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RADIATION TECHNOLOGY IN CONJUNCTION WITH POSTHARVEST PROCEDURES AS A MEANS OF EXTENDING THE SHELF LIFE OF FRUITS AND VEGETABLES

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RADIOISOTOPE AND RADIATION APPLICATIONS (TID-4500)

RADIATION TECHNOLOGY IN CONJUNCTION WITH POSTHARVEST PROCEDURES AS A MEANS OF EXTENDING THE SHELF LIFE OF FRUITS AND VEGETABLES

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Division of Isotopes Development
U.S. Atomic Energy Commission

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February 1, 1967 - January 30, 1968

Department of Pomology, University of California, Davis, California

CONTENTS

SUMMARY

Test shipments of strawberries irradiated to 200 kilorad (Krad) showed a substantial reduction in amounts of unmarketable fruits in comparison to unirradiated fruits subjected to near ideal handling and shipping conditions.

Heat treatments prior to irradiation sensitize the conidia of Botrytis cinerea rot (grey mold of strawberries) to irradiation. Heat treatments (106°F for 30 minutes) gave slightly firmer berries in some tests but had no effect in others. Heat alone and in combination with 200 Krad of gamma radiation exerted no adverse effects on berry quality. Irradiated berries were softer, but combining heat and irradiation did not increase the loss in berry firmness. Heat alone and in combination with irradiation did not intensify the loss of ascorbic acid as compared to unheated samples.

Calcium chloride soaks were ineffective in protecting strawberry fruits from radiation induced loss of firmness or in firming berries subsequent to irradiation.

Gamma radiation in combination with heat gave encouraging results as a means of processing fresh apple juice. Gas chromatographic studies showed little alteration of the volatile fractions in irradiated apple juice. These results compliment taste-panel data where panelists find little flavor difference between irradiated and unirradiated juice.

Heat treatments of sweet cherries had no adverse effect on the texture of irradiated or unirradiated fruit.

Doses as high as 1100 Krad were ineffective in softening abnormally firm, dried dates.

Varying dose rates exerted no statistically significant effect on the loss of ascorbic acid in lemon fruits.

Doses of 25 Krad stimulated opening of brown mushrooms, while 50 and 100 Krad were inhibitory. Taste-panel data indicated no significant difference in flavor between irradiated and unirradiated

samples. The ascorbic-acid content of all mushrooms decreased during 2 weeks storage at 36°F but irradiation did not increase the losses.

Doses of 0-8 Krad showed progressive inhibition of growth in harvested asparagus spears. Doses above 4 Krad gave shorter storage life (12 days at 4 Krad vs. 7 days in the range of 150-700 Krad and 10 days in the range of 8-50 Krad).

Simulated transit and irradiation alone and in combination increased the susceptibility of tomato fruits to mechanical injury. The "tight-fill" method of packing shows promise as a means of alleviating the problem of transit injury in both irradiated and unirradiated tomatoes.

Preliminary tests indicate that the adverse effects of irradiation on peppers preclude any commercial use of the process.

A steam pasteurizer for heat treatment of fruits was designed, tested, and the effectiveness of moist steam in comparison to immersion in hot water compared. Engineering data on heat transfer between the two methods are compared.

During the summer of 1967, 55 tons of strawberries and 26 tons of bananas were irradiated in the Mobile Gamma Irradiator for feeding studies preparatory to preparation of petitions for clearance by the Food and Drug Administration.

EFFECT OF GAMMA IRRADIATION ON STRAWBERRY FRUITS

E. C. Maxie, F. P. Guerrero, Carol F. Johnson,
Henry Rae and Richard Stallman

I. TEST SHIPMENTS.

INTRODUCTION

Spring tests: Previous research with strawberries had shown beneficial effects of ionizing radiation in retarding rot. However, accompanying this is a softening effect on the fruit, which might limit commercial application of the process.

The purposes of these experiments were: 1) evaluate the effects of radiation on control of rot; and 2) establish the susceptibility of irradiated fruit to transit injury in an actual test shipment.

PROCEDURE

Forty trays of 'Shasta' strawberries were obtained on the day of harvest from Salinas Strawberry, Inc., Salinas, California. The fruit had been harvested at the slightly green shoulder stage and had not reached optimum ripeness. Thirty-two trays were hauled to Davis in a refrigerated box and cooled to 43°F while en route. Eight trays were left at Salinas under commercial conditions (36°F) to serve as controls. The treatments, using 4 replications, were:

1. Control (kept at Salinas)
2. 0 Krad
3. 200 Krad

Sub-treatments were shipped and non-shipped.

Irradiation was done in the MGI. The temperature of the irradiation chamber was 45°F, with air circulation at the rate of 125 cfm. Dwell time, based on a dose rate of 9.26 Krad/minute, was 2.4 minutes. Total time in motion for each carrier was 2.4 minutes.

Total time in the radiation field was 21.77 minutes. The 16 trays receiving 0 Krad were run through the irradiator with the plaque in the cask. All of the trays were labeled with "Caution Food Additives" stickers. Sixteen trays were left at Davis and 16 trays were hauled back to Salinas and loaded on a refrigerated truck bound for the New York City Terminal Market, with one stop at Pittsburg, Pennsylvania. The 8 control trays left at Salinas were included in the shipment. The truck departed Saturday, May 13, at 1:00 p.m. and arrived in New York, Wednesday, May 17, at 5:00 p.m. The berries were unloaded at 6:00 a.m., Thursday morning, May 18. The temperature of the truck was monitored with a Ryan Recording Thermometer. It held constant at about 38°F. The fruit remaining at Davis was kept at high humidity at a constant temperature of 41°F.

Two evaluations were made. The first was on Thursday morning, May 18, at 11:00 a.m. and the second on Saturday morning, May 20, at 11:00 a.m. Evaluations were also made at Davis at approximately the same time, allowing for the time difference. The fruit to be evaluated on Saturday was placed in storage (42°F) until Friday morning and then removed to a room with a temperature of 60-70°F. The fruit remaining at Davis received similar handling, except that the humidity was higher and the temperature was a constant 68°F.

The transport distance by truck of the Davis lot was about 160 miles. The lot shipped to New York traveled approximately 3000 miles by truck. The speed of the truck was approximately 50 mph.

The following categories were used to indicate condition of the fruit:

Marketable

- Sound - Firm fruit, no decay
- Soft - Firm fruit with a few soft spots, no decay

Unmarketable

- Soft - Fruit has completely collapsed or has soft spots so large as to render fruit unmarketable, no identifiable decay

Decayed - Fruit with definite decay lesions

The fruits were sorted into the respective categories and weighed to the nearest gram. The weights were converted to percentages of the total. Weight must be used since many fruits in the control lots "nest" together with fungal mycelia and cannot be separated for counting.

RESULTS

Table 1 is a summary of the evaluations of the Davis lot. The first evaluation showed very little decay. The irradiated fruit had 0.1% decay versus 1.4% in the unirradiated. The second evaluation showed a slight increase in decay after 2 days; 9.7% in the unirradiated and only 1.1% in the irradiated. There was little difference in the percent of fruit in the soft category between the two treatments.

