed cans.

However, in the perforated and aerated cans, the products were always superior to those in sealed cans. It is interesting to note that the quality of asparagus irradiated to 0.93 × 10^5 rads was improved when stored at 40° F. (4.4° C.) in a moist condition for 10 days after irradiation. (See Table VIII) Hence, it seems that the radiation

TABLE VII

Effect of Radiation Dose, Condition of Can, and Storage Period on the Flavor of String Beans

Dose × 10^5 rads	Condition of can	Evaluated 24-48 hr. after irradiation: Flavor score	Evaluated 24-48 hr. after irradiation: Judges who disliked (%)	Evaluated 10 days after irradiation: Flavor score	Evaluated 10 days after irradiation: Judges who disliked (%)
0	Perforated	6.7	10	6.7	10
	Sealed	5.5	40	*	*
	Vacuumed	4.6	60	*	*
	Mean	5.6	...	—	...
0.93	Perforated	5.9	30	6.7	10
	Sealed	6.5	20	*	*
	Vacuumed	5.2	60	*	*
	Mean	5.9	...	—	...
2.79	Perforated	6.1	10	6.7	10
	Sealed	5.7	30	*	*
	Vacuumed	3.8	60	*	*
	Mean	5.2	...	—	...
4.65	Perforated	5.6	30	7.2	0
	Sealed	5.1	40	*	*
	Vacuumed	4.2	70	*	*
	Mean	5.0	...	—	...
Can condition mean	Perforated	6.1	...	6.8	...
	Sealed	5.7	...	—	...
	Vacuumed	4.5	...	—	...

L.S.R. @ 0.05:

	24-48 hr.	10 days
Individual	1.6-1.3	1.4-1.3
Dose mean	0.8-0.7	—
Can condition mean	0.7-0.6	—

*Samples were disintegrated in the storage.

TABLE VIII

Effect of Radiation Dose, Condition of Can, and Storage Period on the Flavor of Asparagus

Dose × 10^5 rads	Condition of can	Evaluated 24-48 hr. after irradiation: Flavor score	Evaluated 24-48 hr. after irradiation: Judges who disliked (%)	Evaluated 10 days after irradiation: Flavor score	Evaluated 10 days after irradiation: Judges who disliked (%)
0	Perforated and aerated	5.8	30	6.7	0
	Sealed	5.8	20	2.6	90
	Mean	5.8	...	4.7	...
0.93	Perforated and aerated	5.8	30	6.3	10
	Sealed	5.8	40	3.2	90
	Mean	5.8	...	4.8	...
2.79	Perforated and aerated	6.0	30	5.7	30
	Sealed	4.6	50	2.9	100
	Mean	5.3	...	4.3	...
4.65	Perforated and aerated	6.7	0	6.6	10
	Sealed	4.8	40	3.0	80
	Mean	5.8	...	4.6	...
Can condition mean	Perforated and aerated	6.1	...	6.3	...
	Sealed	5.3	...	2.9	...

L.S.R. @ 0.05:

	24-48 hr.	10 days
Individual	1.5-1.3	1.4-1.2
Dose mean	1.0-0.9	0.9-0.8
Can condition mean	0.6	0.6

TABLE IX

Effect of Radiation Dose, Condition of Can, and Storage Period on the Flavor of Tomatoes

Dose × 10^5 rads	Condition of can	Evaluated 24-48 hr. after irradiation		Evaluated 10 days after irradiation	
		Flavor score	Judges who disliked (%)	Flavor score	Judges who disliked (%)
0	Perforated and aerated	6.9	20	5.9	20
	Sealed	8.1	0	3.3	70
	Mean	7.5	...	4.6	...
0.93	Perforated and aerated	6.1	0	6.0	10
	Sealed	6.7	0	1.9	100
	Mean	6.4	...	4.0	...
2.79	Perforated and aerated	4.7	50	3.0	90
	Sealed	4.5	70	1.4	100
	Mean	4.6	...	2.2	...
4.65	Perforated and aerated	4.3	60	3.5	90
	Sealed	5.5	30	0.9	80
	Mean	4.9	...	2.3	...
Can condition mean	Perforated and aerated	5.5	...	4.6	...
	Sealed	6.2	...	1.9	...

