5-1959

Effects of Gamma-Radiation on the Quality and Shelf-Life of Certain Fruits

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EFFECTS OF GAMMA-RADIATION ON THE QUALITY AND SHELF-LIFE OF CERTAIN FRUITS

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Food and Nutrition

UTAH STATE UNIVERSITY
Logan, Utah

1959

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to my thesis director, Dr. D. K. Salunke, for his untiring efforts and valuable advice given on compiling this thesis. I am also indebted to my major professor, Dr. Ethelwyn B. Wilcox, for her helpful advice and timely suggestions throughout this research. Thanks go, too, to Mrs. Margret Merkley, to the people who served on the taste panel, and to all others who had a part in making this study possible.

I give a special thanks to my husband Jim for his understanding and encouragement.

Diane Weber Box

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INTRODUCTION

The story of the development of food preservation is as old as the story of man. Cavemen and nomadic tribesmen gave little heed to food preservation. They threw away the food left when their hunger was satisfied and searched for more when famished. However, from the time men began to settle down and have permanent homes, the need for some means of retarding food spoilage has been evident.

Salt, at an early age, was employed as a food preservative. Drying and smoking, as methods of food preservation, were utilized before the Christian era and are still in use in many parts of the world.

The use of low temperatures as a method of food preservation has been applied since the time of Nero when slaves brought snow from nearby mountains for this purpose. By the 17th century, attempts to preserve food by low temperatures were made. The creation of an ice making machine by William Cullen in 1775 boosted this method of food preservation. The first successful mechanical refrigeration unit was made in the late 1800's; however, no commercial use was made of this discovery until the 1930's. Freezing, an outgrowth of the process of preserving food with low temperatures, has recently been developed and expanded.

In 1809, Nicholas Appert invented the process of preserving food which is today known as canning. His process consisted of placing food in tightly corked glass jars which were then placed in a boiling water bath. It was not until some 50 years later that Louis Pasteur brought about understanding of this process by his bacteriological discoveries.

Appert's process has been improved and expanded into today's modern canning industry.

These methods mentioned, while great and valuable assets to mankind, have inherent features which still leave much to be desired in the way of an ideal process of food preservation. Salting and smoking are practical only for meats and fish, drying is time consuming, freezing requires equipment for storage, and canning utilizes heavy containers. In addition to these characteristics, all of these methods mentioned alter the food so that it is not in the fresh state.

In looking for a new and desirable method of preserving food, one might consider the drawbacks of those methods previously mentioned. With these factors in mind, development of a process which could be used on a variety of foods, is time and energy saving, and which requires no special equipment for storage would be advantageous. It is also desirable that such method keep the food in the fresh state.

In 1953 the availability of nuclear energy for peaceful purposes was announced by the President of the United States. Since that time the use of radioactive material in agriculture, particularly in food preservation, has been under study.

It is plausible that through this investigative work a new method of food preservation, which meets many of the desired characteristics of an ideal food preservation process, can be developed. This method of food preservation is designated cold sterilization. This is because the high frequency rays are capable of killing microorganisms which contaminate the food. Such a process may take place at cool temperatures without contributing adverse changes in the food.

The studies set forth in this thesis concern the effects of radiation dose on the quality and shelf-life of 5 apricot varieties and

6 sweet cherry varieties. Also included are the effects of radiation dose on the quality, shelf-life, and chemical changes in 2 red tart cherry varieties and the effects of radiation rate and dose on the quality, shelf-life, and color changes in 5 strawberry varieties. It is hoped that the process of radiation may eventually prove feasible for use as an additional means of food preservation. This will depend not only on the effects of the process on the products but also on the availability and economics of the radiation source.

REVIEW OF LITERATURE

According to Kertesz (9), "there is some hope that the importance of peaceful uses of atomic energy may overshadow its application for destruction. A comparatively new and little explored idea is to use radiation for the processing and preservation of food." It has been observed that various high energy radiations can alter chemical compounds and kill microorganisms like bacteria and molds, but it is only during the past decade that such information has been made use of in the field of food processing and preservation. Relatively small gross chemical changes occur in products during irradiation bringing about profound changes in acceptability of the products (20). Ionizing radiations used in sterilizing foods may cause changes in flavor, color, texture, and/or odor (17). Certain enzyme systems are not inactivated even with sterilizing doses of radiation; therefore, breakdown of the fats, proteins, and other constituents may occur to such an extent that the product would be unacceptable (20).

Considering the scope of this thesis, the radiation effects on quality and shelf-life of foods can be divided into five categories, namely: flavor, texture, color, odor, and shelf-life.

Flavor

The undesirable flavor changes in fruits are possibly due to the destruction of the aromas and bouquets which are characteristic of these products. Proteins probably are the most important source of radiation induced off-flavors. Mercaptans, sulfides, disulfides, amines, and many of the carbonyl compounds have their origin in proteins. Sulfur containing amino acids appear to be the most radiosensitive of the amino acids. Other objectionable flavors may also originate in the micro constituents of foods, such as vitamins and pigments. These are highly susceptible to and easily degraded by ionizing radiations (22).

It is also thought that radiation sterilization might bring about a more rapid deterioration of food substances by rendering proteins more susceptible to hydrolysis by proteolytic enzymes (12). This would be due to the fact that whenever proteolytic enzymes are not inactivated and their reaction rates are accelerated a more rapid breakdown of the food may result. This might cause flavor changes.

It is possible to control undesirable off-flavor producing changes to some degree (4). Color, flavor, texture, and odor of products tested remain unchanged when they were irradiated in the presence of a free radical acceptor. To prevent reactions of solutes with free radicals produced by ionizing radiations, certain compounds that will compete for the free radicals can be mixed with the solute, thus affording protection against undesirable side effects (17).

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 oxygen for the normal respiration process and at the same time removing carbon dioxide and other gases given out as a result of respiration and of radiation (19).

Texture

Texture changes in fruit during maturation and storage have been associated with the conversion of protopectin to soluble pectins and a reduction of total pectin substances (13). As the pectin materials are converted to less complex units, a decrease in firmness occurs.

Because of the importance of pectins and cellulose to the cellular structure of the fruit, it is important to determine the effects of irradiation on these constituents. It has been found that textural changes in fruits are directly attributable to radiation degradation of carbohydrates (22). It was also observed that some of the fragments of these degradations are reductone-like products which form brown pigments resulting in discoloration of the food.

McArdle and Nehemias (13) found an indication of a relationship between radiation induced softening and the changes which occur in pectic substances. In their study, gamma radiation caused a decrease in protopectin and total pectic substances and an increase in soluble pectin and pectates. These changes were accompanied by depolymerization of the pectin, pectate, and protopectin molecules as indicated by a decrease in relative viscosity of the three fractions.

Color

Red color development has been found to be inhibited by exposure to ionizing radiations. This is thought to be due to a reduction of lycopene content following irradiation (3). It has also been observed that the red anthocyanin pigments of the fruits such as strawberries and cherries are easily degraded by sterilizing doses of radiation (7).

Carotenoids appear to be among the more stable plant pigments. Beta carotene content of maturing tomatoes was unaffected by irradiation and increased with fruit maturity as was found for normal fruit (22). However, gamma carotene was affected by the irradiation, its development decreasing with high energy electron treatment (3).

Odor

Odor molecules are altered as the dose increases (21). This may lead to the development of undesirable off-odors as found by Pratt and Ecklund (16).

Shelf-life

Proctor et al. (17) state that sufficient doses of ionizing radiations can destroy all types of microorganisms. The amount of radiation required depends on the type and number of spoilage organisms present as well as the type of food material being handled.

Surface sterilization by radiation of food products susceptible to spoilage through molds will make the foods keep longer than without radiation (9). This can be accomplished with only a slight rise in temperature--not more than 50° F. (10).

Kertesz (9) believes that in most instances doses around and above 1×10^6 rads are required for sterilization and preservation. Variability from product to product has been found. Also, the same food may be capable of different types of reactions depending on the circumstances attendant to irradiation.

Radiation lethality is also influenced by factors such as product composition, spore load, pH, moisture, salt content, sugar content, and radiation temperature. Therefore, the exact doses for each particular food must wait upon definite research involving large inoculated packs (22).

It appears that the treatment of foods with radiation will express itself first in the form of combination treatments, complementing rather than replacing present conventional processes such as canning, refrigeration, and dehydration (4).

GENERAL PROCEDURE

Four fruits were used in this study. These included apricots (Prunus armeniaca L., varieties Perfection, Hungarian, Wilson Delicious, Stella, and Chinese), sweet cherries (Prunus avium L., varieties Bing, Napoleon, Windsor, Lambert, Schmidt, and Black Tartarian), red tart cherries (Prunus cerasus L., varieties Early Richmond and Montmorency), and strawberries (Fragaria spp. L., varieties Kasuga, Lindalicious, Marshall, Robinson, and Sparkle).

The experimental procedure was divided into the following categories: selection and preparation of food for irradiation, radiation process, taste quality evaluation, chemical and microbiological changes subsequent to irradiation.