Table 2 shows the results of the evaluation of fruit shipped to New York. In the first evaluation there was little difference in decay between the treatments. The real differences are apparent when a comparison is made of the percentages of fruits in the soft category between the shipped and the non-shipped lots. The shipped lot had a greater amount (10-15%) of fruit in the soft category than the non-shipped (1-2%). The controls had the least amount of fruit in the soft category and the irradiated had the greatest. The fruit receiving 0 Krad, but hauled to and from Davis, was intermediate.

The second evaluation showed a slight increase in the amount of decay in the control and 0 Krad fruit, from about 1% to 7.3 and 8.0% respectively. The amount of fruit in the soft unmarketable category did not increase; however, there was a slight reduction in the amount of fruit in the soft, but marketable category. The reduction was least in the irradiated fruit from 15% to 12.7%.

Table 1. Decay and condition categories of strawberries held at Davis. Two evaluations, average of 4 replications.

	Percent of fruit in each category				
	Marketable		Unmarketable		Net wt.
	sound	soft	soft	decay	in gms
First Evaluation					
Treatment					
0 Krad	97.0	1.3	0.3	1.4	5405
200 Krad	97.8	1.7	0.4	0.1	5183
Second Evaluation					
0 Krad	88.8	0.7	0.8	9.7	5544
200 Krad	97.7	1.0	0.2	1.1	5372

Table 2. Decay and condition categories of strawberries shipped to New York. Two evaluations, average of 4 replications.

	Percent of fruit in each category				
	Marketable		Unmarketable		Net wt.
	sound	soft	soft	decay	in gms
First Evaluation					
Treatment					
Control	87.5	10.9	0.6	1.0	5301
0 Krad	86.6	12.4	0.5	0.5	5332
200 Krad	83.3	15.0	1.2	0.5	5353
Second Evaluation					
Control	85.7	6.6	0.4	7.3	5052
0 Krad	84.5	7.4	0.1	8.0	5216
200 Krad	84.5	12.7	1.6	1.2	5196

Comparing the total net weight of the fruit in the various treatments, weight loss did not increase due to irradiation; however, the fruit in the New York lot evaluated Saturday was lighter in general. The Davis lot did not show this weight loss due to time, but it did show weight loss due to irradiation.

The pathogens were mostly *Botrytis* with some *Cladosporium* infecting the achenes.

DISCUSSION AND CONCLUSIONS

The first evaluations showed little decay in any treatment. The factors contributing to this were a low initial field infection and good storage conditions, with near optimum storage temperatures. The higher percent of fruit in the soft category of the shipped lot compared with the Davis lot reflects transit injury. Since the fruit held at Salinas (control) had the least amount in this category, it is probable that the difference is due to transit injury. Irradiation has been shown to decrease the firmness of the fruit. Since the amount of fruit in the soft category was highest in the irradiated lots, irradiation increases the susceptibility of strawberries to mechanical forces encountered during transit. The loss of weight due to time in the New York lot was due to lower humidities during storage; whereas, the Davis lot was held at a relatively high humidity (90-93%).

This test shipment did not establish that irradiation causes the fruit to be more susceptible to transit injury. This will require several test shipments.

SUMMARY

1. Irradiation maintained decay at a low level.

2. Unirradiated strawberries developed 8-10% decay after 1 day at 68°F.

3. The low level of decay in the fruit apparently reflected a low initial field infection and near optimum storage conditions during the test.

4. The shipped lot had a higher amount of fruit in the soft category than the stationary lot held at Davis.

Late summer tests: Note: It was not possible to conduct test shipments during midsummer because of commitments to irradiate bananas and strawberries for feeding studies. Presented here is a description of tests conducted in late August.

METHODS

One hundred and thirty-six trays of commercially mature strawberries ('Goldsmith' var.) were obtained in 3 sublots from Driscoll Associates, Watsonville, California, on the day of harvest; transported to Davis in a refrigerated box and cooled en route to 42°F. Three test shipments were made to: 1) St. Louis, Missouri, #1; 2) Washington, D. C.; and 3) St. Louis, Missouri, #2. The treatments using 8 replications for the 1st test and 4 for the others were:

1. Control - Fruit left at Watsonville, stored at 36°F, to be included in the shipment.
2. 0 Krad - Fruit run through the MGI with the source in the cask.
3. 200 Krad - Fruit irradiated in the MGI.

The dwell time was 2.65 minutes. Total time in the field was 23.2 minutes. The irradiation chamber was cooled to 48°F and aerated at a rate of 125 cfm. The strawberry trays were all labeled with "Caution Food Additives" stickers.

To compare the effects of the cross-country trip with non-shipped fruit, an additional 16 trays were included in the 3rd test. Eight were irradiated and 8 run through the MGI with the source in the cask (0 Krad). These trays were stored at 36°F at Davis, to be evaluated at a time coinciding with the evaluations in St. Louis.

After irradiation on the day following harvest, the fruit was returned to Watsonville; placed on a pallet along with the control lots. The fruit was loaded aboard a refrigerated truck and placed away from the axles so as to avoid excessive vibration.

The time in transit for St. Louis trips was 64 hours, and the Washington, D. C., trip 82 hours. Ryan recorders indicated that the temperatures were about 38°F in all 3 shipments.

Two evaluations were made of the fruit. The 1st was made within 2 hours after the fruit was unloaded and the 2nd evaluation 24 hours later. Upon unloading, the fruit was placed in the receiving rooms of the Safeway and Kroger Distribution Centers at 53-55°F, with a relative humidity of approximately 70%. Evaluations in the 3rd test were not made until 29 and 50 hours after arrival because the evaluator was delayed en route, the Davis lot was evaluated on schedule; therefore, it is necessary to compare the 1st evaluation of the St. Louis lot with the 2nd evaluation of the Davis lot.

The fruit were separated into 5 categories, and then each category weighed. These weights were converted to percentages. The categories used were:

Marketable - No decay

1. Fruit sound - Minor defects; acceptable.
2. Fruit sound - Moderate defects; acceptable.
3. Fruit is slightly soft with minor and moderate defects evident.

Unmarketable

4. Fruit soft - Collapsed or nearly so, or unacceptable defects.
5. Fruit has decay lesions, either inactivated or with mycelia present, (fruit with achenes infected with Cladosporium are not included if infection would not limit marketability).

Defects as used in these categories refers to picker damage, which becomes evident with time; transit damage and loss of luster.

In addition to the evaluations, 16 samples of 150 gram were selected from the Davis lot and subjected to shear analysis using the Allo-Kramer shear press. An analysis of variance was made on the shear-press data.

RESULTS AND DISCUSSION

The results of Test 1 (Table 3) indicate that irradiation made the fruit very susceptible to transit injury since there was a significant decrease in the amount of fruit in category 1 in the irradiated lot. The decrease in category 1 and the increase in categories 3 and 4 was due to the high amount of excessively soft berries in the test (25%).