L.S.R. @ 0.05:

	24-48 hr.	10 days
Individual	1.2-1.1	1.2-1.1
Dose mean	0.8-0.7	1.0-0.9
Can condition mean	0.5	0.7-0.6

TABLE X

Effect of Radiation Dose, Can Liner, and Can Condition on the Flavor of Lindalicious Strawberries

Dose × 10^5 rads	Can liner	Perforated cans		Sealed cans	
		Flavor score	Judges who disliked (%)	Flavor score	Judges who disliked (%)
0	None	7.1	20	7.0	10
	Polyethylene, 0.0015 in. thick	—	—	5.6	20
	Mylar, type C, 0.0005 in. thick	—	—	6.2	30
	Polyethylene and vacuum	—	—	7.1	0
	Mean	—	...	6.5	...
0.93	None	6.1	30	6.1	20
	Polyethylene, 0.0015 in. thick	—	—	6.1	20
	Mylar, type C, 0.0005 in. thick	—	—	6.6	20
	Polyethylene and vacuum	—	—	3.2	70
	Mean	—	...	5.5	...
2.79	None	6.7	0	5.5	40
	Polyethylene, 0.0015 in. thick	—	—	3.9	60
	Mylar, type C, 0.0005 in. thick	—	—	3.2	90
	Polyethylene and vacuum	—	—	2.8	70
	Mean	—	...	3.9	...
4.65	None	4.7	60	3.9	70
	Polyethylene, 0.0015 in. thick	—	—	3.1	80
	Mylar, type C, 0.0005 in. thick	—	—	3.3	80
	Polyethylene and vacuum	—	—	2.4	80
	Mean	—	...	3.2	...
Can liner mean	None	6.2	...	5.6	...
	Polyethylene, 0.0015 in. thick	—	...	4.7	...
	Mylar, type C, 0.0005 in. thick	—	...	4.8	...
	Polyethylene and vacuum	—	...	3.9	...

L.S.R. @ 0.05:

	Perforated cans	Sealed cans
Individual	1.5-1.3	1.5-1.3
Dose mean	—	0.7-0.6
Can liner mean	—	0.7-0.6

flavor (at low doses) disappears after certain storage periods.

Tomatoes. Ripe tomatoes were sealed in No. 10 cans. Some of the cans were perforated. The cans thus prepared were irradiated to 0.93, 2.79, and 4.65 × 10^5 rads at the rate of 0.93 × 10^6 rads/hr. During the process of radiation the perforated cans were aerated. In general, the observations follow a similar pattern to that of asparagus. However, the quality of tomatoes was much poorer after 10 days' storage in sealed cans than in the perforated cans, regardless of radiation doses. (See Table IX)

Effects Of Can Liners And Can Conditions

Strawberries. Strawberries were placed in cans lined with polyethylene, Mylar, and also in cans with no liners. All samples were sealed in No. 10 cans. Some of the cans with polyethylene were canned under a vacuum. Some of the cans thus prepared were perforated. They were evaluated for quality immediately after irradiation at 0, 0.93, 2.79, and 4.65 × 10^5 rads at the rate of 0.93 × 10^6 rads/hr.

The results show that when can liners within cans were used during irradiation of strawberries, evaluation was detrimental; Mylar was slightly better than polyethylene. Strawberries irradiated at 2.79 and 4.65 × 10^5 rads with aeration were judged more acceptable than those irradiated in sealed cans. At the 4.65 × 10^5 rads level they were all unacceptable. (See Table X)

Tomatoes. A similar study was made with tomatoes using several can liners within sealed cans. These tomatoes were evaluated for quality immediately after irradiation. Tomatoes packaged in DuPont's experimental material No. 322 and irradiated at the 2.79 × 10^5 rads were judged better than those in other materials.

After a storage period of 10 days, a decrease in tomato acceptability with increased radiation dose was similar to that shown when judged immediately after irradiation. The

