IRRADIATION PASTEURIZATION OF MICHIGAN GROWN STRAWBERRIES

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

George O. Birk Jr.

1966

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ABSTRACT

IRRADIATION PASTEURIZATION OF MICHIGAN GROWN STRAWBERRIES

by George O. Birk Jr.

The effect of gamma irradiation on Michigan grown strawberries of the Robinson var. has been studied. Doses of 200 Krad of gamma rays extended the shelf life of the fruit by 3 to 5 days with no adverse effect on flavor and color. A significant softening of the fruit resulted from irradiation, but some refirming was observed on subsequent cold storage. Overwrapping of the fruit prior to irradiation appeared to offer little benefit. If the fruit was held 24 hrs. at ambient temperature prior to irradiation, the beneficial effects of the irradiation were negated.

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by

George O. Birk Jr.

A THESIS

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

CHAPTER I

INTRODUCTION

Radiation may be described as the flow of energy between two points. This energy flow may take the form of electromagnetic waves, examples of which are light waves, heat and x-rays, as well as gamma rays, or it may take the form of atomic particles such as cathode rays and alpha rays.

During this study, only ionizing radiations will be considered, or those which are capable of ionizing the receptor molecule. As the ionizing radiation passes through matter, its primary means of energy dissipation are ejection of electrons and excitation of molecules. When an electron is ejected the atom or molecule is left positively charged and is said to be ionized. The initial ejection of the electron is referred to as the primary ionization, and further ionizations caused by the ejected electron are referred to as secondary ionizations.

The forms of radiation generally referred to as ionizing radiation may be divided into electromagnetic waves which include x-rays and gamma rays and atomic particle radiations which include cathode rays, beta rays, fast protons, fast neutrons and alpha rays. Many of the ionizing radiations, particularly the heavy particle radiations such as alpha rays, neutrons, and protons are capable of nuclear transformations or inducing radioactivity, and must be avoided when working with foods.

Electromagnetic waves, and accelerated electrons may also induce radioactivity when used at high energy levels (above 10 Mev). Work on the radiation of foods has been limited mainly to gamma rays and accelerated electrons.

Gamma rays are the electromagnetic radiation emitted by naturally occurring or artifically induced radioactive elements. These electromagnetic waves are of short wave length, but have high penetrating values.

Cathode rays or accelerated electrons are generated by several types of machines. The penetrating ability of these electrons is very limited as compared to electromagnetic radiation.

Chemical effects due to ionizing radiations may be initiated through direct hits of the ionizing radiation onto the molecules, or through the products of radiolysis of water, in an aqueous system.

The effect of ionizing radiation on the living cell has been found to be highly dose-dependent. Radiation at low doses produces only limited changes in living cells, e.g., in the rate of respiration or the rate of cell division, while very high doses result in gross cell damage and death. Intermediate dose ranges mainly cause genetic changes, ranging from increased rates of mutation to interference with the mechanisms of cell reproduction itself.

Soon after the discovery of x-rays by Roentgen in 1895, it was discovered that if organisms were exposed to the rays for a sufficient time, they would die. Much research has been conducted since, to find a practical application for this phenomenon.

The research for this thesis has been devoted to studying the effects of gamma radiation as a means of pasteurizing Michigan grown

Robinson Strawberries. In this work, optimum dose levels were determined in relation to microbial reduction, shelf life extension, as well as color, flavor and texture retention. In addition, the effect of pre-irradiation packaging to prevent recontamination following irradiation, and the effect of a twenty-four hour post-harvest delay in the irradiation of strawberries was studied as they affect shelf life extension, color, flavor and texture of the irradiated fruit. It is hoped these data will aid in the ultimate determination of radiation conditions for the commercial radiation pasteurization of fresh strawberries.

CHAPTER II

LITERATURE REVIEW

As early as 1898, three years after Roentgen discovered x-rays, Pacionott and Porcell observed the effects of ionizing radiation on microbes (10). Although work continued on studying the effects of ionizing radiation on microorganisms, it was not until 1930 that Wyckoff (25) published the first significant results on the bactericidal effects of ionizing radiation. At this time, he also tried to explain the lethal effects of ionizing radiation on microorganisms. His work and that of others was then used to develop the target theory which was described by Lea (14). In 1930, a French Patent was issued to Otto Wust for the preservation of food by ionizing radiation (18).

In addition to the bactericidal effects of ionizing radiation, many other side effects were also being studied. In 1938, Kersten and Dwight (13) reported on the effect of x-ray irradiation on solutions of apple pectins. Their study showed a reduction in relative viscosity associated with irradiation. In 1940, Dale (6) reported on the effects of x-rays on pure enzyme systems. His work indicated that enzymes in pure solutions at relatively low concentrations could be inactivated by relatively low doses of irradiation, but when in the cell this ceased to be true and enormous doses were necessary to inactivate the unpurified enzymes. Anderson and Harrison (1) studied the quantitative effect of x-rays on ascorbic acid in simple solutions and naturally occurring substances.

The major emphasis on the radiation preservation of foods began in 1946 with the development of the large capacity electron generator. Brasch and Huber (2) working with a type of generator called the Capacitron reported in 1947 the ability to bring about sterility in foodstuffs and microorganism cultures with cathode rays. They also noted some of the harmful effects of ionizing radiation on the flavor, color and texture of the irradiated foods. They tried to minimize or eliminate these side effects by lowering the temperature during irradiation or removing the oxygen by vacuum or replacing the air by an inert gas.

In 1948, Trup and Van De Graaf (22) published a report in which they described the functioning of the electron generator, its capabilities and limitations as a means of preserving foods. Dunn and associates (9) the same year published extensive results on their work with the cathode rays and x-rays. This included determination of the radiosensitivity of pure cultures of various microorganisms, the bactericidal effect on microorganisms in milk and fruit juices, as well as the effect of ionizing radiation on enzymes and ascorbic acid.

In the early 1950's, Proctor and associates (19, 20) published reports in which they cited some of the undesirable side effects of ionizing radiations, and the connection of these effects with the free radicals formed by the radiolysis of water. Many of these side effects could be reduced or eliminated by irradiation in the frozen state or by addition of free radical scavengers such as ascorbic acid, niacin and sodium sulfite. By this time, it was well recognized that many of these side effects were dose-dependent and a positive method of reducing side effects was to reduce the dose.