There was no difference in the amount of decay between the 3 treatments until the 2nd evaluation. In the 2nd evaluation decay increased from 6.9 to 11.4%; 6.5 to 20.5%; 6.0 to 9.3% in control, 0 Krad and irradiated fruit respectively. No nests were found in the 1st evaluation but by the 2nd evaluation several nests were seen in the unirradiated fruit. The large increase in decay in the 0-Krad lot was due to the low quality of fruit in 2 of the trays, emphasizing the need for randomization in setting up tests. As reported by Mitchell *et al.*,[1] damage due to picker variability is very significant.

The results of Test 2 (Table 4) show that the control fruit held up better during transit. The irradiated fruit had 8.8% in category 2; whereas, control and 0-Krad fruit had 2.9 and 5.8% respectively. Irradiated fruit had only 2.7% in category 3, and the other 2 treatments did not have any fruit in category 3. The difference in the amounts of fruit in this category is not considered significant since the fruit was still marketable. The control and 0-Krad fruit had 3.6

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[1] Mitchell, F. G., E. C. Maxie and A. S. Greathead. Handling strawberries for fresh market. Circular 527, Calif. Agric. Ext. Service.

Table 3. Test shipment #1 - St. Louis, Missouri. Percent fruit in each class.*

	Marketable						Unmarketable				Total
	1		2		3		4		5 Decay		
	I	II	I	II	I	II	I	II	I	II	
Control	82.8	81.6	8.5	6.4	1.8	0.6	--	--	6.8	11.4	18.3
0 Krad	85.4	69.8	7.2	8.8	0.8	0.9	0.1	--	6.5	20.5	27.0
200 Krad	58.9	54.2	8.3	10.6	16.6	17.1	10.2	8.8	6.0	9.3	15.0

* Class definitions:

1. Fruit sound - Minor defects; acceptable.
2. Fruit sound - Moderate defects; acceptable.
3. Fruit is slightly soft with minor and moderate defects evident.
4. Fruit soft - Collapsed or nearly so, or unacceptable defects.
5. Fruit has decay lesions, either inactivated or with mycelia present, (fruit with achenes infected with Cladosporium are not included if infection would not limit marketability).

Table 4. Test shipment #2 - Washington, D. C. Percent fruit in each class.*

	Marketable						Unmarketable				Total
	1		2		3		4		5 Decay		
	I	II	I	II	I	II	I	II	I	II	
Control	93.5	89.2	2.9	3.6	—	0.1	--	—	3.6	7.1	10.7
0 Krad	86.5	85.4	5.8	4.6	--	0.6	--	—	7.7	9.4	17.1
200 Krad	78.8	79.7	8.8	9.6	2.7	3.7	0.1	0.5	9.6	6.5	15.1

* Class definitions:

1. Fruit sound - Minor defects; acceptable.
2. Fruit sound - Moderate defects; acceptable.
3. Fruit is slightly soft with minor and moderate defects evident.
4. Fruit soft - Collapsed or nearly so, or unacceptable defects.
5. Fruit has decay lesions, either inactivated or with mycelia present, (fruit with achenes infected with Cladosporium are not included if infection would not limit marketability).

and 7.7% decay respectively in the 1st evaluation; whereas, the 200-Krad fruit had 9.6%. Again this was due to the presence of only 2 trays of low quality fruit with a large amount of decay. By the 2nd evaluation all 3 treatments showed a slight decrease in quality. Nests were evident in the unirradiated fruit and the amount of decay increased slightly. In general, the 0-Krad fruit was intermediate in quality between the control and 200-Krad fruit.

The final test shipment in this series was sent to St. Louis, Missouri. The results (Table 5) show that a 2nd evaluation made about 50 hours after the fruit were placed at 55°F was more meaningful, with respect to decay. In the 1st evaluation the control fruit had 80% in category 1 and 0 Krad and 200 Krad, 61 and 66% respectively. However, by the 2nd evaluation the 200-Krad fruit had decreased to 55%, while control and 0-Krad fruit showed 51 and 27% respectively. The decrease in quality of the unirradiated fruit was due to development of decay nests, 34% in the control and 57% in the 0-Krad lots. Decay in the irradiated fruit increased very slightly from 8.5 to 11.8%. The decrease in quality of the irradiated fruit was due to a loss of luster and slight desiccation of the fruit. The defects became more noticeable as the fruits lost moisture.

In comparing the results of the Davis lot, it was necessary to match the 1st evaluation of the St. Louis lot with the 2nd evaluation of the Davis lot. In almost all of the categories, (except no. 1) the St. Louis lot had the highest percent of fruit in categories 2, 3, and 4. After 1 day at 55°F the control fruit increased in the amount of decay from 4 to 11% and the 200-Krad fruit increased from 2.8 to 6%.

As seen in Table 6, the irradiated fruit are made softer by irradiation. The difference is significantly different at the 1% level, and helps to explain why irradiated strawberries are more susceptible to transit injury than are unirradiated fruits.

Table 5. Test shipment #3 - St. Louis, Missouri, and Davis, California. Percent fruit in each class.*

	Marketable						Unmarketable				
	1		2		3		4		5 Decay		Total
St. Louis	I	II	I	II	I	II	I	II	I	II	
Control	80.5	50.8	8.1	11.8	--	3.1	--	0.3	11.4	34.0	46.5
0 Krad	60.9	27.2	21.2	12.0	3.7	4.5	2.5	--	11.7	56.3	68.0
200 Krad	65.6	55.1	22.4	21.3	3.1	8.5	0.4	3.3	8.5	11.8	20.3
Davis**											
0 Krad	90.1	80.3	5.2	6.8	0.5	1.7	--	0.2	4.2	11.0	15.2
200 Krad	76.9	76.5	16.7	13.1	2.3	3.6	1.3	0.7	2.8	6.1	8.9

* Class definitions:

1. Fruit sound - Minor defects; acceptable.
2. Fruit sound - Moderate defects; acceptable.
3. Fruit is slightly soft with minor and moderate defects evident.
4. Fruit soft - Collapsed or nearly so, or unacceptable defects.
5. Fruit has decay lesions, either inactivated or with mycelia present, (fruit with achenes infected with Cladosporium are not included if infection would not limit marketability).

** Compare evaluation II Davis with evaluation I St. Louis.

Table 6. Allo-Kramer shear press. Crushing resistance of irradiated and unirradiated strawberries.

	Lbs. force required*
0 Krad	86.58
200 Krad	74.38**

* Average of 16, 150 gram samples.

** Significantly different at P=0.01.

II. EFFECT OF COMBINATION HEAT AND IRRADIATION TREATMENTS ON STRAWBERRIES.

The use of combination treatments of heat and irradiation may reduce the irradiation dose required for rot control by one-half. Presented here are descriptions of 2 series of experiments conducted to test the effect of combination treatments on strawberry fruits.