Selection

Food selected was of prime quality, of the same variety, and as far as possible, of uniform maturity. It was obtained from either the farms of the Utah State Experiment Station or from the Pacific Fruit and Produce Company, Logan, Utah.

Preparation

In preparation for irradiation the fruits and vegetables were packaged. Prior to packinging some foods received a fungistatic chemical treatment (2), the purpose of which was to inhibit mold growth. The foods were dipped in the 1 percent aqueous solution of sorbic acid and packaged subsequent to drying; as for the untreated, the food was placed in brown Kraft paper bags. If the foods were of such nature that they might be easily bruised or crushed, carboard dividers were used to divide the bag into 3 or 4 compartments along its length. Also, cushioning material was put in the bottom of some bags for protection. The bags were placed in number 10 tin cans, and the cans were then perforated at the bottom. This was done to facilitate normal respiration and to allow for use of air during radiation. The tops of the bags were then folded, stapled, and the cans sealed with a sealer.

After packaging, the cans containing the food were stored at 40° F. until transportation by refrigerated truck, within 6 to 12 hours, to the Material Testing Reactor Station near Arco, Idaho.

Radiation technique

The source of the gamma radiation facility was the Material Testing Reactor Station. The facility used as its fuel source spent fuel rods from the Material Testing Reactor. These spent rods were discharged into a water-filled canal 18 feet deep. The rods, 6 x 6 x 24 inches in size, were moved into frames. In order to stop the gamma rays which are emitted from these spent fuel rods, these frames remained under 18 feet of water.

In the canal in which the frames of spent rods were placed, there was a 20-foot vertical aluminum pipe. This pipe was weighted with lead and sealed at the bottom. It is referred to as the U.I.A.[1] column. For irradiation foods were lowered into this column. A container known as an aeration chamber (figures 1 and 2) was used for lowering the food in the U.I.A. column. This chamber was constructed from a 2-foot section of 7-inch diameter aluminum irrigation pipe. One end was welded shut with an aluminum bottom and weighted with 35 pounds of lead. The top

[1]Named after the University of Idaho at Aberdeen.

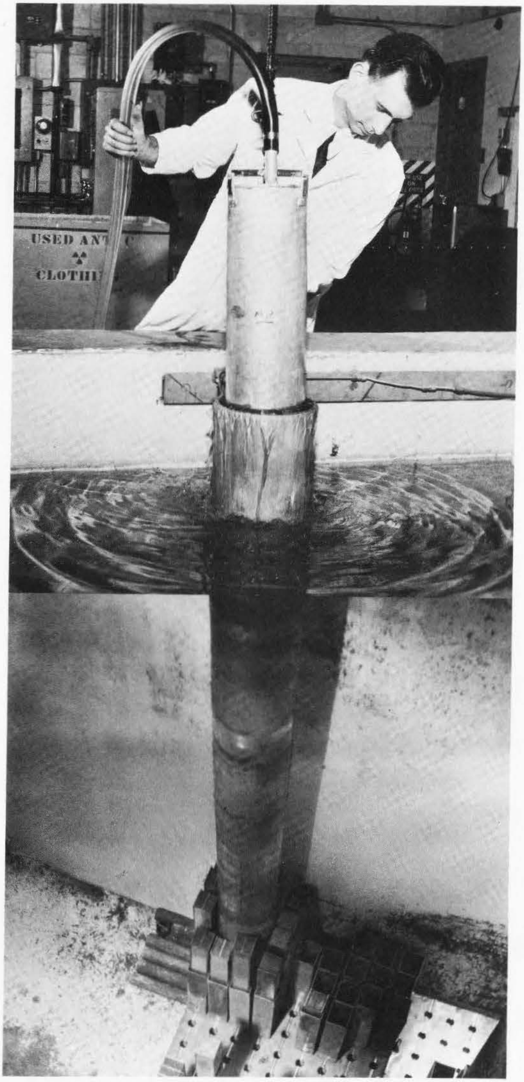

Figure 1. The aeration chamber used to hold the can containing fruits during the process of irradiation

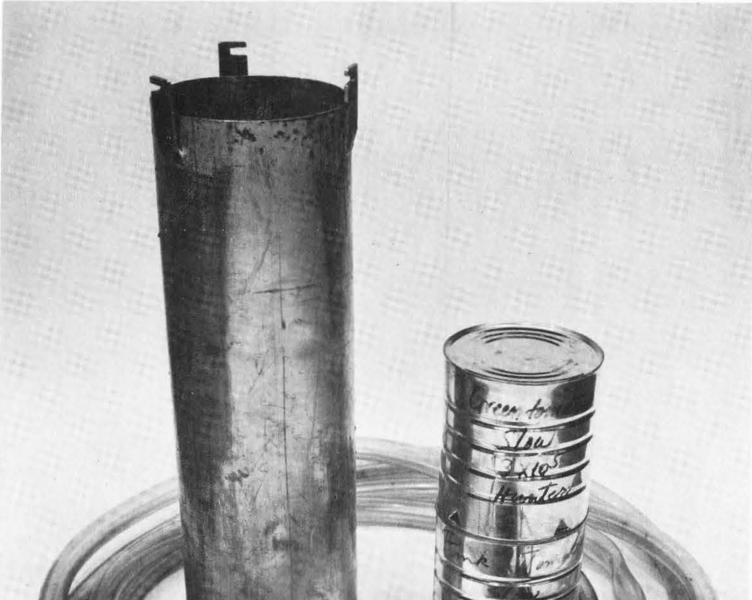

Figure 2. Parts of aeration chamber

consisted of an aluminum lid made tight by a rubber gasket. Into this lid was fastened by means of a gasket a 6-inch piece of 3/4-inch iron pipe. To this piece of pipe was clamped a 25-foot length of 1-inch Tygon tubing. Threaded through this 1-inch tubing was a 25-foot length of 1/2-inch outer diameter Tygon tubing. When 2 punctured No. 10 cans were placed in the aeration chamber, air could be forced at 10 pounds pressure per square inch into the cans. To accomplish this, within the chamber the air or gas was divided with a glass Y and taken by auxiliary tubing to each punctured can. The exhaust air escaped from the chamber through the space between the small tube and the wall of the large tube.

For irradiation, 2 No. 10 cans of food were placed in the aeration chamber. This chamber was then lowered to the bottom of the water column. It was allowed to remain for a calculated length of time.

Dosimeter measurements were used to calculate the dose (amount of radiation) and rate (length of exposure to gamma rays). Details of this procedure are given by Cotton and Siu (5). After the dose and rate were determined, they were controlled by the distance between the cans and the fuel elements and the length of time the cans remained exposed to the gamma rays. To insure equal dosage for both cans in the aeration chamber, at the end of half of the allotted radiation time the chamber was brought to the surface and the two cans rearranged, putting the top can on bottom and the bottom can on top.

After irradiation, each can of food was inspected by health officials for the emission of radiation. In any case of suspected contamination the product was kept at the center for further study. None of the fruits used in this study were thus retained.

The food was then transported from the reactors to Logan by refrigerated truck (40° F.). Upon arrival at Logan, it was stored at 40° or 50° F.

Quality evaluation

Immediately after storage and at intervals thereafter, the food was appraised for taste quality by a panel of 10 trained judges, persons familiar with the flavor properties of the products to be judged. Judges were familiarized with the test procedures by oral explanation. As suggested by Peryam and Girardot (14), instructions were also printed on the scoring sheet. For scoring a Hedonic scale form suggested by Peryam and Pilgrim (15) was employed (figure 3). On this scale 9 terms were used to describe degrees of acceptance. These range from like extremely (score 9) to dislike extremely (score 1). The judges were asked to report their immediate response by tasting of the sample, spitting it out into a waste receptacle, and immediately circling the term on the scale which most nearly described their response to the sample. Scoring was done individually, without knowledge of the results from the other panel members. No conversation, social activity, or other interruption was made in the test room and no psychological pressure was exerted on judges.

Judging was done in a large darkened room which was relatively free from noise. A large table in the room was divided into individual cubicles by cardboard dividers. Each cubicle was furnished with red illumination and waste receptacles. The purpose of the colored illumination was to present each sample as nearly alike visually as possible. Water and crackers were provided for rinsing the mouth between samples.

Samples were prepared raw and/or cooked, depending on the product. All preparation was done in a uniform manner so that like products would

Name ______________________ Date ____________

Score	Sample ____	Sample ____	Sample ____	Sample ____
9	_Like Extremely	_Like Extremely	_Like Extremely	_Like Extremely
8	_Like Very Much	_Like Very Much	_Like Very Much	_Like Very Much
7	_Like Moderately	_Like Moderately	_Like Moderately	_Like Moderately
6	_Like Slightly	_Like Slightly	_Like Slightly	_Like Slightly
5	_Neither Like Nor Dislike	_Neither Like Nor Dislike	_Neither Like Nor Dislike	_Neither Like Nor Dislike
4	_Dislike Slightly	_Dislike Slightly	_Dislike Slightly	_Dislike Slightly
3	_Dislike Moderately	_Dislike Moderately	_Dislike Moderately	_Dislike Moderately
2	_Dislike Very Much	_Dislike Very Much	_Dislike Very Much	_Dislike Very Much
1	_Dislike Extremely	_Dislike Extremely	_Dislike Extremely	_Dislike Extremely
	Comments	Comments	Comments	Comments

Directions: Completely encircle the category which best describes your reaction to the sample written above the column. Then under Comments, give your reasons for rating the sample as you did. did. (i.e. Flavor too strong, odor not pleasant, too much seasoning, etc.)