The Atomic Energy Commission (AEC) began supporting research to study the potential of gamma emitting isotopes in the preservation of foods in about 1950 (13). Much of the early work was done by Brownell and associates at the University of Michigan. Brownell and associates (3, 4, 5) noted that the storage life of a product could be extended by this form of ionizing radiation, but that many of the characteristic undesirable changes on the flavor, color, odor and texture were present. Their study included shelf life extension of fruit and vegetables as judged by the visual appearance of mold, the use of taste panels with a statistical analysis of the results and general observations on color and textural changes. Their results indicated that each product would have to be evaluated separately, and that to achieve sterility very high doses would be required, in many cases far above those compatible with a good product, from a sensory and physical standpoint.

In 1954, the Food Technology Studies of the AEC were taken over by the Quartermaster Corps of the Army. The Army issued contracts to over 80 institutions to do this research. These were primarily academic institutions, but the food industry was also represented.

The Food Irradiation Program was reevaluated in 1960 (23) at which time the responsibility for research was divided, with the AEC assuming the responsibility for research in radiation pasteurization while the Department of the Army retained responsibility for work on radiation sterilization of foods. The term radiation pasteurization was introduced to indicate the destruction of most but not all of the microorganisms present in the food.

Since 1960, considerable research has been done by Maxie and Sommer (17) at the University of California. Their group studied the effects of irradiation pasteurization on texture, flavor and shelf life extension, as well as the post harvest physiology of fruits and vegetables. These studies were a guide to the future potential of irradiation preservation of fruit and vegetables. In 1963 (16), they reported that strawberries seem to offer the greatest promise of any fruit treated. A dose of 200 Krad appeared to yield the most desirable results. In 1965 (12), the California workers reported their results on physical and sensory tests on fresh strawberries subjected to gamma irradiation.

Truelsen (21), working in Denmark with small fruits, found that irradiation could extend the life of the fruits, but that the textural changes would probably be the limiting factor, from the acceptance standpoint. He also found that environmental conditions during ripening and harvest would markedly determine the effectiveness of irradiation. Other workers in Europe including Vidal (24) in France, D. deZeeuw (7) in Holland, and Herregods and M. DeProost (11) in Belgium determined optimum pre and post irradiation storage conditions as well as optimum dose levels to use on the various fruits.

CHAPTER III

METHODS AND MATERIALS

Irradiation Sources

Cobalt-60 was the source of the gamma rays used in these experiments. The Cobalt-60 sources housed at the Phoenix Memorial Laboratory and the Phoenix Radiation Facility of the University of Michigan in Ann Arbor were employed. The activity of the sources was 10,000 and 5,000 curies, respectively.

The encapsulated Cobalt-60 was kept immersed in demineralized water tanks when not in use. At the time of use, the source was raised by remote control into the irradiation chamber, which was equipped with an air circulation system. The dose received by a sample was determined by the distance from the source and the time of irradiation. Dosimetry data were provided by the University of Michigan. Figure 1 shows the basic elements of a Cobalt-60 irradiation facility, while Figure 2 shows the relationship of dose-rate to distance for each of the sources.

Irradiation

Samples to be irradiated were placed in rings around the source cage. The distance from the outside of the source cage to the center of the sample being irradiated was determined by the dose-rate desired (Figure 2). When a large number of samples were to be irradiated at a given time, at a constant dose-rate, vertical layering of the samples

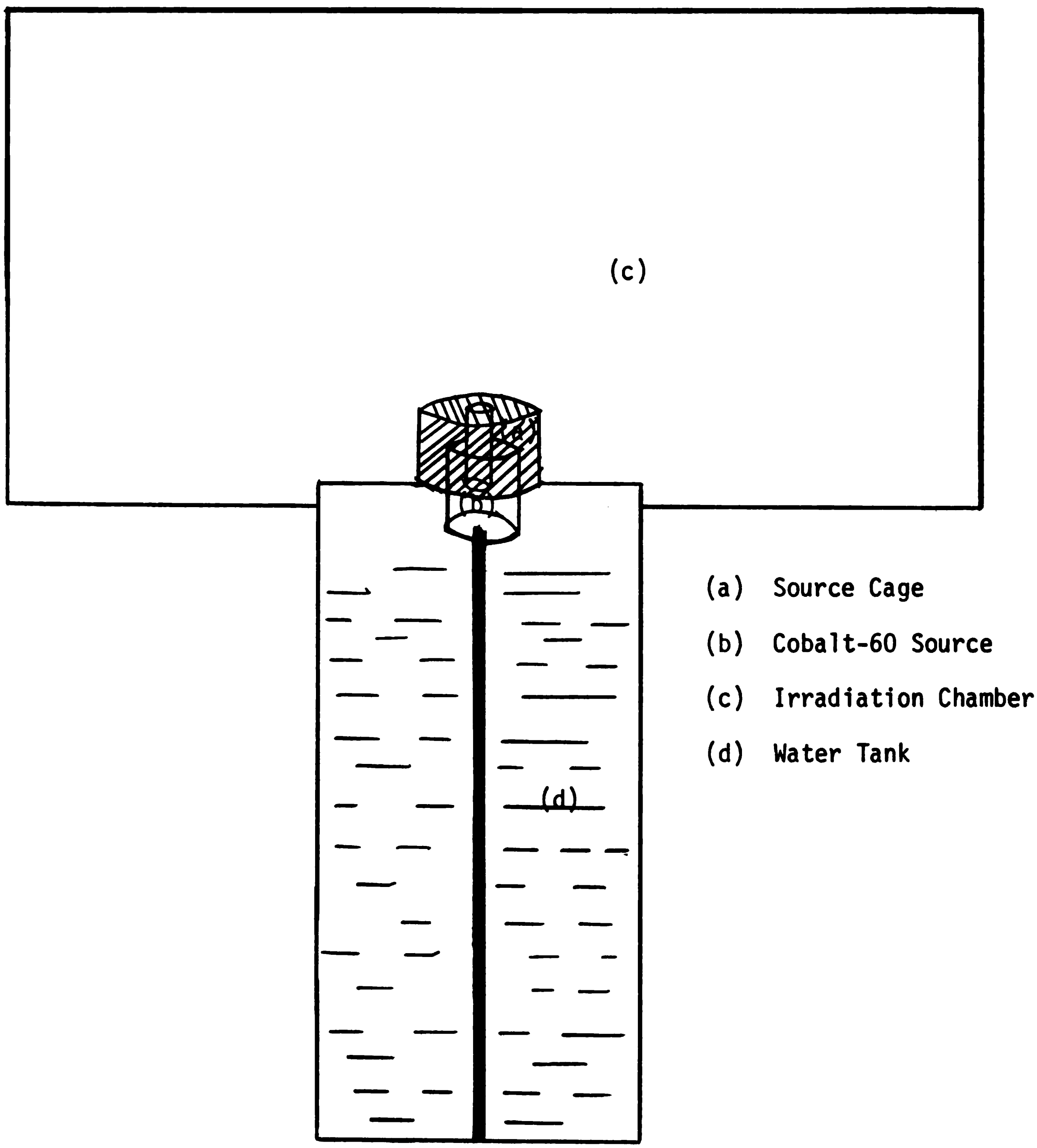

Fig. 1.--Basic components of Cobalt-60 facility.