GENERAL PROCEDURE

Experiment No. 1 (Early summer): Texture measurements of strawberries treated with heat and irradiation: The fruit was transported from Salinas to Davis at 37°F in a refrigerated truck, sorted into three maturities (M_1 - mostly green; M_2 - pink or slightly green; M_3 - fully ripe), and stored overnight at 33°F. The following day 9 baskets of each maturity were given the following treatments: control - no treatment; 200 Krad only; heated in 110°F moist air for 30 min plus an additional 20 min in an insulated box; and the above heat treatment plus 200 Krad. The heated berries were treated in the morning, cooled and those to be irradiated were treated in the afternoon. All berries were then stored at 41°F until sampled 1, 7, and 10 days following irradiation.

Three baskets from each maturity and treatment were sampled on each shear date. The fruit was warmed to room temperature by forced air prior to shearing. Five samples of 150 gram each were crushed in a metal box with a flat-plate plunger. Stems were not removed (we had shown earlier that the stems did not affect the shear readings). Maximum peaks were recorded and analyzed using analysis of variance.

RESULTS

The results are summarized in Table 7. The treatments and maturity affected the shear readings the most with days in storage having a lesser effect. The treatment by maturity interaction was significant. This is partly explained by the fact that there were

Table 7. Effect of heat and 200 Krad of gamma radiation alone and in combination on texture of 'Shasta' strawberries.*

	Treatment by maturity interaction				
	Control	200 Krad	Heat	Heat + irrad.	Maturity average
M_1 (green)	104.27	75.67^{d}	98.60	72.13^{cd}	87.67
M_2 (pink)	86.93^{e}	66.60^{b}	88.27^{e}	67.93^{bc}	77.43
M_3 (ripe)	75.73^{d}	61.80^{a}	77.13^{d}	61.33^{a}	69.90
Treatment Averages	66.73^{a}	51.02^{b}	66.00^{a}	50.35^{b}	
	Day 1	Day 7	Day 10		
Day Averages	76.32^{a}	83.43	74.35^{a}		

* Average shear press readings on berries heat and irradiation treated are given for the main effects and the treatment by maturity interaction.

Averages connected by the same letter are not significantly different at the 0.05 level of probability.

greater treatment differences in the green berries (M_1) than in the other maturities. When compared to the controls, there was a decrease in crushing resistance of the heat-treated berries in the green stage (significant on 7th day only). But for the other two maturities, the heat treatment resulted in significantly firmer berries the 7th and 10th days.

Overall, the treated berries crushed the 10th day tended to measure the same as those taken the first day, with the 7th day being significantly firmer than the other two. The controls were significantly softer the 10th day.

There were no significant differences between the 200 Krad alone versus heat plus 200-Krad treatments.

Experiment No. 2 (Late summer): The treatments were:

1. Control - no treatment.
2. Heat - held in moist air at 106°F for 36 min.
3. Irradiation - 200 Krad.
4. Heat and irradiation - heated at 106°F for 36 min, cooled and irradiated to 200 Krad.

PROCEDURE

Two studies were made. The first lot was evaluated by using the triangle test for flavor and aroma and by crushing the berries using the Allo-Kramer shear as described in our earlier reports. Texture was evaluated in a paired test on the sliced fruit. The fruit was tested 2, 3, 4, 7, 8, 9, and 10 days after treatment. The second lot was evaluated with a paired test and only sliced fruit was used. Evaluations followed on 1, 2, 3, 4, 7, 8, 9, and 10 days after treatment. The treated lots were always compared to the control. Eleven to twelve experienced judges evaluated flavor and texture under red illumination, and color under Haluk grading lamps.

One shear press reading per treatment was made each day of sensory evaluation (with the exception of the first week). The flat-plate plunger and 150 gram samples were used for all readings.

RESULTS

There was little difference in flavor in either the triangle or paired test (Tables 8 and 9). One comparison in each test was significant at P=0.05. The aroma comparisons were not consistent from test to test or week to week and no definite conclusions can be drawn.

The strawberries treated with irradiation or heat and irradiation were significantly softer according to the judges. In the first texture test there was a tendency for the heat treated berries to be firmer. This was not significant, however, and there was no difference in the second test.

The shear readings are summarized in Table 10. The differences between the treatments were the same each session and show the same direction as indicated by the judges. The controls, however, were not significantly different from any of the treatments, while the judges could distinguish between the control and the two treatments.

Experiment No. 1: Effect of heat and irradiation alone and in combination on the ascorbic-acid content of strawberry fruits:

PROCEDURE

'Shasta' strawberries were obtained from a Sacramento wholesaler and used in tests to study the combination of heat and irradiation on the ascorbic-acid content of the fruit.

Strawberry crates were split in half and equal quanities randomly selected for treatment as follows: 0 Krad, no heat; 0 Krad + heat; 200 Krad, no heat; and 200 Krad + heat. Fruit to be heated was placed in a 110°F steam chamber for 30 min and then placed in an

Table 8. Results of the first sensory evaluation session using the triangle test and the paired test on irradiation and heat treated berries.

	Con vs. 106°F	Con vs. 200 Krad	106°F + Con vs. 200 Krad
FLAVOR - Triangle Test			
1st week	14/36 judgments	13/36 judgments	16/36 judgments
2nd week	21/48 judgments	13/48 judgments	23/48* judgments
AROMA - Triangle Test			
1st week	12/36 judgments	12/36 judgments	20/36** judgments
2nd week	32/48*** judgments	12/48 judgments	24/48* judgments
TEXTURE - Paired Test			
1st week	21 - 15	16 - 20	8 - 28**
2nd week	31 - 17	12 - 36***	16 - 32*

* Significant at P=0.05.

** Significant at P=0.01.

*** Significant at P=0.001.

Table 9. Results of the second sensory evaluation using only the paired test.

	Con vs. 106°F	Con vs. 200 Krad	Con vs. 106°F + 200 Krad
FLAVOR - Better Flavor			
1st week	25 - 19	15 - 29*	20 - 24
2nd week	24 - 20	19 - 25	18 - 26
AROMA - Better Aroma			
1st week	33** - 11	14 - 30*	17 - 27
2nd week	22 - 22	29* - 15	19 - 25
TEXTURE - Softer			
1st week	20 - 24	5 - 39***	9 - 35***
2nd week	21 - 23	12 - 32**	9 - 35***

* Significant at P=0.05.

** Significant at P=0.01.

*** Significant at P=0.001.

Table 10. Allo-Kramer shear press readings taken during sensory evaluation. Data are expressed in pounds force.

	106°F	Control	200 Krad	106°F + 200 Krad
1st session - Ave. of 4 readings:				
	90.5	79.8	68.5	70.0
2nd session - Ave. of 8 readings:				
	104.5	100.8	89.6	89.5

Figures connected by the same line are not significantly different at P=0.05.

insulated box to maintain the temperature for an additional 20 min. The fruit was then cooled to room temperature by placing in a 32°F room with circulating air for 15 min. Fruit to be irradiated was treated at ambient temperature to 200 Krad. Following treatment one-half of the fruit was analyzed immediately (one day later) and the remainder stored at 41°F for analysis after 10 days.