Figure 3. Hedonic Scale to estimate the acceptibility of foods by sensory evaluation

have only one variable. Each product was presented in a coded standard waxed cup. Two separate codes were used with each set of samples, five judges receiving each code.

After judging, the flavor score of each sample was obtained by adding the scores earned by that sample and dividing by the number of judges. The like responses indicate the percentage of judges rating the sample 5 (neither like nor dislike) or above.

Comparison of flavor scores for foods at the beginning of the storage period and after varying periods of storage provided one basis for judging the decrease in taste quality of the food after storage. Also, comparison of the non-irradiated foods against the same food which received varying doses of radiation was made. This provided a basis for judging the extent to which radiation improved the storage quality of the food.

Chemical changes and other observations

Color.--Color studies were made using three methods:

1. A Junior Coleman Spectrophotometer was used to measure the light transmittance of cherry juice. The readings taken were at galvanometer settings of 530 and 550 mm. The reading indicated density of the juice.
2. The Hunter Color and Color Difference meter (1) (figure 4) was used for determining (a) Rd--luminous reflectance, (b) a--redness, (c) b or yellowness to grayness, and (d) a/b--relationship of redness to yellowness of strawberry color. To obtain these measures a standard "red" plate with readings as follows was employed: Rd = 7.3, a = + 61.5, and b = + 20.6.

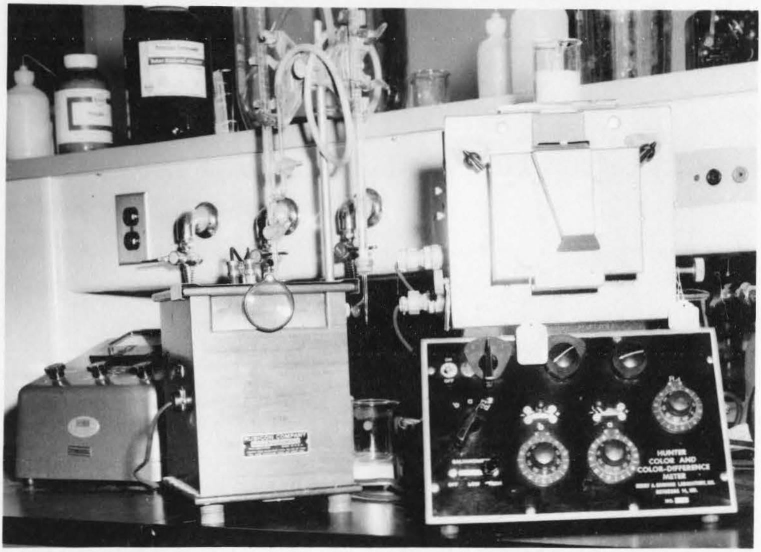

Figure 4. The Hunter color and color difference meter with the galvanometer attachment; to the right of the galvanometer is Beckman's pH meter.

3. Other color evaluation was conducted visually. A scoring scale with five levels, from excellent natural red color, X, to extreme fading or color change, XXXXX, was employed. Foods were scored after observation.

pH.--Acidity was measured by using a Beckman pH meter.

Mold growth.--Estimation of mold growth was done by visual means according to the following index: X--no mold growth, XX--slight growth, XXX--moderate growth, XXXX--very much growth, XXXXX--profuse mold growth.

Softness.--Softness was judged subjectively by comparing like foods which received different levels of radiation.

Statistical analyses were conducted whenever possible, according to Duncan (6), with adjustments made as suggested by Dr. R. L. Hurst, Head, Department of Statistics, Utah State University. The least significant range (L.S.R.) was obtained by multiplying the standard error of means by the studentized range in Duncan's multiple range test. Since there is a small difference between the largest and smallest value, only the largest and smallest are included in this thesis. The smallest value corresponds to the least significant difference (L.S.D.).

Studies were divided into 4 experiments:

Experiment 1: Effects of radiation dose on the quality and shelf-life of 5 apricot varieties.

Experiment 2: Effects of radiation dose on the quality and shelf-life of 6 sweet cherry varieties.

Experiment 3: Effects of radiation dose on the quality, shelf-life, and chemical changes in 2 red tart cherry varieties.

Experiment 4: Effects of radiation rate and radiation dose on quality, shelf-life, and color changes in 5 strawberry varieties.

RESULTS

Experiment 1: Effects of radiation dose on the quality and shelf-life of 5 apricot varieties

Five varieties of apricots, Perfection, Hungarian, Wilson Delicious, Stella, and Chinese (Large Early Montgamet), were irradiated to 0, 1, 3, and 5 x 10^5 rads. After 2 days of storage they were evaluated by the panel of judges. Taste scores are presented in table 1. It will be noted that there was no consistent decline in scores of most of the varieties as the radiation increased. The possible exceptions were Hungarian and Stella varieties. All varieties seemed to be slightly softer as the radiation dosage increased. Perfection, Hungarian, and Wilson Delicious varieties developed brown spots on the skin when treated with the higher dosage of radiation. The scores indicated that all varieties at all doses were 7.0 (like moderately) to 8.0 (like very much) by the judges.

The apricots were then judged after 8 days' storage at 50° F. The results are presented in figure 5 and table 2. The non-irradiated controls of most of the varieties, except Chinese, had not changed significantly during the week. The Chinese decreased 1 classification. As the radiation dose increased the fruits exhibited brown spots, bruising, and softening. However, the judges still liked the taste "moderately" to "very much." The Chinese variety had developed mold at the 0 and 1 x 10^5 rads levels but no mold was developed at the 3 and 5 x 10^5 rads levels.

Table 1. Effect of radiation dose on the preference of apricot varieties, evaluated 2 days after irradiation

Dose x 10^5 rads	Perfection		Hungarian		Wilson Delicious		Stella		Chinese	
	Prefer-ence score	Like responses percent	Prefer-ence score	Like responses percent	Prefer-ence score	Like responses percent	Prefer-ence score	Like responses percent	Prefer-ence score	Like responses percent
0	7.6	100	7.6	100	7.5	100	7.2	100	8.2	100
1	7.6	100	7.2	90	7.3	90	7.5	90	7.9	100
3	7.1	90	7.5	90	7.6	100	6.6	90	7.1	90
5	7.7	100	6.7	90	7.2	90	6.8	90	7.5	100
L.S.R.:[a] 0.05	0.9 - 0.8		1.1 - 1.0		0.9 - 0.8		0.9		0.8 - 0.7	

[a]The L.S.R. (least significant range) is obtained by multiplying the standard error of means by the studentized range in Duncan's Multiple Range test. Since there is a small difference between the largest and smallest value, only the largest and smallest values are presented in this thesis. The smallest value corresponds to the often misused L.S.D. (least significant difference). This interpretation is suggested by Dr. R. L. Hurst, Head, Department of Applied Statistics, Utah State University, Logan.

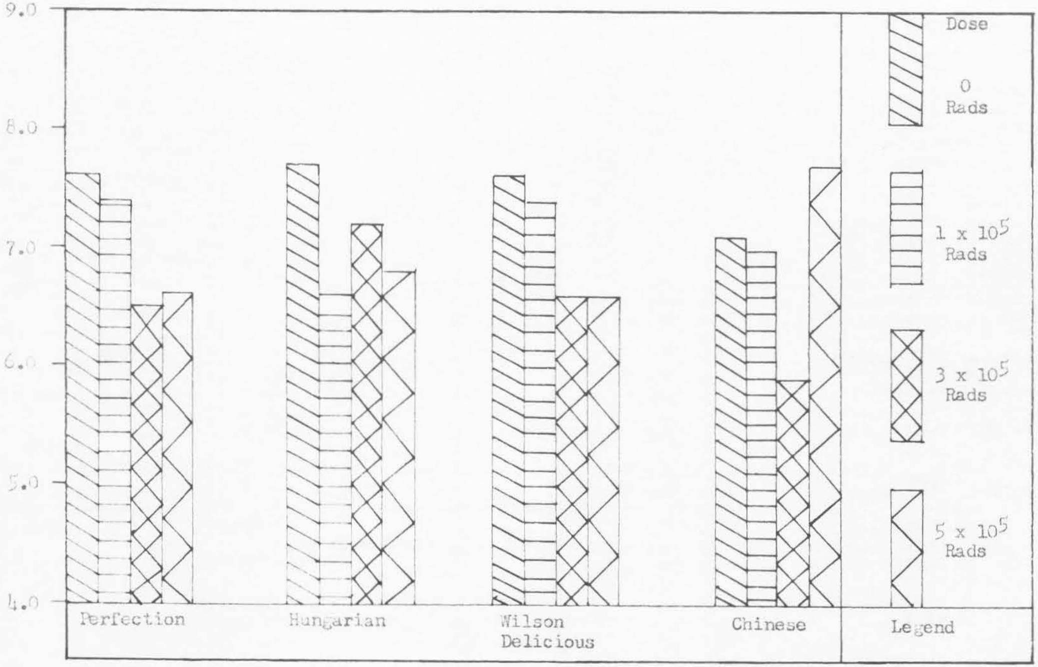

Figure 5. Effect of radiation dose on the preference of apricot varieties, evaluated 8 days after irradiation