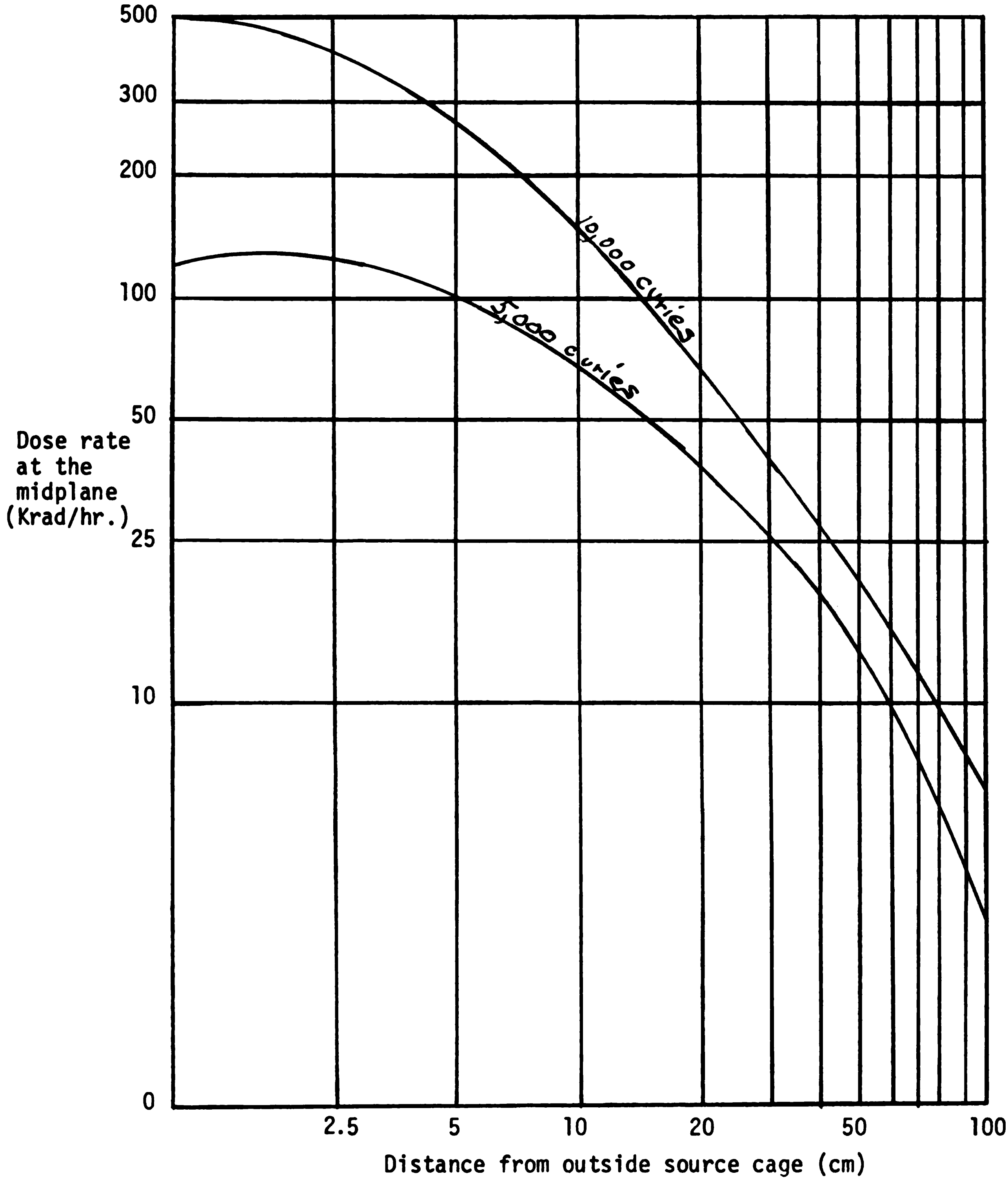

Fig. 2.--Dosimetry data for 10,000 and 5,000 curie Cobalt-60 sources of the University of Michigan.

was employed. In certain cases, the number of samples was increased by arranging them in concentric rings around the source and readjusting the irradiation time. At half dose, non-fluid samples were rotated 180° along a vertical axis to insure uniformity of dose within each sample.

Product

Strawberries of the Robinson Variety were obtained from Southeast Michigan. The fruit was picked, starting at 7:00 a.m., so that it would be cool, inspected and packed. Fruit exhibiting physical damage, or excessively over or underripe was excluded from the experiment.

Packaging Supplies

A. One-pint wood rim cups No. 9506 were purchased from the Fruit and Produce Packaging Company, Division Inland Container Corporation. This was the standard fruit container used in these experiments.

B. Twelve-pint berry flats No. 26611 were purchased from the same company.

C. Polyethylene bags, 1.5 mil. in thickness, size 5" x 3 1/2" x 13", manufactured by the Dow Chemical Company, were used to overwrap the fruit containers.

D. Saran film, household type, was used as overwrap in one experiment.

Packaging

A. Preliminary Experiments (1963)

(1) In 1963, the fruit was packed in polyethylene bags for subsequent study of the irradiation effect on the microbial population, the texture and the flavor of the fruit on storage.

(2) For measuring the effect of irradiation on the color of individual berries, the fruit was placed in cardboard egg crate dividers and immobilized with saran film overwrap.

B. Major Experiments (1964, 1965)

(1) Non-overwrap fruit. The graded fruit was filled into one-pint wood rim cups. After filling, the pint containers were placed in berry flats at the rate of twelve pints per flat. The purpose of the flat was to protect fruit from being crushed, to keep treatments separated, and for ease of handling.