TABLE XI

Effect of Radiation Dose, Can Liner, and Can Condition on the Flavor of Tomatoes

Dose × 10^5 rads	Can liner	Perforated cans: Evaluated 24-48 hr. after irradiation: Flavor score	Perforated cans: Evaluated 24-48 hr. after irradiation: Judges who disliked (%)	Perforated cans: Evaluated 10 days after irradiation: Flavor score	Perforated cans: Evaluated 10 days after irradiation: Judges who disliked (%)	Sealed Cans: Evaluated 24-48 hr. after irradiation: Flavor score	Sealed Cans: Evaluated 24-48 hr. after irradiation: Judges who disliked (%)	Sealed Cans: Evaluated 10 days after irradiation: Flavor score	Sealed Cans: Evaluated 10 days after irradiation: Judges who disliked (%)
0	None	7.0	0	7.1	20	6.2	20	5.7	0
	30-lb. unbleached kraft paper bag	—	—	—	—	6.5	10	5.7	30
	Polyethylene, 0.0015 in. thick	—	—	—	—	7.1	0	5.6	10
	Polyethylene, perforated	—	—	—	—	5.4	20	6.5	10
	DuPont No. 322	—	—	—	—	6.0	30	5.5	10
	Mylar, type C, 0.0005 in. thick	—	—	—	—	6.0	30	6.0	20
	Mean	—	....	—	....	6.2	....	6.1	....
2.79	None	5.5	30	4.5	40	3.7	80	3.8	60
	30-lb. unbleached kraft paper bag	—	—	—	—	4.2	60	5.0	30
	Polyethylene, 0.0015 in. thick	—	—	—	—	4.0	60	4.9	40
	Polyethylene, perforated	—	—	—	—	2.6	90	4.5	60
	DuPont No. 322	—	—	—	—	5.4	30	5.3	20
	Mylar, type C, 0.0005 in. thick	—	—	—	—	—	—	6.5	20
	Mean	—	....	—	....	4.0	....	5.0	....
4.65	None	5.5	40	4.9	40	2.7	80	2.8	90
	30-lb. unbleached kraft paper bag	—	—	—	—	3.5	80	2.3	90
	Polyethylene, 0.0015 in. thick	—	—	—	—	2.5	100	3.0	90
	Polyethylene, perforated	—	—	—	—	2.6	90	3.2	80
	DuPont No. 322	—	—	—	—	3.3	70	3.3	70
	Mylar, type C, 0.0005 in. thick	—	—	—	—	—	—	2.6	90
	Mean	—	....	—	....	2.9	....	2.8	....
Can liner mean	None	6.0	....	5.0	....	4.2	....	4.6	....
	30-lb. unbleached kraft paper bag	—	....	—	....	4.7	....	4.3	....
	Polyethylene, 0.0015 in. thick	—	....	—	....	4.5	....	4.5	....
	Polyethylene, perforated	—	....	—	....	3.5	....	4.9	....
	DuPont No. 322	—	....	—	....	4.9	....	4.7	....
	Mylar, type C, 0.0005 in. thick	—	....	—	....	6.0	....	5.0	....
Can condition mean	Perforated 5.5	—	....	—	....	—	....	—	....
	Sealed 4.5	—	....	—	....	—	....	—	....

L.S.R. @ 0.05:	Perforated, 24-48 hr.	Perforated, 10 days	Sealed, 24-48 hr.	Sealed, 10 days
Individual	1.5-1.3	1.6-1.3	1.5-1.3	1.6-1.3
Dose mean	—	—	0.5	0.6-0.5
Can liner mean	—	—	0.8-0.7	0.9-0.8
Can condition mean	—	—	—	0.5

only exception was in the material, Mylar. Tomatoes in this material were judged equally acceptable at the 2.79 × 10^5 rads with those of the control. Tomatoes irradiated at 2.79 and 4.65 × 10^5 rads with aeration through perforation, were judged higher than those irradiated in sealed cans, but all were of poor quality. (See Table XI)

SUMMARY AND CONCLUSIONS

From the observations and results of the experiments reported in this paper, on the different radiation doses, can-lining materials, aeration during radiation, and condition of can, on the quality and shelf life of certain fruit and vegetable products, they can be summarized and concluded as follows:

In general, it seemed that the can-lining materials such as saran, parchment, cellophane, Mylar, and DuPont's experimental film No. 322, may have more possibility to be used during the irradiation process than other materials used. The success of the preservation of the irradiated fresh fruits and vegetables will depend upon the availability of a semi-permeable film which will allow normal respiration of the product and at the same time will prohibit the entry of microbes.

Aeration, during irradiation of fruits and vegetables, is essential to extend the shelf life as well as to retain the natural flavor of fresh fruits and vegetables by supplying O_2 for the normal respiration process and at the same time removing CO_2 and other gases given out as a result of respiration and of radiation.

Acknowledgments

The authors are grateful to Major J. P. Berg and Mr. D. L. Hunke and their staff at the Dugway Proving Ground, Dugway, Utah, and Material Testing Reactor, Phillips Petroleum Co., Idaho Falls, Idaho, respectively, for their assistance and cooperation in making the necessary arrangements for the radiation.

Literature Cited

1. Duncan, D. B., "Multiple range and multiple F test," *Biometrics*, 11 (1), 1 (1955).
2. Peryam, D. R., and Girardot, N. F., "Advanced taste-test method," *Food Engineering*, 194, 58 (1952). (*End*)