Table 2. Effect of radiation dose on the preference of apricot varieties, evaluated 8 days after irradiation

Dose x 10^5 rads	Perfection		Hungarian		Wilson Delicious		Chinese	
	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent
0	7.6	90	7.7	100	7.6	100	7.1	90
1	7.4	100	6.6	90	7.4	100	7.0	90
3	6.5	90	7.2	100	6.6	90	5.9	80
5	6.6	100	6.8	90	6.6	90	7.7	100
L.S.R.: 0.05	1.0 - 0.9		0.8		0.8		1.3 - 1.2	

Experiment 2: Effects of radiation dose on the quality and shelf-life of 6 sweet cherry varieties

Six varieties of sweet cherries, Bing, Windsor, Lambert, Napoleon, Schmidt, and Black Tartarian were irradiated at 0, 1, 3 and 5 x 10^5 rads. The Bing and Windsor were at the stage of excellent commercial ripeness, the Lambert and Napoleon were on the green side, the Schmidt was on the over-ripe side, and the Black Tartarian was very ripe. The samples of sweet cherries were stored at 40° F. and were evaluated for taste quality by a panel of 10 trained judges at 1 day, 10 days, 4 weeks, and 5 weeks after irradiation.

One day storage after irradiation.--It can be noted from table 3 that all varieties at all doses of radiation were scored between 6.5 (like slightly) and 8.6 (like very much). With each variety, the lowest score was at the 5 x 10^5 rad dose. The Bing averaged 8.3 (like very much), Lambert, Black Tartarian, Windsor, and Schmidt averaged 7.4 (like moderately), while the Napoleon was 6.7 (like slightly).

In all varieties, the judges stated that increased radiation dose gave a softer fruit. The Napoleon and Lambert varieties were somewhat sour or bitter because they were harvested ahead of their best eating quality.

Ten days storage after irradiation.--Table 4 shows that three varieties, Bing, Lambert, and Black Tartarian, decreased slightly in quality, but remained in the same taste groups that they were in when evaluated at one day after radiation. Two varieties, Napoleon and Windsor, decreased enough in taste quality during the 10-day period so as to decrease a unit in the taste group classification. The sixth variety, Schmidt, seemed to increase in quality but remained in the

Table 3. Effect of radiation dose on the preference of sweet cherry varieties, evaluated 1 day after irradiation

Dose	Bing		Napoleon		Black Tartarian		Lambert		Schmidt		Windsor	
x 10^5 rads	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent
0	8.2	100	6.7	90	7.6	90	7.8	90	7.1	90	7.7	100
1	8.5	100	6.7	90	7.7	100	8.1	100	7.5	100	7.2	90
3	8.6	100	7.0	90	7.5	100	8.0	100	7.1	90	7.6	100
5	7.8	100	6.5	90	6.7	90	7.4	100	6.6	80	6.7	90
L.S.R.: 0.05	0.6		0.8		0.7		1.0 - 0.9		1.1 - 1.0		0.9 - 0.8	

Table 4. Effect of radiation dose on the preference of sweet cherry varieties, evaluated 10 days after irradiation

Dose x 10^5 rads	Bing		Napoleon		Black Tartarian		Lambert		Schmidt		Windsor	
	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent
0	8.3	100	6.6	90	7.7	100	7.7	100	7.8	100	6.5	90
1	8.3	100	5.9	80	7.7	100	7.9	100	7.7	100	7.2	100
3	7.9	100	5.6	80	6.7	80	8.2	100	7.5	100	6.2	80
5	7.4	90	5.6	80	6.6	90	7.1	90	7.6	100	6.9	90
L.S.R.: 0.05	0.9 - 0.8		1.1 - 1.0		0.9 - 0.8		1.0		0.8 - 0.7		1.2 - 1.1	

same taste group.

Within each variety, cherries irradiated at 5×10^5 rads were softer in texture than those of lower doses but in some cases were no worse than those irradiated at 3×10^5 rads. In general there was no mold growth, an exception being on a few fruits with ruptured skins at low doses of radiation.

Four weeks after irradiation.--Table 5 presents the taste acceptance scores of the irradiated sweet cherries stored for 4 weeks. Before being presented to the judges, however, nearly all spoiled fruits were removed. It may be noted that the average scores of Napoleon and Lambert remained in the same taste classification, Bing and Black Tartarian dropped 1 step, and Schmidt and Windsor dropped into the second lower group when all were compared with the scores obtained when judging one day after irradiation.

Tables 5 and 8 leave a false impression because no adjustment had been made for spoiled (moldy) fruits. An estimate of the percentage of edible (non-spoiled) fruit at the time of sampling was then made. An adjusted score for each variety at each dose was calculated by multiplying the estimated percentage of good fruit by the score obtained from tables 5 and 8. For example, if the average score was 8.0 and 80 percent of the fruit was edible, the adjusted score became (8.0 x .80) 6.4.

These adjusted data are presented in tables 6 and 9. The scores obtained from 3 and 5×10^5 rads doses of radiation are noticeably better than those at 0 and 1×10^5 rads doses. There was much less spoilage at the higher doses of radiation. The Bing and Lambert varieties showed up well at the higher doses, Windsor and Schmidt were

Table 5. Effect of radiation dose on the preference of sweet cherry varieties, evaluated 4 weeks after irradiation

Dose x 10^5 rads	Bing		Napoleon		Lambert		Black Tartarian		Schmidt		Windsor	
	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent
0	8.0	100	6.2	90	7.8	100	6.6	90	6.2	100	5.4	70
1	7.9	100	6.6	100	7.6	100	6.8	100	6.3	90	6.0	90
3	8.0	100	5.9	90	7.8	100	6.9	100	6.2	100	5.9	90
5	7.6	100	6.1	100	7.2	90	6.6	100	5.0	60	5.7	80
L.S.R.: 0.05	0.8 - 0.7		1.1 - 1.0		0.8 - 0.7		1.1 - 1.0		1.4 - 1.3		1.0 - 0.9	

Table 6. Effect of radiation dose on the preference of sweet cherry varieties, evaluated 4 weeks after irradiation. Scores adjusted for spoilage. Percentage spoiled estimated by interpolation of spoilage from 10 days to 5 weeks.

Dose x 10^5 rads	Bing	Napoleon	Black Tartarian	Lambert	Schmidt	Windsor
0	3.0	3.1	2.8	4.2	4.2	4.3
1	3.3	3.3	3.2	2.9	3.7	4.6
3	7.3	4.6	4.4	7.5	5.7	5.3
5	7.8	4.5	6.2	7.0	4.9	5.2
Average	5.3	3.9	4.1	5.4	4.6	4.8

fair and Napoleon and Black Tartarian were poor.

Five weeks after irradiation.--The spoiled (moldy) fruit was removed from the cans of sweet cherries and the percentages of the same were calculated and presented in table 7.

Figure 6 and table 8 present the taste scores given to the edible fruits of the 6 varieties of sweet cherries irradiated to different doses and stored for 5 weeks. The average scores for the varieties decreased during the week, Black Tartarian dropping to the next unit lower in the classification while the other 5 remained in the ones they were in the previous week.

To give a more accurate picture of the true value of the radiation, an adjusted score was determined by multiplying the scores in table 8 by the percentage of edible fruit. These data are presented in figure 7 and table 9. The average scores of all varieties were decreased during the week. Bing and Lambert irradiated at the higher doses were quite acceptable. The other varieties irradiated at the higher doses were on the border line of acceptability. All varieties at low doses of irradiation were poor in acceptability because of spoilage.

In summary, after 5 weeks of storage, each variety in the study showed similar color development. The controls of each variety were darkest because of normal sweet cherry ripening. The higher the dose of radiation, the lighter was the flesh color of the edible fruits. The color of fruits of the highest dose of radiation was hardly changed from the color of the fruits at the time of the beginning of the storage. The higher doses of radiation retarded the rate of maturation (figure 8).

Table 7. Effect of radiation dose on keeping qualities of 6 varieties of sweet cherries evaluated after 5 weeks storage at 40° F.