The non-overwrapped fruit was protected during shipment by covering the entire flat with a large 12" x 8" x 30", 1.5 mil. polyethylene bag which was not sealed but simply fit over the flat.

(2) Overwrapped fruit. After filling the pint cups with fruit, the cups were fitted into the polyethylene bags. The open end of the bag was twisted shut and taped under the cup. This resulted in a water vapor-tight container for the fruit, which would limit dessication. After overwrapping, the fruit cups were placed in the twelve pint berry flats for handling and storage.

C. Randomizing samples for irradiation. The filled flats were randomly divided into groups prior to irradiation.

<u>Storage of Samples</u>

The samples were held for storage tests at 44°F ± 1°, or at 38°F ± 1°. The fruit was stored in appropriately coded berry flats. A platform 2" above the floor was used for placement of the trays, to allow air circulation during storage.

Sampling Procedure

At regular predetermined intervals, samples were removed from the berry flats for testing. In order that the person selecting the fruit would show no partiality, a pint container was removed from the same location in each flat being tested. Samples receiving the same treatment were kept together for testing. The person who selected the samples was not allowed to grade the fruit, as his knowledge of the treatment might bias his judgment.

Testing Procedure

A. Color

(1) Equipment used

(a) For visual evaluation, no equipment was used.

(b) For instrumental evaluation, a Gardner Automatic Color Meter was used, standardized with the reference plate DR2, ($L = 24.8$, $a_L = +20.4$, and $b_L = +6.0$).

(2) Test Procedure

(a) In the visual evaluation, a comparative inspection of the samples was made by several researchers.

(b) In the instrumental evaluation, three readings were made for each Gardner value on a given area of each individual strawberry. The strawberry was rotated around a vertical axis,and at three random positions readings were taken. The color values of nine fruits were obtained, after which each fruit was placed, tested side up, on the egg crate divider, covered with saran film, irradiated and the same general area tested again 24 hours later.

B. Sound Fruit Determination

The net weight of a predetermined number of pint cups of strawberries was obtained, after which each cup was graded by a judge unfamiliar with the treatment administered to the fruit. Fruit exhibiting lesions was removed. For the purpose of this experiment, lesions include visible microbial growth, discolorations, and soft spots in the fruit. On completion of inspection of all the fruit tested within a treatment, the net weight of the sound fruit was determined, and the percentage of sound fruit remaining after a given storage period was calculated.

C. Texture Evaluation

(1) Equipment

A L.E.E.-Kramer Shear Press, model SP-12, with electronic recording attachment was used in this experiment. A 250-pound proving ring was attached and the shearing head consisting of the cell box, guide cover and blade element were standard models supplied with the press.

(2) Test Procedure

A 100 gram sample of capped strawberries was obtained by random selection from each pint container representing a specific treatment. The fruit was placed in the cell box and installed in the Shear Press. The shear force was determined under the following standardized conditions:

(a) Proving ring - 250 lbs.

(b) Selector - Low

(c) Range setting - 50

(d) Oil pressure - 20 lbs.

(e) Sample weight - 100 gms.

The machine was standardized to zero and one hundred on the recorder dial several times daily.

For evaluation of results, the peak readings from the chart were used. These peak readings were converted to pounds of force per gram of product. At a range setting of 50, fifty pounds of force is distributed over the one hundred point scale on the chart, so that each point represents 0.5 pounds force. Therefore, the peak reading times 0.5 pounds yields the total pounds of force to shear 100 gms. of sample.

D. Flavor Evaluation

(1) Sample Preparation

Before testing, the fruit was capped and washed. It was then passed three times through a strawberry slicer, to produce a homogeneous mixture of fruit chunks, and blended with one-tenth its weight of sucrose. The addition of sugar tends to mask differences in natural sweetness among samples, which might affect the judgment of the taster.

(2) Flavor Tests

(a) A standard two-tailed triangular test was conducted on the strawberries to differentiate between irradiated and non-irradiated fruit. In this test, the tasters were asked to identify the odd sample, and subsequently their preference. The panel consisted of fifteen untrained tasters.

(b) A Hedonic Scale Method of measuring food preference was used, when the number of treatments being evaluated was increased. In this test, the panel members were asked to rate each sample individually over a nine point scale ranging from 1 to 9, with 1 representing "dislike extremely" and 9 representing "like extremely."

The results were subjected to statistical analysis to determine differences in preference between treatments. An untrained panel of 15 members was used for this test.

(3) Taste Panel Procedure

The fruit to be evaluated by the panels was served in four ounce coded cups to the taster in the tasting booths. Red lights were installed in the booths to eliminate color as a variable, and all the fruit was served at ambient temperature. The tasters scored and identified their ballots, to be used during subsequent statistical evaluation.

E. Microbial Reduction

(1) Materials

(a) Difco Bacto Plate Count Agar was used in making total plate counts.

(b) Difco Bacto Potato Dextrose Agar was used in determining yeast and mold counts.

(c) Sterile .0025 Molar phosphate buffer, pH 7.0

(2) Method of Microbial Assay

(a) Strawberries were weighed into a sterile container, and sterile water was added at a ratio of 1 gm. fruit + 10 ml. water. The fruit was soaked in this solution for 30 minutes with intermittent shaking. Total plate counts and mold counts were made on this wash water.

F. Statistical Procedures

Analysis of variance was carried out using an F test as described by Dixon and Massey (8). When a significant difference of means was found between treatments, these means were compared using the Duncan's Multiple Range Test, described by LeClerg (15).

CHAPTER IV

RESULTS AND DISCUSSION

During the first year of these experiments, 1963, the work was primarily concerned with developing background information for more extensive research. This involved determining optimum dose levels in regard to microbial reduction, shelf life extension, color, flavor and textural changes.

Strawberries of the Robinson var. were obtained from the Michigan State University horticultural farm in East Lansing, Michigan. The fruit which was packed in polyethylene pouches was used for microbial counts, texture and flavor evaluation. The berries packed in the egg crate dividers were subjected to color evaluation using the Gardner Automatic Color Meter. Those samples undergoing color evaluation were irradiated with gamma rays at doses of 0, 100, 200, and 300 Krad, while the pouches received doses of 0, 150, 200, and 250 Krad. A summary of the results of the color evaluation is shown in Table 1 and results of microbial counts are shown in Table 2.