Sampling for ascorbic-acid analysis consisted of one quarter of each of 25 sound berries selected at random from each triplicate sample per treatment. As in our previous work on ascorbic acid, the methods of Loeffler and Ponting (1942, Ind. Eng. Chem. Anal. Ed., 14:846-849) and Hughes (1956, Biochem. J., 64:203-208) were used for analysis. Values for dehydro-ascorbic acid were obtained by substracting the value for reduced from the total ascorbic acid present. All ascorbic-acid data are reported as mg ascorbic acid per 100 gm fruit.

The results are shown in Table 11. There was no effect of any treatment on the ascorbic-acid content of fruits analyzed 1 day after treatment. After 10 days at 41°F, there was slightly less ascorbic acid in fruits subjected to 200 Krad than in unirradiated fruit. Heat alone, and in combination with irradiation exerted no measurable effect on the ascorbic-acid content of the fruit.

Experiment No. 2:

PROCEDURE

The procedure was the same as in Experiment No. 1, except that fruits were sampled at 1, 7, and 10 days.

RESULTS

The results of the second experiment are shown in Table 12. Again, heat alone and in combination with irradiation, exerted no

Table 11. Effect of heat and irradiation alone and in combination on the ascorbic-acid content of 'Shasta' strawberry fruits.*

Days storage at 41°F	Form of ascorbate	No heat treat		Heat treated	
		0 Krad	200 Krad	0 Krad	200 Krad
1	Reduced	45.36	36.64	43.88	36.19
1	Dehydro	2.69	11.03	4.83	13.07
1	Total	48.06	47.67	48.71	49.26
10	Reduced	48.73	37.73	49.74	42.13
10	Dehydro	4.77	7.83	4.80	6.35
10	Total	53.49	45.56	54.54	48.48

* Comments:

1. Immediately after irradiation: Appears to be a conversion from reduced to dehydro-ascorbic in irradiated samples (since total ascorbic-acid values are similar for all treatments).

2. Ten days after irradiation: Unirradiated sample show an increase of total ascorbic acid after storage. No change in total ascorbic occurred in irradiated samples after storage.

Table 12. Effect of heat and irradiation alone and in combination on the ascorbic-acid content of 'Shasta' strawberry fruits.

Days storage at 41°F	Form of ascorbate	No heat treat		Heat treated	
		0 Krad	200 Krad	0 Krad	200 Krad
1	Reduced	87.63	65.55	79.47	64.68
1	Dehydro	5.45	15.29	8.08	16.05
1	Total	93.06	80.84	87.57	80.73
7	Reduced	85.56	71.94	86.11	74.00
7	Dehydro	6.18	8.03	5.09	9.69
7	Total	91.74	79.97	91.20	83.68
10	Reduced	86.87	81.95	86.66	82.47
10	Dehydro	3.35	3.72	3.94	5.48
10	Total	90.21	85.67	90.60	87.95

Strawberries from Salinas Strawberries, Inc.

measurable effect on the ascorbic-acid content of the fruit as compared to irradiation alone.

III. EFFECT OF CALCIUM SOAKS ON TEXTURE OF IRRADIATED STRAWBERRIES.

Gamma irradiation has been shown to induce calcium release from plant tissues. Theoretically, one might expect to partially offset the textural loss in fruits such as strawberries by soaking the fruit in solutions of calcium salts. However, there is reason to doubt the practical applicability of the process for: 1) strawberries and many other fruits cannot tolerate dipping because of damage to the fruit and/or the package; and 2) the relative immobility of calcium in plant systems make it improbable that the calcium ion would penetrate into the cells in sufficient amounts to materially affect the texture of irradiated fruits.

Two tests were conducted with 'Shasta' strawberries to determine the effect of calcium soaks on the texture of the irradiated fruits. The treatments were: no soak; water soak; 0.5% calcium soak in combination with 0 and 200 Krad applied before and after soaking. For each of the two studies 6 crates of 'Shasta' strawberries were sorted and only sound fruit used. Six individual pint baskets (about 5 pounds) were used for each treatment. Water and 0.5% $CaCl_2$ soaks were made for one hour. Those berries to be irradiated following treatment were drained approximately 1/2 hour. Following treatments, all berries were stored at 32°F for 7 or 8 days, warmed to room temperature, and sheared. Eight samples of 100 gram each were sheared for each treatment using the standard shear compression cell.

RESULTS

The treatment averages and analysis of variance table are summarized in Tables 13 and 14. There was a very highly significant difference between irradiated and control samples as has been shown in previous experiments. Neither experiment showed a significant difference between soaking in 0.5% $CaCl_2$ solution vs. no soaking. The water-soaking treatment was significantly softer than the other two treatments in the first experiment and significantly softer than the 0.5% $CaCl_2$ treatment in the second experiment.

From these data it is clear that calcium soaks have no value in firming irradiated strawberry fruits.

Table 13. Effect of using a $CaCl_2$ soak prior to irradiation on texture of 'Shasta' strawberries.

	No soak	Water soak	0.5% $CaCl_2$ soak	
	lbs.	lbs.	lbs.	Overall mean
0 Krad	61.88	63.38	62.75	62.67
200 Krad after soak	49.62	47.75	51.62	49.67[a]
200 Krad before soak	48.25	44.12	50.00	47.46[a]
Overall mean	53.25[ab]	51.75	54.79[b]	

Analysis of Variance Table

	S.S.-	D.F.	M.S.	F.
Total	4475.99	71		
Dose	3241.36	2	1620.68	100.10**
Soak	111.03	2	55.52	3.43*
Interaction	103.73	4	25.93	1.60
Error	1019.87	63	16.19	

Means followed by the same letter are not significantly different at 0.05 level of probability.

Table 14. Effect of a post-irradiation soak in $CaCl_2$ on texture of 'Shasta' strawberries.

	No soak	Water soak	0.5% $CaCl_2$ soak	
	lbs.	lbs.	lbs.	Overall mean
0 Krad	58.50	57.38	55.38	57.08
200 Krad after soak	43.38	41.75	48.25	44.46[a]
200 Krad before soak	48.75	42.50	47.75	46.33[a]
Overall mean	50.21[a]	47.21	50.46[a]	

Analysis of Variance Table

	S.S.	D.F.	M.S.	F.
Total	3804.88	71		
Dose	2227.76	2	1113.88	59.79**
Soak	157.00	2	78.50	4.28*
Interaction	246.50	4	61.62	3.31*
Error	1173.62	63	18.63	

Means followed by the same letter are not significantly different at 0.05 level of probability.

GAMMA IRRADIATION FOR PROCESSING OF APPLE JUICE

Carol F. Johnson

Workers at Seibersdorf, Austria, have reported good results with irradiation for processing of apple juice. California is a leading state in the production of thermally processed apple juice, and the injustry has expressed an interest in the possible use of irradiation. Reported here are the results of an experiment to test the effect of gamma irradiation on commercially pressed apple juice.

PROCEDURE

Apple juice (90 quarts each filtered and unfiltered) was purchased from Ryder and Sons in Watsonville, California. Some of the juice was pasteurized commercially and bottled. The remaining juice was bottled, steam capped, and immediately chilled with ice. Transportation to Davis was under refrigerated conditions at 37°F. The controls to be frozen were placed at 10°F immediately and the remainder of the juice held at 36°F until the following day. Part of the juice was treated to 300 Krad and another group heated to 50°C in hot water and irradiated to 300 Krad while held at this temperature (about 1 hr).