Variety	Dose x 10^5 rads	Edible fruit		Non-edible fruit	
		No. of fruits	Percent of total	No. of fruits	Percent of total
Bing	0	31	15.0	176	85.0
	1	33	18.8	143	81.2
	3	153	89.0	19	11.0
	5	155	98.1	3	1.9
Black Tartarian	0	45	18.9	193	81.1
	1	88	24.6	269	75.4
	3	111	49.6	113	50.4
	5	183	92.4	15	7.6
Napoleon	0	43	30.5	98	69.5
	1	43	30.7	97	69.3
	3	100	70.4	42	29.6
	5	96	61.9	59	38.1
Windsor	0	190	70.1	81	29.9
	1	117	60.9	75	39.1
	3	165	85.5	28	14.5
	5	190	88.8	24	11.2
Lambert	0	40	36.4	70	63.6
	1	20	12.5	140	87.5
	3	149	94.9	8	5.1
	5	177	96.7	6	3.3
Schmidt	0	81	54.0	69	46.0
	1	100	43.3	131	56.7
	3	173	89.2	21	10.8
	5	208	96.7	7	3.3

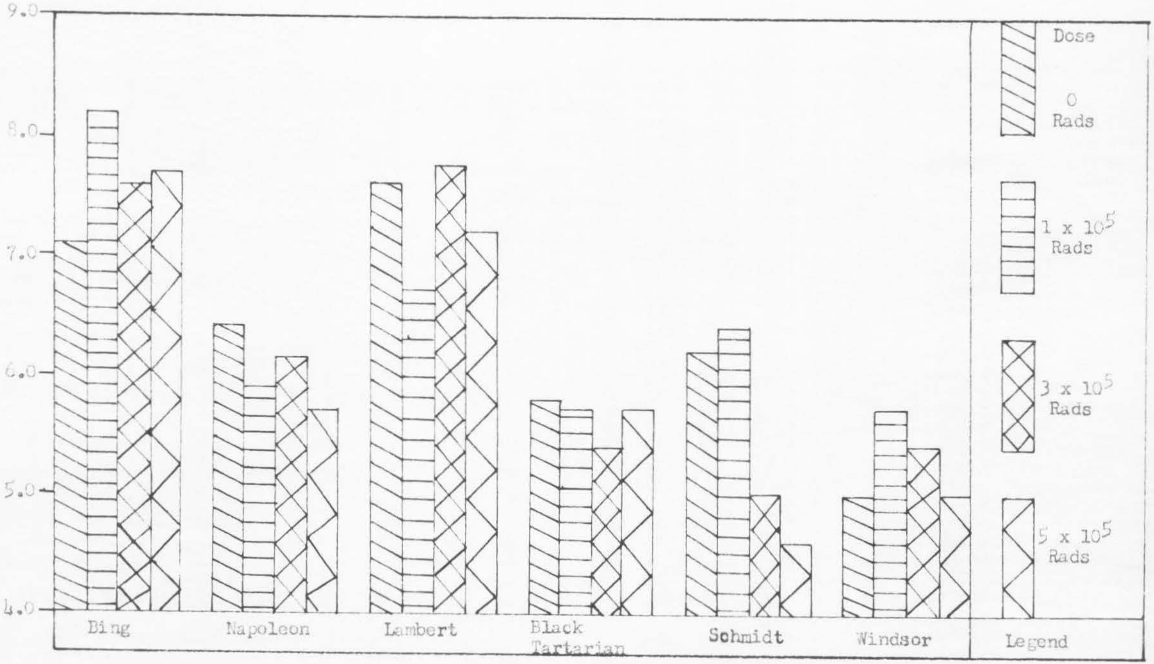

Figure 6. Effect of radiation dose on the preference of sweet cherry varieties, evaluated 5 weeks after irradiation

Table 8. Effect of radiation dose on the preference of sweet cherry varieties, evaluated 5 weeks after irradiation

Dose	Bing		Napoleon		Lambert		Black Tartarian		Schmidt		Windsor	
$\times 10^5$ rads	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent
0	7.1	80	6.4	100	7.6	90	5.8	70	6.2	80	5.0	60
1	8.2	100	5.9	70	6.7	70	5.7	60	6.4	80	5.7	80
3	7.6	100	6.1	80	7.7	100	5.4	70	5.0	50	5.4	60
5	7.7	100	5.7	70	7.1	100	5.7	70	4.6	50	5.0	70
L.S.R.: 0.05	1.1 - 1.0		1.5 - 1.4		0.9		1.5 - 1.4		1.2 - 1.1		1.0 - 0.9	

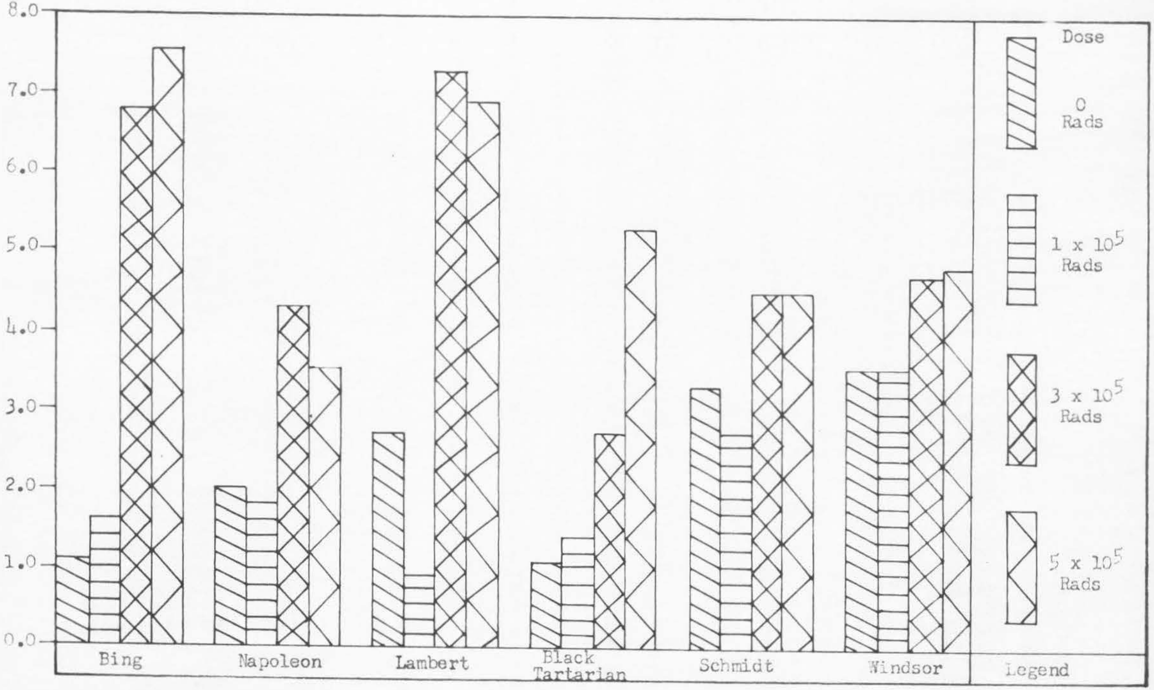

Figure 7. The effect of radiation on the preference of sweet cherry varieties evaluated 5 weeks after irradiation. Scores adjusted for spoilage

Table 9. Effect of radiation on the preference of sweet cherry varieties evaluated 5 weeks after irradiation. Scores adjusted for spoilage. Percentage spoiled counted at 5 weeks time.

Dose $\times 10^5$ rads	Bing	Napoleon	Black Tartarian	Lambert	Schmidt	Windsor
0	1.1	2.0	1.1	2.7	3.3	3.5
1	1.6	1.8	1.4	0.9	2.7	3.5
3	6.8	4.3	2.7	7.3	4.5	4.7
5	7.5	3.5	5.3	6.9	4.5	4.8
Average	4.2	2.9	2.6	4.4	3.8	4.1

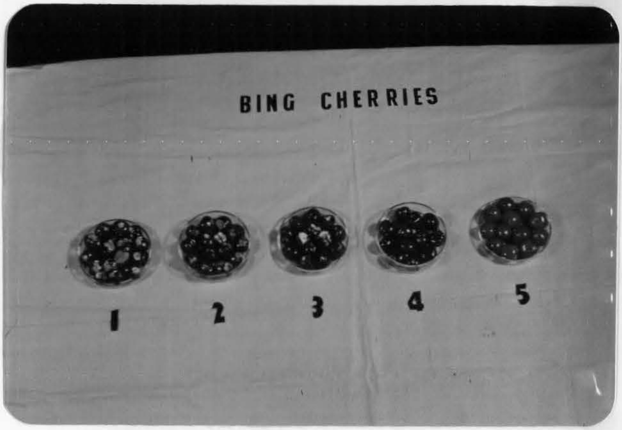

Figure 8. The effect of radiation dose on the microbial growth and maturation of Bing sweet cherries (photographed 5 weeks after irradiation). Left to right: 1 = control, 2 = control (sorbic acid), 3 = 1×10^5 rads, 4 = 3×10^5 rads, 5 = 5×10^5 rads.