Statistical analysis of these data indicated that no significant color changes were caused by irradiation except to the b_L value. After 200 and 300 Krad of irradiation, the yellow component (b_L) of the color did not change, while it decreased after 0 and 100 Krad. Increasing (b_L) values denote increased yellowness. This change, however, was hardly perceptible upon visual observation.

TABLE 1.--Effect of irradiation on the Hunter Color Values of Michigan strawberries. (Each value is the average of 27 readings, 3 on the same side of each of 9 berries).

Dose (Krad)	Pre-irradiation			Post-irradiation		
	L	a_L	b_L	L	a_L	b_L
0	20.4	11.9	6.2	19.7	10.8	5.8
100	21.1	13.1	6.7	20.0	11.4	6.2
200	21.1	12.5	6.7	20.0	10.7	6.8
300	21.4	12.3	6.5	20.1	10.5	6.5

TABLE 2.--Percent reduction of total counts (TC) and mold plus yeast counts (MYC) of Michigan strawberries upon irradiation. (Each value is the average of two experiments).

Dose (Krad)	0	150	200	250
TC	0	89	96	95
MYC	0	87	84	80

Sensory evaluations indicated that a slight off-flavor and some texture damage resulted at doses of 200 Krad or above.

In a subsequent experiment, samples (ca 100 gms) of Robinson Strawberries were placed in 1.5 mil. polyethylene bags and sealed. The number of bags was equally divided with half receiving a dose of 200 Krad while the balance were used as controls. These samples were placed on storage at 35°F. At regular time intervals, the samples were checked visually for the appearance of microbial growth. When samples showed growth, they were removed from the test.

The initial appearance of mold as detected by visual observation on Michigan strawberries packed in polyethylene bags was retarded 4 to 8 days by 200 Krad of gamma irradiation (Figure 3). The subsequent mold appearance followed the same rapid rate in irradiated and control fruit. The gradual physical disintegration of the fruit in the bag, however, indicated that the appearance of mold alone can not be used as the sole criterion of keeping quality.

In order to test the feasibility of irradiation pasteurization of strawberries on a more practical basis, the following experiment was initiated.

<u>1964 Season</u>

Strawberries of the Robinson var. were purchased in Southeastern Michigan. A total of 312 pints were filled, overwrapped and packed into twelve pint berry flats. These flats were randomly divided into two lots, one of which was irradiated at 200 Krad, and the other held as a control. The irradiation was performed at ambient temperatures (80°-85°F) for 4 hours. The fruit was transported approximately 10 miles to the irradiation site and 66 miles following irradiation to be placed in controlled temperature storage at 44°F ± 1°F at the Food Science Laboratory in East Lansing. This experiment was repeated the following day with the exception that the fruit was not overwrapped.

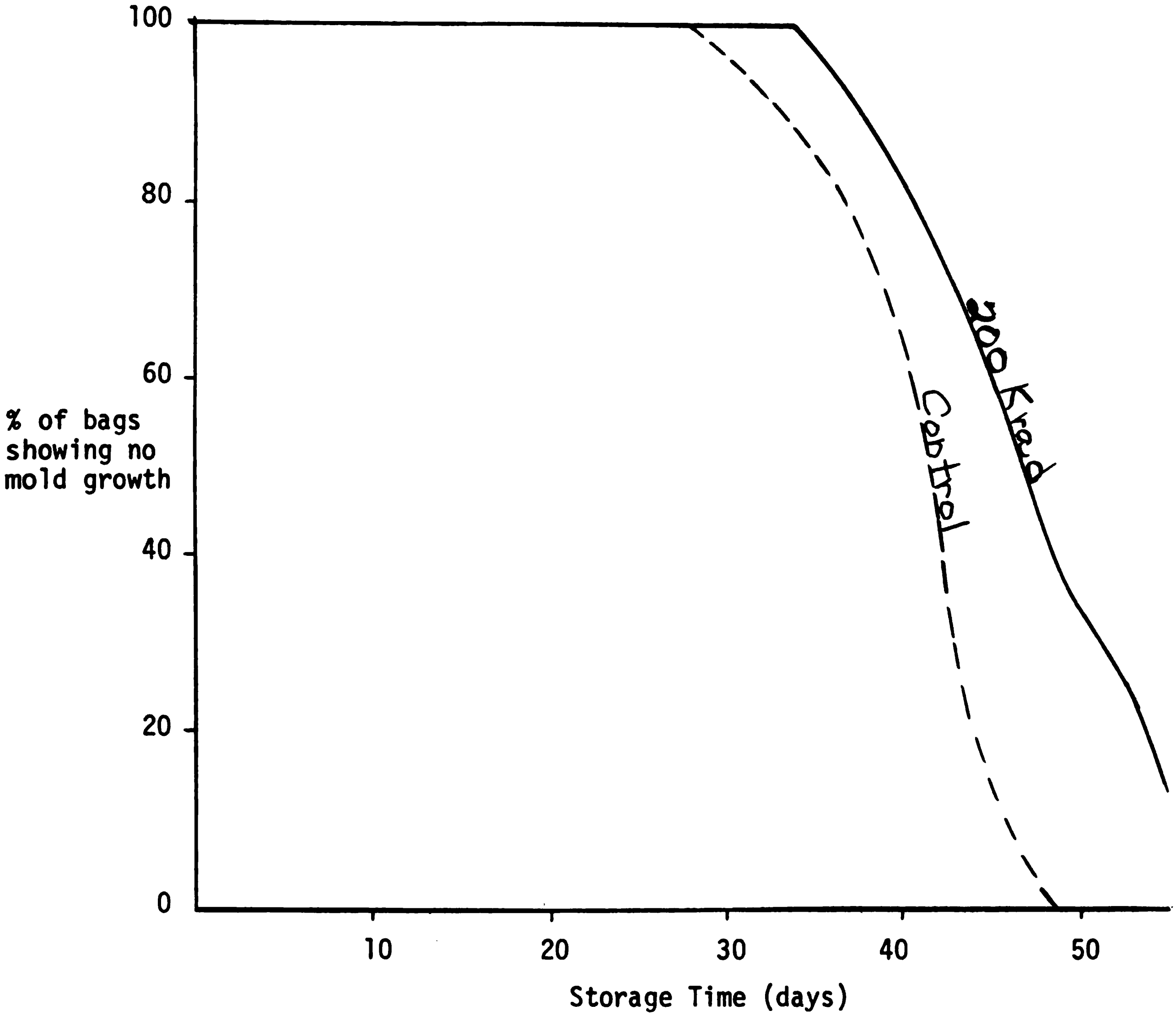

Fig. 3.--Effect of Gamma irradiation on the appearance of mold on Robinson strawberries stored at 34°F. (The figures are an average of 3 trials per treatment.)