SENSORY EVALUATION

The taste-panel evaluations were scheduled for a 2-month period, with sampling at 0, 1, and 2 months. However, the study was terminated early from losses due to fermentation. The filtered juice was evaluated the 1st week after irradiation and the unfiltered juice the 2nd week following irradiation and again the 6th week. In filtered samples the 300 Krad only treatment was evaluated the 1st week only, after which time all samples fermented. The unfiltered juice lasted longer than the filtered in both the quart bottles and 60-ml serum bottles. According to the processor, there may have been a build up of yeast in the filtering process used.

Two different tests were used to evaluate the juice - a paired and a traingle test. All judges were trained using apple juice adjusted to different levels of sweetness and acidity. Nine to ten judges used the triangle test in which they were asked to select the odd sample. Six other judges evaluated the juice in a paired comparison in which they were asked to indicate the sample with the better flavor and the degree of difference (Scheffe, J. Am. Stat. Ass., 47:381, 1952). Tasting was done for 4 consecutive days each evaluation week. The flavor samples were served in small glass beakers under red lights, and aroma samples in capped glasses (50 ml of juice).

PHYSICAL MEASUREMENTS

Titratable acidity expressed as percent malic acid and soluble solids were taken on the juice served for the taste panel. Acidity determinations were made on two days and soluble solids on all 4 evaluation days. The data were not analyzed statistically.

RESULTS

The results of the sensory evaluations are summarized in Tables 1, 2, and 3. Data from the panel using the paired test resulted in more significant differences between treatments than the data from the panel using the triangle test. The plus scores in the paired test indicate the samples which were more often selected as having a better flavor. The scores do not represent overall quality but differences as related to "better flavor".

Table 1. Sensory evaluation of filtered apple juice the first week following heat and irradiation treatment.

FLAVOR

Triangle test		Paired test F=56.87 σ^2 = 5.77		soluble solids	acidity
Frozen vs. 300 Krad	23/38***	Frozen	+1.271	13.80	0.355
		Pasteurized	+0.979	13.68	0.334
Frozen vs. 50°C + 300 Krad	14/38	50°C + 300 Krad	-0.479	13.50	0.362
Pasteurized vs. 300 Krad	27/38***	300 Krad	-2.729	13.60	-.378
Pasteurized vs. 50°C + 300 Krad	19/38*				

AROMA

Triangle test		Paired test F=97.58 σ^2 = 5.21	
Frozen vs. 300 Krad	31/37***	Frozen	+1.604
		Pasteurized	+1.458
Frozen vs. 50°C + 300 Krad	18/37*	50°C + 300 Krad	+0.271
Pasteurized vs. 300 Krad	29/37***	300 Krad	-3.333
Pasteurized vs. 50°C + 300 Krad	21/37**		

* Significant at P=0.05.

** Significant at P=0.01.

*** Significant at P=0.001.

Scores connected by the same line are not significantly different at P=0.05.

Table 2. Sensory evaluation of unfiltered apple juice the second week following treatment.

FLAVOR

Triangle test		Paired test F=27.52 σ^2 = 5.14		soluble solids[a]	acidity[a]
Frozen vs. Pasteurized	16/39	Frozen	+0.805	13.85	0.384
		Pasteurized	+0.750	13.55	0.365
Frozen vs. 50°C + 300 Krad	14/39	50°C + 300 Krad	-1.555	13.75	0.392
Pasteurized vs. 50°C + 300 Krad	19/39*				

AROMA

Triangle test		Paired test F=22.52 σ^2 = 6.90	
Frozen vs. Pasteurized	20/38*	Frozen	+0.778
		Pasteurized	+0.917
Frozen vs. 50°C + 300 Krad	22/38**	50°C + 300 Krad	-1.695
Pasteurized vs. 50°C + 300 Krad	28/38***		

* Significant at P=0.05.

** Significant at P=0.01.

*** Significant at P=0.001.

Scores connected by the same line are not significantly different at P=0.05.

[a] Data not analyzed.

Table 3. Second sensory evaluation of unfiltered apple juice the sixth week following treatment.

FLAVOR

Triangle test		Paired test $F=6.20$, $\sigma^2=8.08$		soluble solids[a]	acidity[a]
Frozen vs. Pasteurized	15/35	Frozen	+0.805	13.90	0.384
Frozen vs. 50°C + 300 Krad	15/35	Pasteurized	+0.056	13.60	0.362
Pasteurized vs. 50°C + 300 Krad	17/35	50°C + 300 Krad	-0.861	13.85	0.396

AROMA

Triangle test		Paired test $F=14.56$, $\sigma^2=7.94$	
Frozen vs. Pasteurized	15/35	Frozen	+1.028
Frozen vs. 50°C + 300 Krad	17/35	Pasteurized	+0.389
Pasteurized vs. 50°C + 300 Krad	15/35	50°C + 300 Krad	-1.416

Scores connected by the same line are not significantly different at P=0.05.

[a] Data not analyzed.

There were no differences for flavor or aroma between the frozen and pasteurized samples in either test. On the second testing of the unfiltered juice, only the paired test resulted in differences between the controls (pasteurized and frozen) and the treated samples. Both tests indicated fewer differences between the unfiltered samples after they had been in storage for 6 weeks. The judges described some off flavors in the heat and irradiated samples for the unfiltered juice and in the irradiated only samples for the filtered juice.

Acidity and soluble solids averages are also given in Tables 1, 2, and 3. The pasteurized samples were slightly lower in soluble solids and acidity as compared to the frozen samples, while the heat and irradiated samples were slightly higher in acidity.

Table 4 gives a tabulation of the length of storage for the samples treated in the serum bottles and shows that the unfiltered samples held up better in storage.

We consider these results encouraging and believe that irradiation should be thoroughly tested as a processing technique for apple juice.

Table 4. A tabulation by days of number of bottles in storage at 68°F before the seal on 60-ml serum bottles was broken by gases produced by fermentation. There were a total of 28 bottles in each treatment group.

Days after irradiation	Filtered				Unfiltered			
	con	heat	irrad	heat + irrad	con	heat	irrad	heat + irrad
4	7	-	-	-	6	2	6	-
5	2	6	1	-	7	-	5	-
7	3	18	3	-	11	9	12	1
8	5	-	-	1	3	2	-	-
11	8	3	10	3	1	12	3	6
12	-	-	2	3	0	-	-	2
13	-	1	2	1		3	-	3
14	-	0	4	4		0	-	1
15	-		1	-			-	-
18	-		3	5			1	-
21	-		1	2			-	1
25	-		-	-			1	1
26	-		-	2			0	-
32	-		-	1				-
55	-		-	1				-
74	-		-	-				1
Remaining bottles after 84 days	3		1	5				12

STUDIES ON IRRADIATED MANGOES AND PAPAYAS

Carol F. Johnson, Henry L. Rae,
Richard Stallman and E. C. Maxie

One experiment each was conducted during 1967 on mangoes and papayas irradiated in Hawaii and shipped to California. The data from these experiments have been submitted to the Hawaii Department of Agriculture for inclusion in their annual report. Both fruits show excellent response to irradiation in our opinion.