Experiment 3: Effects of radiation dose on the quality, shelf-life, and chemical changes in 2 red tart cherry varieties

Two varieties of tart cherries--Early Richmond and Montmorency--were irradiated to 0, 1, 3 and 5 x 10^5 rads. The Montmorency was at a pre-commercial stage of ripeness while the Early Richmond was on the over-ripe side. Both varieties were evaluated raw as well as cooked with 40 percent sugar syrup. The Montmorency was evaluated for a taste study at 1, 10, 18, and 25 days after irradiation. The Early Richmond was tasted at 1 and 10 days after irradiation.

Figure 9 and table 10 present the data on the Montmorency cherries. The raw fruit scores increased during the first 18 days of storage, probably indicating a ripening of the fruit. There was not much change during the next 7 days. The results of the low doses at 18 and 25 days of storage are open to question since no adjustment was made for the spoiled (moldy) fruit.

The cooked fruit scores were higher than the raw fruit scores, showing the need of sugar for a more acceptable product. As time went on, however, the taste scores declined, especially at the higher doses of irradiation. The reason for this change is not evident at this time. There was less mold on cherries given higher doses of irradiation.

Figure 9 and table 11 contain the data of the Early Richmond cherries. There seemed to be no consistent differences in the taste scores as radiation increased. With time, there was a decrease in score, probably due to the extreme ripeness of the fruit. It was noted, also, that there was less mold growth at higher (3 and 5 x 10^5 rads) doses of irradiation (figure 10).

Chemical measurements.--It was noticed in the Montmorency cherries for the taste panel that the juice of the cooked sample which had

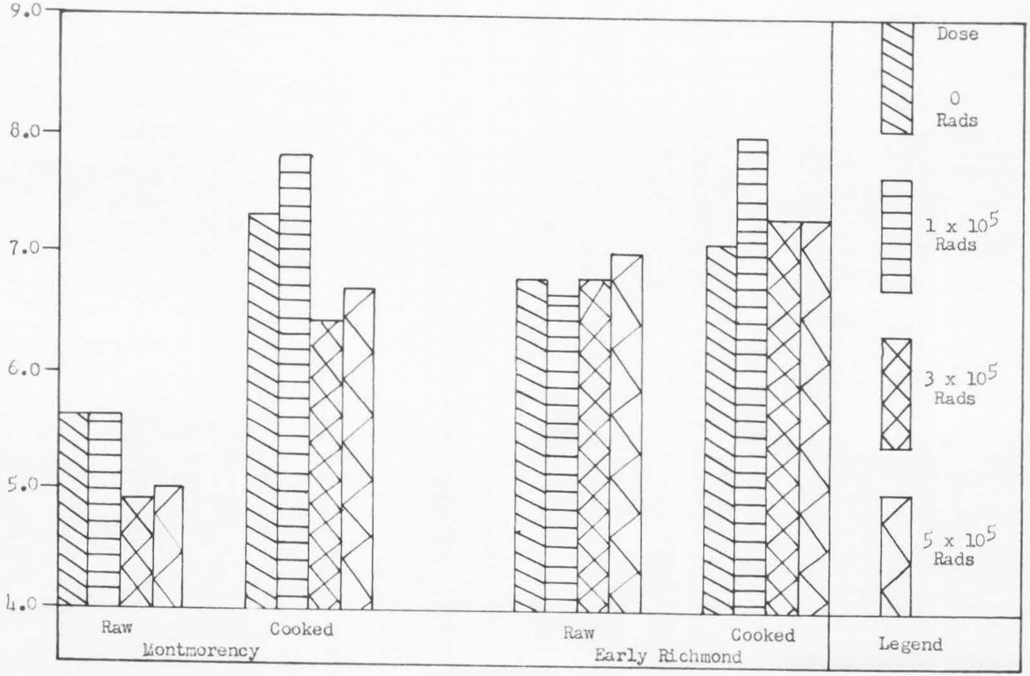

Figure 9. Effect of radiation dose on the preference of red tart cherries evaluated 10 days after irradiation

Table 10. Effect of radiation dose on the preference of raw and cooked Montmorency tart cherries

Dose	Evaluated 1 day after irradiation				Evaluated 10 days after irradiation				Evaluated 18 days after irradiation				Evaluated 25 days after irradiation			
	Raw		Cooked		Raw		Cooked		Raw		Cooked		Raw		Cooked	
$\times 10^5$ rads	Preference score	Like response %	Preference score	Like response %	Preference score	Like response %	Preference score	Like response %	Preference score	Like response %	Preference score	Like response %	Preference score	Like response %	Preference score	Like response %
0	5.4	60	7.7	100	5.6	80	7.3	90	6.3	80	7.0	100	6.2	80	7.4	100
1	5.1	70	7.5	90	5.6	80	7.8	100	6.2	90	7.8	100	6.0	90	7.3	90
3	5.3	70	7.6	100	4.9	60	6.4	70	6.0	70	6.3	90	5.3	60	6.7	90
5	5.4	60	7.1	100	5.0	70	6.7	90	5.9	70	6.5	90	6.1	90	5.9	70
L.S.R.: 0.05	1.2 - 1.1		1.0		1.2 - 1.1		0.9 - 0.8		0.8		0.8 - 0.7		1.0		1.1 - 1.0	

Table 11. Effect of radiation dose on the preference of Early Richmond tart cherries

Dose x 10^5 rads	Evaluated 1 day after radiation				Evaluated 10 days after radiation			
	Raw		Cooked		Raw		Cooked	
	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent
0	7.3	100	8.0	100	6.8	90	7.1	90
1	7.2	100	7.8	100	6.7	100	8.0	100
3	7.2	100	7.7	100	6.8	80	7.3	100
5	6.8	90	7.9	100	7.0	90	7.3	100
L.S.R.: 0.05	0.7 - 0.6		0.7 - 0.6		1.1 - 1.0		0.8 - 0.7	

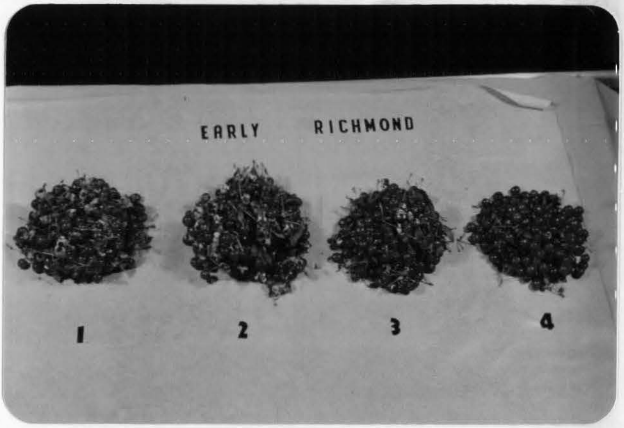

Figure 10. The effect of radiation dose on the microbial growth and maturation of Early Richmond tart cherries (photographed 5 weeks after irradiation). Left to right: 1 = control, 2 = 1 x 10^5 rads, 3 = 3 x 10^5 rads, 4 = 5 x 10^5 rads.

received the highest radiation dose (5×10^5 rads) was less red in color than the control sample. The study was, therefore, conducted to evaluate color changes quantitatively.

A sample of raw cherries was squeezed in a cloth. The juice thus extracted, sample A, was first tried for light transmittance and found to be non-transmissable due to density. Filtration was tried, but it was too slow. Centrifugation was found to be the answer to the problem. All of sample A was centrifuged. Part of sample A was diluted 1:1 with distilled water to produce sample B. Part of sample B was examined by the Spectrophotometer. A slight decrease in light transmittance was found at both 530 and 550 mm settings as radiation dosage increased. Part of sample B was boiled for 6 minutes, cooled, and then read in the Spectrophotometer. There was an increase in light transmittance in both machine settings as the radiation increased up to 5×10^5 rads. At higher dosage, however, the transmittance decreased slightly. Part of sample A was diluted 1:1 with a 40 percent sugar solution. The mixture was then boiled 6 minutes, cooled, and then examined in the Spectrophotometer. An increase in transmittance was found as the dosage increased to 5×10^5 rads, but this was reversed as the dosage went to 20×10^5 rads.

In summary, 10 ml. samples of the juice of each dose-sample were examined in a Spectrophotometer for light transmittance. At both 530 and 550 mm wave-lengths, there is a direct relationship of transmittance and dosage. As the dosage increases, the light transmittance, that is the dilution of the red pigment, increases.

A portion of sample B was examined for acidity with a Beckman pH meter. There seemed to be a slight decrease in acidity as the dosage of radiation increased to 3×10^5 rads.

Experiment 4: Effects of radiation rate and radiation dose on quality, shelf-life, and color changes in 5 strawberry varieties

Five varieties of strawberries were dipped in a 0.25 percent solution of sorbic acid and were irradiated at 2 rates and to 5 dose levels. The varieties were Kasuga, Lindalicious, Marshall, Robinson, and Sparkle. The rates of irradiation were 1×10^6 and 5.5×10^6 rads per hour. The doses given were 0, 1, 2, 3 and 4×10^5 rads.