At regular time intervals, sample lots composed of thirteen pints per treatment were withdrawn from storage for evaluation. The fruit was evaluated as to general appearance and color, keeping quality, flavor and textural changes.

Color and General Appearance

Visual observation indicated that exposure to 200 Krad of gamma radiation had little or no effect on the color of Robinson strawberries, or on their general appearance. Irrespective of irradiation, a very significant difference existed between overwrapped and non-overwrapped fruit. Overwrapped fruit retained their brilliant color and bright green calyx for over eleven days of storage at 44°F, while non-overwrapped fruit developed a dull sheen, a brown, wilted calyx, and a generally dessicated appearance.

Sound Fruit Determination

The results on lesion development indicated that irradiation will delay the formation of lesions in Robinson Strawberries which have been overwrapped by 4 to 6 days, and in non-overwrapped fruit by 2 to 4 days (Figures 4 and 5).

Texture Evaluation

The results obtained from the texture evaluation are summarized in Table 3. The results show a highly significant softening of the strawberry following irradiation and a subsequent refirming on storage. This refirming is also evident in the non-irradiated samples on storage. It is unlikely that the refirming was due to dessication because the

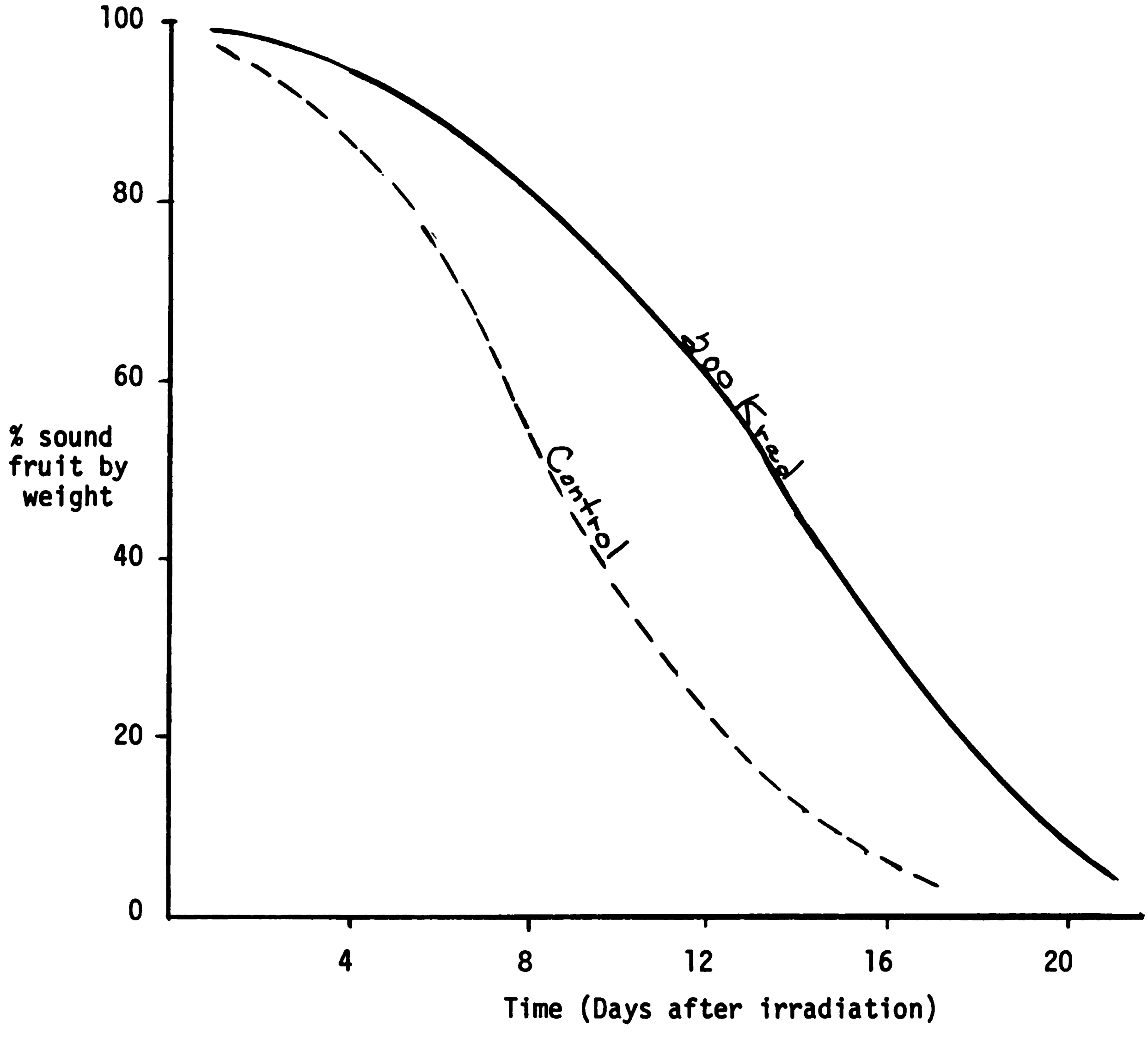

Fig. 4.--Effect of Gamma irradiation (200 Krad) and subsequent storage at 44°F on the keeping quality of over-wrapped Robinson strawberries. (Sample size 13 pints)