EFFECT OF HEAT AND IRRADIATION ALONE AND IN COMBINATION ON THE TEXTURE OF SWEET CHERRIES

Carol F. Johnson, E. C. Maxie and Richard Stallman

Combination heat and irradiation treatments have shown less injury to peaches and nectarines than irradiation alone because the dose required is reduced approximately one-half. Thus combination treatments were used on sweet cherries to test the effect on texture of the fruit.

GENERAL PROCEDURE

Field run fruit was sorted and treated the same day as harvested. Heat treatments were made in moist air at 45°C for 5 and 15 min. The fruit was cooled and irradiated at a dose of 100 Krad. The fruit was stored at 41°F in 7 to 8 # lots in open containers. Each treatment was composed of 4 lots or reps which were sampled for shear readings 1 and 6 days after treatment.

One hundred gm samples of pitted cherries (about 14 fruit) were sheared on the Kramer shear press using the standard shear compression cell and 30-second stroke. The fruit was warmed to room temperature prior to the texture readings.

The maximum peaks were recorded and analyzed by analysis of variance.

RESULTS

The average shear values for each treatment are given in Table 1, along with the overall averages. There was a statistically significant softening due to irradiation. The overall heat treatment resulted in higher texture readings in fruits subjected to 45°C for 5 min when compared with those receiving no heat, and those receiving 45°C for 15 min, with the differences being most evident after 6 days. Overall the cherries sheared on the 6th day tended to be softer than those sheared the 1st day after irradiation.

Table 1. A summary of the shear readings taken on Bing cherries treated with heat and irradiation.

	No treatment	45°C 5 min	45°C 15 min	100 Krad	45°C 5 min + 100 Krad	45°C 15 min + 100 Krad
1 day after[a] irradiation	260.8	273.5	270.0	225.5	233.0	222.0
6 days after[a] irradiation	261.8	265.8	249.5	214.2	239.2	209.0

Overall averages:

Irradiation[b]	0 Krad -	263.5
	100 Krad -	223.8
Time[b]	1 day -	247.5
	6 days -	239.9
Heat[c]	45°C - 5 min -	252.9
	45°C - 15 min -	237.6 |
	No heat -	240.6 |

[a] Each figure is an average of 4 readings.

[b] Each figure is an average of 24 readings.

[c] Each figure is an average of 16 readings.

For the overall averages, figures connected by the same line are not significantly different at P=0.05.

EFFECT OF GAMMA IRRADIATION ON TEXTURE OF DATES

E. C. Maxie, Richard Stallman and Carol F. Johnson

In many seasons, dates grown in the Imperial Valley of California fail to soften to an acceptable texture upon ripening. At the request, and with the cooperation of Dr. Charles W. Coggins of the Department of Horticultural Sciences, University of California, Riverside, California, we investigated the effects on texture of dates of a wide range of doses of gamma irradiation.

GENERAL PROCEDURE

The dates were irradiated at 32°F to doses of 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 and 1100 Krad. They were stored for 4 days at 32°F, warmed to room temperature, and sheared with the Allo-Kramer shear press. A second shear reading was made after 2 weeks storage at room temperature.

Individual dates were split, pitted and placed cut side down in a standard shear compression cell. A 30-second down stroke was used for all readings. Ten dates were measured for each treatment on each shearing date.

RESULTS

Table 1 summarizes the results of the shear readings. There were no statistically significant differences between treatments taken the first time. After holding the fruit at room temperature for 2 weeks, significant differences at the 0.05 level of probability were found. The results were too erratic for any consistent trends concerning the effect of irradiation on dates. There was no practical softening effect of irradiation on the texture of the dates.

Table 1. Average shear press readings[a] for irradiated dates.

	Pounds force to shear											
	Krad											
	0	100	200	300	400	500	600	700	800	900	1000	1100
1st shear readings	242.3	271.6	228.6	242.8	230.4	249.1	257.2	254.9	238.5	265.2	232.0	262.2
	200	800	700	600	1100	1000	500	300	0	900	400	100
2nd shear readings	230.2	230.5	257.5	257.8	260.7	272.6	275.3	276.9	279.6	280.1	280.7	302.1

[a] Each figure represents an average of 10 determinations.

Figures connected by the same line are not significantly different at 0.05 level of probability.

EFFECT OF DOSE RATE OF GAMMA IRRADIATION ON LEMON FRUITS

E. C. Maxie, Henry L. Rae and Richard Stallman

A key parameter that has not received adequate attention in the irradiation of fruits and vegetables is the effect of dose rate. We chose to study this parameter by using the effects of gamma irradiation on the ascorbic-acid content of lemon fruits, since the general effects had been precisely determined earlier (Maxie et al., Radiation Botany 4:405-411, 1964).

PROCEDURE

Commercially mature, but green 'Eureka' lemons were obtained directly from a packing house near Riverside, California. The lemons were transported to Davis in vented boxes at ambient temperatures and treated within 7 days of harvest.

Fruits were irradiated to 0 and 200 Krad. Half of the irradiated fruit was given a fast dose-rate treatment by irradiating in the center chamber of the Mark II Irradiator to 200 Krad in 43 min; the other half was given a slow dose rate which required 8 hours and 20 minutes. The latter was achieved by placing a single layer of 12 fruits in the center chamber of the Mark II and lowering the chamber to a position 32 inches above the floor of the well. Fruits were irradiated at ambient temperature and subsequently stored at 59°F. Quadruplicate samples of 6 fruits each were withdrawn for analysis 0, 15, and 26 days after irradiation.

Data were recorded on percent weight loss of the intact fruit, then samples were juiced with the Sunkist Power Reamer and the juice analyzed for ascorbic acid, percent citric acid, percent soluble solids and percent recoverable juice. An appropriate volume (20 or

25 ml) of juice was filtered through cheesecloth and analyzed for ascorbic acid by the methods of Loeffler and Ponting (1942, Ind. Eng. Chem. Anal. Ed. 14:846-849) and Hughes (1956, Biochem J. 64:203-208).

An analysis of variance was made on each set of data except for dehydro-ascorbic acid.

RESULTS

Table 1 shows the effect of slow vs. fast rate of gamma irradiation on the ascorbic-acid content of juice extracted from lemon fruits.

Ascorbic-acid content of all irradiated fruit declined over the experimental period; the total ascorbic acid loss became significant (P=0.01) by the last evaluation date, while the reduced ascorbic acid loss was significant at each testing period. The analysis of variance showed that the irradiated samples contained significantly less ascorbic acid (total and reduced) than the control samples (P=0.01). No significant differences existed between those samples receiving slow and fast rates of irradiation.

Table 2 shows the effect of slow vs. fast rate of gamma irradiation on some chemical and physical attributes of lemons.