The results of the taste tests after 1 day on the above strawberries are presented in figures 11 and 12 and table 12. The results, as far as the rate of irradiation, were quite erratic and should not be considered different. When considering the dose of radiation, there was no difference between 0, 1, 2, and 3×10^5 rads. The fruits at 4×10^5 rads were less acceptable than the rest. There was a decrease in firmness with an increase in the dosage of radiation.

The greater part of each sample of strawberries as described in table 13 were left in the No. 10 cans in a 40° F. storage for a period of 6 weeks. At the end of this time the fruits were evaluated as to mold growth (figure 13).

Table 14 presents the results of visual color estimation. The color of the fruits attacked by the mold faded and the color of the non-moldy fruit was as excellent natural color which was confirmed by Hunter color values Rd, a, b, and a/b. Table 15 indicates that in general, a/b values are increased as the radiation dose advanced, which means that the red color of strawberries was retained at the higher doses of radiation (3 and 4×10^5 rads), regardless of varieties studied. This was presumably due to the lack of mold growth on strawberries irradiated at the high doses. The mold growth absorbed the red color of the fruits studied.

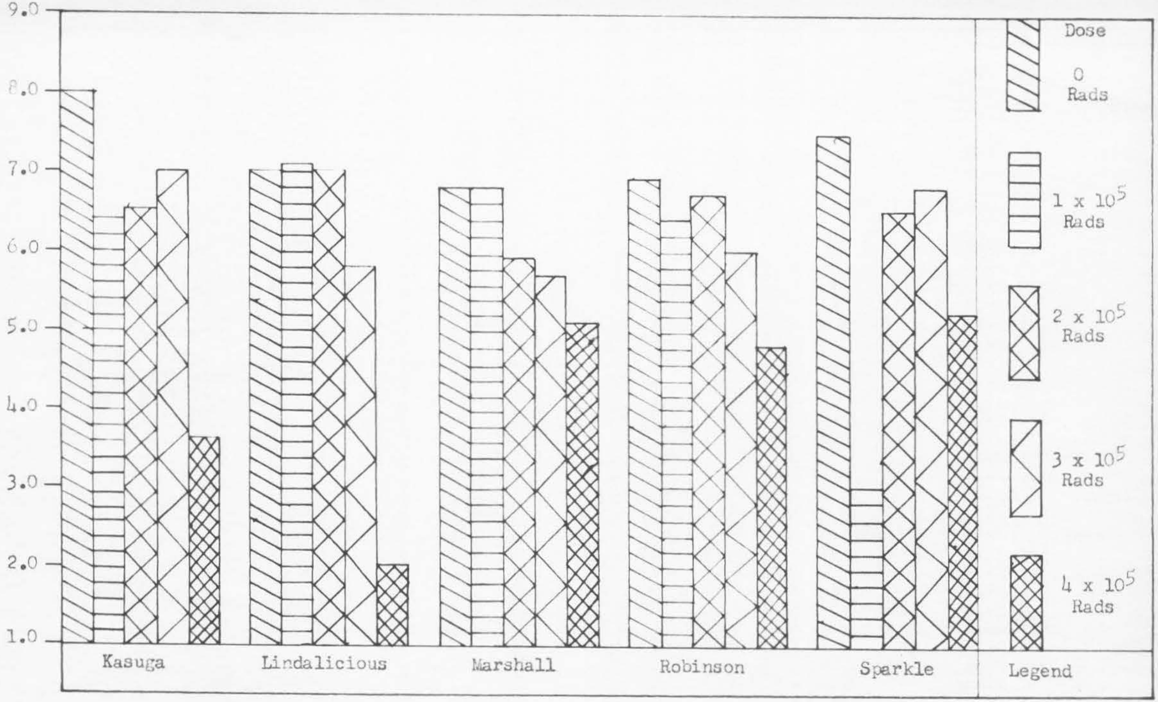

Figure 11. Effect of radiation dose and rate on the preference of strawberry varieties evaluated 1 day after irradiation at 1×10^6 rads/hr.

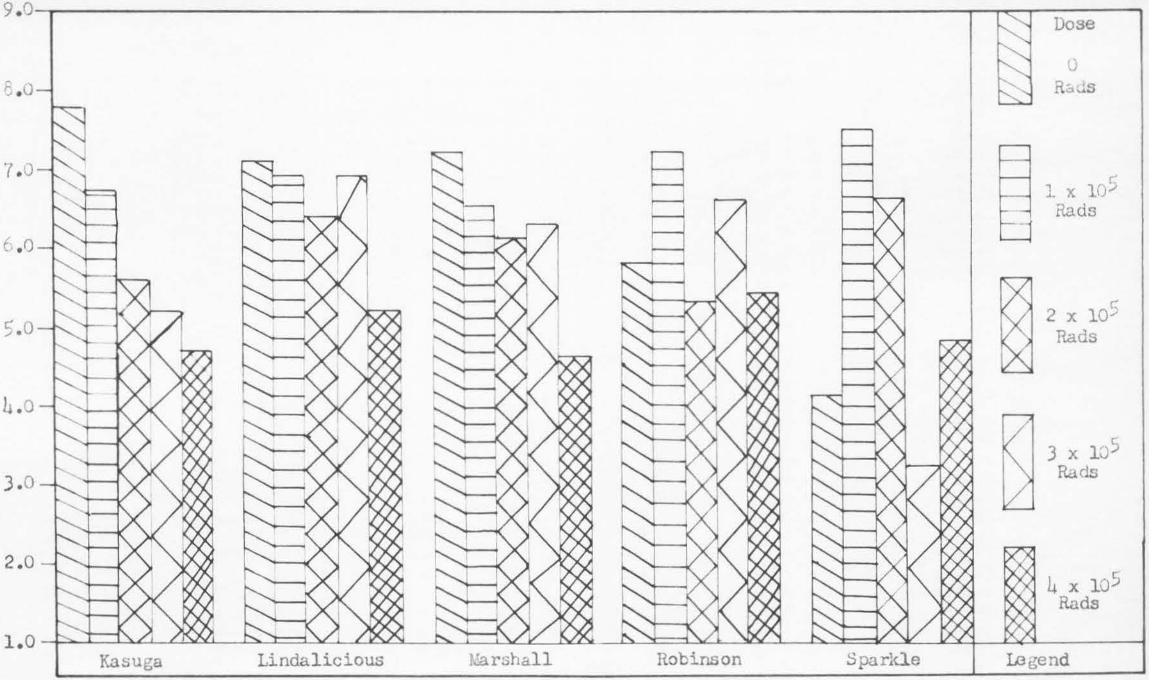

Figure 12. Effect of radiation dose and rate on the preference of strawberry varieties evaluated 1 day after irradiation at 5.5×10^6 rads/hr.

Table 12. Effect of radiation dose and rate on the preference of strawberry varieties, evaluated 1 day after irradiation

Rate $\times 10^6$ rads/hr.	Dose $\times 10^5$ rads	Kasuga		Lindalicious		Marshall		Robinson		Sparkle	
		Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent	Preference score	Like responses percent
1	0	8.0	100	7.0	90	6.8	100	6.9	100	7.5	100
	1	6.4	80	7.1	100	6.8	80	6.4	90	3.0	0
	2	6.5	80	7.0	100	5.9	70	6.7	100	6.5	100
	3	7.0	100	5.8	80	5.7	80	6.0	90	6.8	100
	4	3.6	20	2.0	0	5.1	60	4.8	60	5.2	60
L.S.R.:	0.05	1.3 - 1.2		1.1 - 1.0		1.3 - 1.2		1.1 - 1.0		1.1 - 1.0	
5.5	0	7.8	100	7.1	100	7.2	100	5.8	70	4.1	60
	1	6.7	90	6.9	100	6.5	90	7.2	100	7.5	100
	2	5.6	80	6.4	90	6.1	90	5.3	30	6.6	90
	3	5.2	60	6.9	100	6.3	80	6.6	90	3.1	20
	4	4.7	60	5.2	60	4.6	40	5.4	70	4.8	50
L.S.R.:	0.05	1.4 - 1.2		1.2 - 1.1		1.2 - 1.1		1.2 - 1.1		1.2 - 1.1	

Table 13. Effect of radiation dose on the microbial growth scores[a] for 4 strawberry varieties after 6 weeks' storage at 40° F.