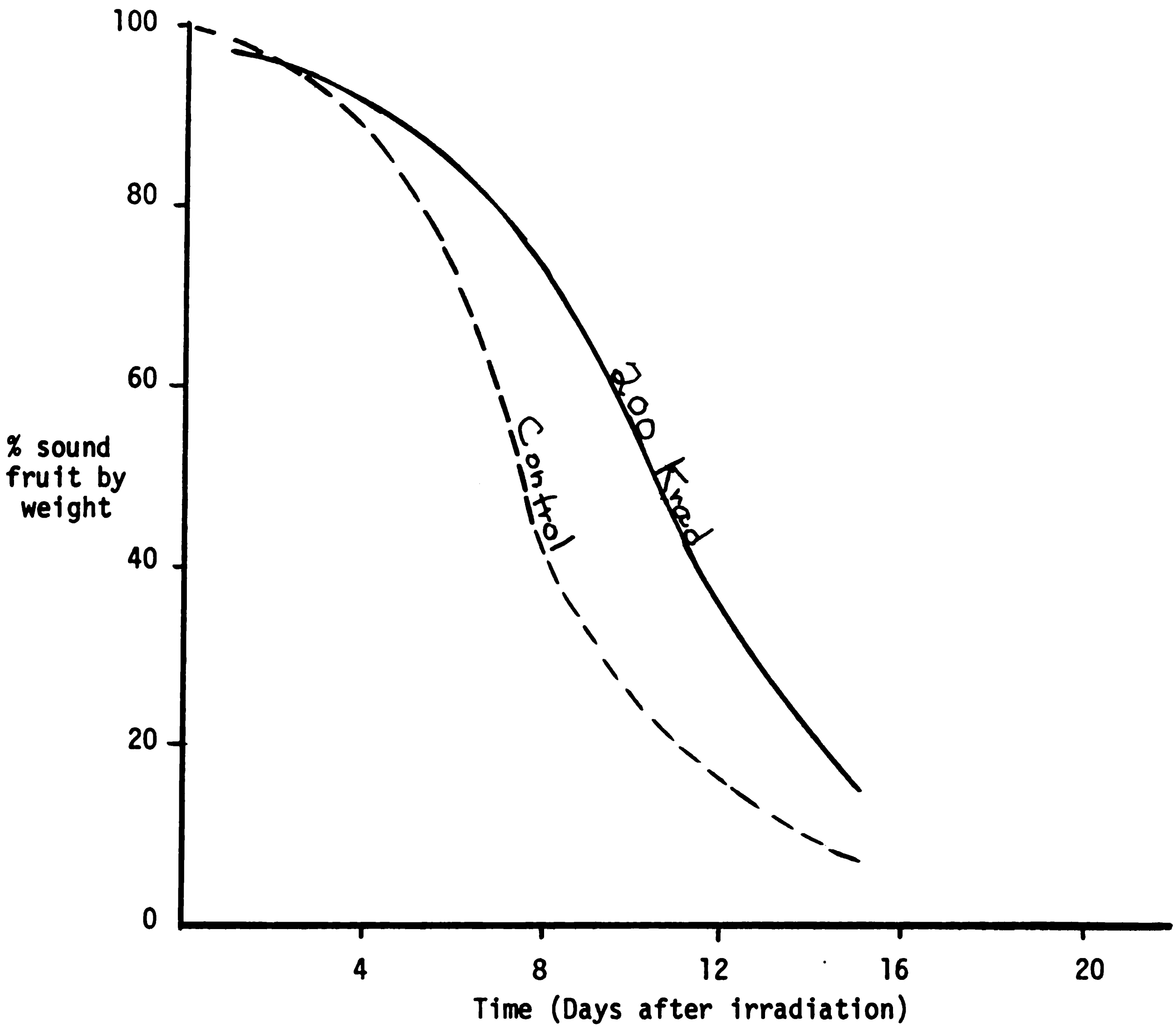

Fig. 5.--Effect of Gamma irradiation (200 Krad) and subsequent storage at 44°F on the keeping quality of non-overwrapped Robinson strawberries. (Sample size 13 pints)

relative humidity around the berries was close to 100%, at least in the overwrapped packages.

TABLE 3.--Effect of gamma irradiation (200 Krad) and subsequent storage at 44°F on the texture of Robinson Strawberries. (Each shear press value is the average of 12-13 tests, expressed as pounds of force per gram of product.)

	Overwrapped			Non-overwrapped		
Storage (days)	Control	Irradiated	Difference	Control	Irradiated	Difference
1	.229	.182	.047xx	.241	.179	.062xx
3	.266	.215	.051xx	.259	.189	.070xx
5	.278	.228	.050xx	.299	.221	.078xx
7	.289	.248	.041xx	.296	.233	.063xx
9	.297	.228	.069xx	.303	.238	.065xx
11	.288	.240	.048xx	.301	.263	.038x
13	----	.251	----	----	.270	----

xx 1% level of significance

x 5% level of significance

Flavor Evaluation

A two-tailed triangular taste test was used in the flavor evaluation of the Robinson strawberry, and the results are presented in Table 4. In using this test, only the preference of those correctly identifying the samples can be used as a valid indication of preference.

TABLE 4.--Effect of 200 Krad gamma irradiation, packaging and subsequent storage at 44°F on the flavor of Robinson strawberries

Package and Storage Time after Irradiation (days)	Number of Tasters	Correct Identifications	Prefer Irradiated
Overwrap			
1	28	9	5
3	30	18^{xx}	13^{xx}
8	15	12^{xxx}	9^{xxx}
Non-overwrap			
1	30	14	9
3	30	17^{xx}	8
7	15	2	0

^{xx} 1.0% level of significance

^{xxx} 0.1% level of significance

Results of taste test on overwrapped fruit indicates a significant preference for irradiated strawberries. Such preference was not evident in the non-overwrapped fruit. No significant difference in preference was found between overwrapped and non-overwrapped irradiated fruit. This might indicate an off-flavor development in the overwrapped fruit which was stopped or delayed by irradiation.

1965 Season

In order to confirm data obtained during the 1964 strawberry season, and to expand the research, work was continued in 1965 on the irradiation pasteurization of Robinson strawberries. The fruit was

purchased from the same location in southeast Michigan and selected as in the previous year.

A total of 480 pint containers were filled, of which 240 were overwrapped and 240 non-overwrapped with polyethylene bags. The two lots were further subdivided so that 120 pints of overwrapped and 120 pints of non-overwrapped could be held at ambient temperatures for 24 hours prior to irradiation, while samples of comparable size were irradiated immediately. For every sample irradiated, a similar sample was kept as a control. Half of the samples from each lot were irradiated at the Phoenix Radiation Facility at a dose rate of 21.5 Krads. per hr., while the balance was irradiated at a dose rate of 31.25 Krads per hr. at the Phoenix Memorial Laboratory. Thus, eight lots of 60 pints were obtained for the experiment. A total dose of 200 Krad was administered to the irradiated samples.