Dose x 10^5 rads	Kasuga	Lindalicious	Marshall	Sparkle
0	XXXXX	XXXXX	XXXXX	XXXXX
1	XXXX	XXXXX	XXX	XXX
2	XXXX	X	X	X
3	X	X	X	X
4	X	X	X	X

[a]XXXXX Profuse growth
XXXX Very much growth
XXX Moderate growth
XX Slight growth
X No growth

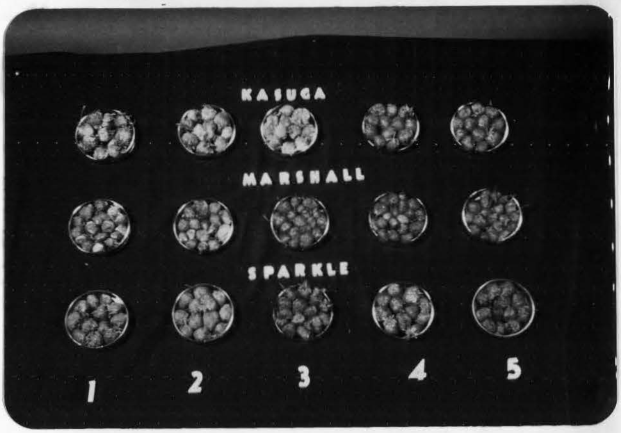

Figure 13. The effect of radiation dose on microbial growth and color changes in Kasuga, Marshall, and Sparkle strawberries (photographed 5 weeks after irradiation). Left to right: 1 = control, 2 = 1 x 10^5 rads, 3 = 2 x 10^5 rads, 4 = 3 x 10^5 rads, and 5 = 4 x 10^5 rads.

Table 14. Effect of radiation dose on visual color scores[a] for 4 strawberry varieties after 6 weeks' storage at 40° F.

Dose x 10^5 rads	Kasuga	Lindalicious	Marshall	Sparkle
0	XXXXX	XXXXX	XXXXX	XXXXX
1	XXXXX	XXXX	XXXX	XXXXX
2	XXX	XX	XX	XX
3	X	XX	XX	XX
4	XX	XXX	XXX	XX

[a]XXXXX Extreme fading or change of color
XXXX Very much fading or color change
XXX Moderate fading or color change
XX Very slight fading or color change
X Excellent natural red color--no fading

Table 15. Effect of radiation dose on the average Hunter color and color difference values obtained on 4 strawberry varieties

Variety	Dose $x\ 10^5$ rads	Rd	a	b	a/b
Sparkle	0	5.1	1.0	15.4	0.06
	1	5.6	2.3	15.8	0.14
	2	3.7	0.7	12.9	0.05
	3	4.8	3.7	14.0	0.26
	4	5.4	2.8	13.1	0.21
Marshall	0	5.1	2.4	14.6	0.16
	1	4.7	0.8	14.8	0.05
	2	3.9	4.2	13.0	0.32
	3	3.8	3.4	13.0	0.26
	4	4.4	6.7	13.4	0.50
Kasuga	0	5.0	1.2	14.6	0.08
	1	5.7	1.4	13.3	0.10
	2	5.0	1.8	14.0	0.12
	3	3.8	1.6	13.4	0.11
	4	4.1	5.4	13.4	0.40
Lindalicious	0	5.7	1.8	15.4	0.11
	1	5.3	0.9	14.4	0.06
	2	4.5	2.6	12.8	0.20
	3	4.5	2.1	12.8	0.16
	4	4.6	1.9	13.4	0.14

In general it was found that the white mold was rather predominant on the product at the control and lower dose (1×10^5) levels whereas this mold was not sufficient to be recorded at the higher levels. However, on the products irradiated at the higher dose (3 and 5×10^5 rads) bluegreen mold was noticed.

DISCUSSION

The results obtained in the experiments conducted are discussed under three categories as follows: pasteurization and retention of quality in fruits by gamma radiation, chemical changes in fruits induced by gamma radiation, and pre-irradiation chemical treatment of fruits.

Pasteurization and retention of quality in fruits by gamma radiation

In this study bacteria and fungi were destroyed at doses over 2×10^5 rads and less than 4×10^5 rads. As can be seen in tables 6 and 9, after 4 weeks' storage, fruits which received doses of 3×10^5 rads and 5×10^5 rads showed much less spoilage than the fruits at lower doses. This concurs with previous findings by Gerber et al. (7). A reduced spoilage of products by bacteria and fungi is apparently due to the so-called "radio-pasteurization" of the fruits with gamma radiation.

At doses over 4×10^5 rads eating quality declined rapidly. This was due to degradation of food constituents such as proteins, carbohydrates, vitamins, and pigments and formation of off-odors, flavors, colors, and textures as found by Simon (22) and McArdle and Desrosier (12). At lower doses the degradation of these constituents was less severe thus producing less changes in flavor and other characteristics.

At lower doses such as 2×10^5 rads, the fruits retained their desirable flavor, texture, color, and odor characteristics. In most cases these products were almost identical to the non-irradiated controls in these respects. At the same time, they were pasteurized which in turn increased their shelf-life.

Chemical changes in fruits induced by gamma radiation

As was found by Madsen (11) softening increased as the dosage of gamma radiation increased. Such softening was due to the radiation breakdown of carbohydrates in the fruits. The protopectins and pectic substances which provide the cellular structure of the fruits were broken down; hence, the fruits became softer. This is in agreement with Simon (22) and McArdle and Nehemias (13).

The color of sweet cherries, red tart cherries, and strawberries was affected by radiation. In the sweet cherries and in the red tart cherries the maturation rate, hence the development of red color, was retarded by the higher doses (3 and 5×10^5 rads). Also, compared to juice from the non-irradiated control cherries, less color was in the juice from the red tart cherries at the higher doses. The strawberries after 1 month's storage had more red color retained by fruits which received higher (over 2×10^5 rads) doses than by fruits receiving lower doses. The Sparkle variety showed less color loss than the other 3 strawberry varieties. The retardation of color development in sweet cherries and red tart cherries agrees with Burnes (3) who noted such a change which he attributed to a reduction of lycopene content following irradiation.

There was very little difference in the pH of juice extracted from red tart cherries at different dose levels. The readings increased from 5.25 at the control level to a high of 5.35 at 3×10^5, 5×10^5, and 10×10^5 rads and dropping to 5.30 at 20×10^5 rads. It is possible that the pH may influence the lethality of certain microbes by radiation (22).

Relatively firm fruits such as sweet cherries and apricots showed less softening with radiation than the relatively soft fruits such as strawberries and red tart cherries. The amount of pectin and cellulose degradation varied between crops, varieties of the same crops, and immature and mature fruits of the same variety. Immature fruits were found to withstand the radiation with less changes in texture than the mature fruits.

Little variation in the amount of softening of the 5 apricot varieties was found. In sweet cherries, however, some varietal difference was observed. The Bing and Lambert varieties showed the least softening, the Napoleon and Black Tartarian varieties showed moderate softening, and the Schmidt and Windsor varieties showed the most softening. In red tart cherries, the Montmorency variety showed slightly less softening than the Early Richmond variety. The Sparkle variety of strawberries had less softening than the Kasuga, Lindalicious, and Marshall varieties.

As shown in figure 5, pasteurizing doses of radiation slow down the normal ripening process. This is attributed to slowed respiration and slowed metabolism as was found in other studies (7, 8). Such a slow down in ripening would be of great value to shippers and transporters since it would make it possible for produce to be held in transit over longer periods of time without resulting in an undesirable product. Produce could also be stored for relatively long periods of time before being sold fresh or being processed.

<u>Pre-irradiation chemical treatment of fruits</u>

The fruits dipped in sorbic acid before irradiation displayed a slightly greater resistance to the growth of bacteria and fungi than those fruits which did not receive the dip. The use of such a chemical treatment might inhibit the fungus growth which could not be killed by lower (1 and 2 x 10^5 rads) levels of radiation. Such a combination treatment might prove more desirable than radiation used alone. This is also proposed by Schweigert (20) and Proctor *et al.* (18).

For practical purposes, the "threshold dose" of radiation at which a product could be preserved without producing undesirable changes may be in the vicinity of 2×10^5 to 3×10^5 rads. It seems that this would be sufficient to pasteurize, to retain quality, and to lengthen ripening time of fruits studied.

SUMMARY AND CONCLUSIONS

The studies presented in this thesis were conducted to determine the effects of gamma radiation on the shelf-life and quality changes in 5 varieties of apricots, 6 varieties of sweet cherries, 2 varieties of red tart cherries, and 5 varieties of strawberries. A summary of the results obtained and conclusions drawn therefrom are below.

I. Growth of mold was inhibited on all fruits at doses of 3×10^5 rads and higher.

II. The taste acceptability of the fruits was lowered at doses of 3×10^5 rads and higher.

III. A pre-irradiation dip of sorbic acid (1 percent) for fruits showed some promise in combating fungal growth which was not destroyed by irradiation.

IV. Varieties of the fruits studied had an increased shelf-life with doses of radiation exceeding 1×10^5 rads. Maturation rate of the fruits was slowed down by higher (3×10^5 rads and 5×10^5 rads) doses of gamma radiation. At doses of 2×10^5 rads the fruits retained their desirable flavor, color, texture, and odor characteristics.

V. No consistent trend of effects was noticed as a result of radiation rate differences.

It is a well recognized fact that certain varieties of fruits and vegetables are suitable for certain purposes. For example, specific varieties are bred for canning and other varieties are developed for freezing. Hence, it seems from the observations presented in this thesis that some varieties of fruits are much more suitable for preservation by radiation than others. Likewise, proper maturity of a given fruit is an essential factor in obtaining optimal quality of the processed (canned and frozen) product. Such is also true in case of preservation of fruits by radio-pasteurization.

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