Code	Treatment			
INC --	Immediate	Irradiation,	Non-overwrap,	Control
INI --	"	"	"	, Irradiated
IOC --	"	"	Overwrap,	Control
IOI --	"	"	"	, Irradiated
DNC --	Delayed	Irradiation,	Non-overwrap,	Control
DNI --	"	"	"	, Irradiated
NOC --	"	"	Overwrap,	Control
DOI --	"	"	"	, Irradiated

Following irradiation, the samples were immediately placed on storage at 38°F $\pm$ 1°. A total time of 14 hours elapsed between picking and placing in cold storage when the fruit was irradiated within 2 hours of harvest, but the time increased to 36 hours in the delayed irradiation.

The sequence of presentation of samples of the various lots to graders was randomized. The same methods of keeping quality and texture evaluation described previously were again employed, and only the initial effect on flavor was evaluated using a Hedonic Scale test.

Sound Fruit Determination

The effects of irradiation on the delay of lesion formation in Robinson strawberries is summarized in Table 5.

When the results shown in Table 5 were graphed and smooth curves were drawn between points, the following observations were made: (1) The sooner the fruit was irradiated following harvest the more effective the irradiation was in extending the shelf life. (2) In contrast to results obtained in 1964, overwrapping did not improve the keeping quality of the fruit irradiated without delay. In delayed irradiation, overwrapping appeared to offer some protection. Perhaps the growing conditions affect the response of the fruit to irradiation. The 1965 season was cooler than the 1964 season.

Texture

The texture was evaluated in a manner similar to that described previously, and the results are shown in Table 6.

TABLE 5.--The effect of 200 Krad gamma irradiation, overwrap, 24 hours delayed irradiation, and storage at 38°F on lesion formation of Michigan-grown Robinson strawberries (sample size 12 pints).

	Days of Storage (% sound fruit by weight)					
Treatment	4	9	12	15	19	23
Immediate Irradiation						
Overwrapped						
Control	99.9	77.7	63.5	44.3	43.6	42.5
200 Krad	95.4	79.8	67.3	66.3	49.7	47.5
Non-overwrapped						
Control	96.0	83.2	64.7	55.3	51.1	38.9
200 Krad	98.2	88.8	75.2	70.7	55.9	42.6
24 hrs. Delayed Irradiation						
Overwrapped						
Control	74.5	68.0	49.2	49.4	34.0	22.6
200 Krad	92.1	81.2	57.8	61.9	43.6	43.9
Non-overwrapped						
Control	92.7	66.7	52.4	44.3	32.4	33.1
200 Krad	87.9	70.5	51.2	54.1	40.6	31.6

TABLE 6.--Effect of 200 Krad gamma irradiation, time of irradiation, packaging and subsequent storage at 38°F on the texture of Robinson strawberries. (Each Shear Press Value is the average of 12 tests expressed as pounds of force per gram of product.)

	Immediate Irradiation				24 hrs. Irradiation delay			
Storage Days	Overwrap		Non-overwrap		Overwrap		Non-overwrap	
	Cont.	Irrad.	Cont.	Irrad.	Cont.	Irrad.	Cont.	Irrad.
4	.029	.026	.030	.021	.028	.023	.034	.029
9	.030	.025	.032	.025	.031	.025	.032	.031
12	.035	.026	.034	.027	.029	.024	.034	.029
15	.032	.027	.037	.025	.025	.024	.029	.027
19	.032	.027	.038	.029	.032	.024	.038	.030
23	.031	.026	.035	.028	.029	.021	.032	.025

An F test indicated a significant difference between means of the various treatments. A Duncan Multiple Range Test at the 5% level was used to differentiate between treatments with the following results.

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The data obtained indicate that irradiation results in a significantly softer fruit (Table 6). Maximum softening of the fruit occurs if it is overwrapped and held 24 hours prior to irradiation, while non-overwrapping with immediate cooling of non-irradiated fruit results in a minimum of softening.

Flavor

The various treatments were evaluated for flavor preference using a Hedonic Scale System with a value of 9 representing "extreme like" and 1 being "extreme dislike." Results of this evaluation are summarized in Table 7.

TABLE 7.--Effect of gamma irradiation, time of irradiation, and packaging on the flavor of Robinson strawberries. (Numbers are the Hedonic Value assigned each treatment and are the average of 30 tastings. Flavor analysis was conducted 4 days following harvest.)

Treatment	Hedonic Value
Immediate Irradiation	
Overwrap	
Control	4.5
Irradiated	5.9
Non-overwrap	
Control	4.8
Irradiated	5.4
24 hrs. Delayed Irradiation	
Overwrap	
Control	4.9
Irradiated	5.7
Non-overwrap	
Control	5.7
Irradiated	4.8

The only significant difference obtained was between the immediate irradiated (5.9) and non-irradiated (4.5) samples which were overwrapped. This is in agreement with the results of the 1964 experiment and might indicate that an off-flavor develops in overwrapped non-irradiated fruit which can be stopped by irradiation. In irradiation, however, no beneficial flavor effect can be derived by overwrapping the fruit.

CHAPTER V

SUMMARY

The ability to extend the shelf life of Michigan-grown strawberries of the Robinson var. by the use of ionizing radiation was investigated over a 3-year period (1963, 1964, 1965). The fruit was harvested, graded, and packed in a conventional manner. Some of the fruit baskets were overwrapped by covering with polyethylene bags.

The fruit was irradiated with doses of 200 Krad of gamma radiation from Cobalt-60. Doses as high as 300 Krad were used in the first year, but those over 200 Krad were eliminated in later experiments because of adverse sensory effects. Following irradiation, samples were placed on storage at controlled temperatures (34 to 44°F).

The shelf life extension was studied by determining the percent sound fruit of any given treatment, remaining after any given period of storage. The results showed an extension of 3 to 5 days in the shelf life of irradiated fruit. The benefits of overwrapping to extend the shelf life of irradiated fruit were inconsistent from year to year and, therefore, of doubtful value. Irradiation appeared to help fruit which was held at ambient temperature 24 hours prior to irradiation, but the extension of shelf life did not appear to be any greater than that which might be obtained with just good handling procedures and immediate cooling.

No adverse effects on flavor were found due to irradiation at 200 Krad.

Gamma irradiation of strawberries at 200 Krad was found to result in a significantly softer product, but considerable refirming was observed on post-irradiation cold storage.

No adverse effect on color was noted up to the dose of 300 Krad.

In conclusion, it appears that Michigan-grown strawberries, var. Robinson, are amenable to pasteurization with gamma irradiation.

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