All attributes for irradiated fruit except percent weight loss decreased in value over the time of the experimental period; the percent weight loss increased. The percent citric acid for all treatments are statistically different (P=0.01) from the other, with the fast dose rate showing the greatest loss of acidity. In all other measurements, no statistical differences exist between the slow and fast irradiation treatments. Irradiation resulted in a reduction in percent soluble solids and percent recoverable juice, and increased the weight loss due to storage.

From the data presented here, dose rate does not seem critical with respect to the feasibility of using gamma irradiation. However, much more work needs to be done before a firm conclusion can be drawn.

Table 1. Effect of slow vs. fast application of gamma rays on ascorbic-acid content of lemons. Results expressed as mg ascorbic acid per 100 ml juice.

Days following irradiation		Control	200 Krad Fast	200 Krad Slow	
			Total ascorbic acid		Mean
0		38.68[a]	39.04	38.27	38.68
15		41.56	36.53	34.93	37.67
26		40.00	22.71	24.36	29.02
	Mean	40.08	32.75	32.52	
			Reduced ascorbic acid		Mean
0		39.62	38.46	36.49	38.19
15		39.94	33.20	30.56	34.67
26		39.00	18.07	21.40	26.15
	Mean	37.85	29.91	29.48	
			Dehydro-ascorbic acid[1]		
0		-----	0.58	1.78	
15		1.62	3.34	4.36	
26		1.00	4.64	2.96	

[a] Average of 4 reps/treatment/day.

[1] Dehydro-ascorbic acid not analyzed statistically.

Any mean values connected by the same line are not statistically significant at 0.01 level of probability.

Table 2. Effect of slow vs. fast application of gamma rays on some chemical and physical measurements on lemons.

Days following irradiation		Control	200 Krad Fast	200 Krad Slow	
			% Citric acid[a]		Mean
0		5.46	5.16	5.28	5.30
15		5.73	4.60	4.60	4.96
26		5.94	4.05	4.30	4.76
	Mean	5.71	4.59	4.73	
			% Soluble solids[b]		Mean
0		7.58	7.52	7.55	7.55
15		7.85	7.28	7.28	7.48
26		7.95	6.72	7.05	7.24
	Mean	7.99	7.18	7.29	
			% Wt loss[c]		Mean
0					
15		6.2	6.1	6.6	6.30
26		5.6	7.4	7.8	6.92
	Mean	6.15	6.74	7.20	
			% Juice[d]		Mean
0		58.79	52.88	54.45	55.37
15		54.26	52.83	49.08	52.06
26		51.31	54.41	50.05	51.92
	Mean	54.78	53.37	51.19	

[a] Total acidity as % anhydrous citric acid.

[b] Average of 4 reps/treatment/day.

[c] Wt loss as % fresh wt.

[d] % juiced reamed based on storage wt.

Any mean values connected by the same line are not statistically significant at 0.05 level of probability.

EFFECT OF IRRADIATION ON THE VOLATILE COMPOUNDS OF APPLE JUICE*

Walter Henning
Department of Food Science and Technology

INTRODUCTION

Irradiation pasteurization of fruit, fruit juices, and vegetables has been one of the major areas of research in recent years at the University of California at Davis. Extensive studies have been made on the irradiation pasteurization of apple juice. Sensory evaluation of the irradiated juice indicated that the volatile compounds may have been slightly altered, although the product was still acceptable. This study was to determine whether or not the volatile compounds were indeed affected, and if so, to determine what chemical changes were induced by irradiation.

METHODS AND APPARATUS

A. IRRADIATION TREATMENT.

The apple juice samples were irradiated in one quart bottles in the Mark II Food Irradiator. The samples were given doses of 300, 500, 750 and 1000 kilorad (Krad). The apple juice used in this experiment was made from a mixture of Delicious and Yellow Newtown pippen in the ratio of 2:1. Prior to irradiation the juice was kept frozen at 10°F.

B. METHODS OF ISOLATING THE VOLATILES.

Devising a technique for isolating the volatile compounds from fresh or irradiated apple juice in high enough concentration to be chromatographed, separated, and analyzed, proved to be our major problem.

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* **Part of a Master of Science project done cooperatively between the Department of Food Science and Department of Pomology.**

We found that adsorption of the volatiles onto activated charcoal was the most satisfactory means of collecting them. The samples, both fresh controls and the irradiated, were distilled separately under vacuum. The water vapor and volatile compounds were then recondensed and passed through 400 mg of activated charcoal. The charcoal was eluted three successive times with carbon disulfide. An equal volume (about 2 ml) of carbon tetrachloride was then added to the combined carbon disulfide fractions. This solution was condensed to about 50 μls by blowing nitrogen over it. Since the CS_2 has a much higher vapor pressure than the CCl_4, we were left with essentially 50 μls of CCl_4 containing the volatile compounds. This solution was sufficient for gas chromatography.

A second method employed for isolating the volatiles from the apple juice was direct ether extraction. We subjected each quart of apple juice analyzed to three successive extractions with 150 ml of ether. The ether phases for each sample were combined and condensed to a small volume first by careful heating and then by blowing nitrogen over the solution. This small volume of ether containing the volatiles could be chromatographed directly after we inserted a pre-column into our GLC apparatus. The pre-column was required to trap any non-volatile compounds which might have been picked up from the direct ether extraction.

C. GAS-LIQUID CHROMATOGRAPHY OF THE VOLATILES.

The volatiles were subjected to gas-liquid chromatography for separation and retention time analysis. Two different columns were used, one being a 1/8" x 10' triton x-305 column with a thermal detector. Further analysis was done by using a 1/8" x 19' SF96 (50) column coupled to a flame detector. The flow rates for the columns were 60 μl/min for the triton x-305 and 35 μls/min for the SF96 (50) column. Most of the chromatograms were programmed between 70°C and 150°C, although many were run isothermally at either 72°C or 187°C.

D. INFRARED ANALYSIS.

Infrared analysis was performed using a Beckman IR8 infrared spectrophotometer.

PROCEDURES AND RESULTS

Upon comparing chromatograms of apple-juice volatiles given 1000 Krad with chromatograms of fresh apple-juice volatiles, it was observed that two peaks were noticeably decreased following the irradiation treatment. The first of these two peaks was collected and by infrared spectroscopy was determined to be trans 2-hexenal (labeled 'H' on Figs. 1-3). The identification of this compound was further confirmed by comparing its retention time on the SF96 (50) column with that of known pure trans 2-hexenal obtained from K and K Laboratory in New York. Although the irradiation effect on trans 2-hexenal was very distinct with a dose of 1000 Krad, we found that the decreases in this compound with doses smaller than 1000 Krad was much less distinct (see Figs. 1-3). An experiment was designed to show how the concentration of trans 2-hexenal decreased with increasing dose, and the results are shown in Table 1.

Since trans 2-hexenal decreased with increasing dose, our interest now centered on what became of this particular compound. If trans 2-hexenal was being converted into another volatile compound we should have noticed either a new peak following irradiation or an enhancement of a peak already present with the fresh juice. Neither was found. Consequently we utilized a model system to attempt to explain our findings. Using various amounts of trans 2-hexenal (from 1 μl to 15 μl) in quart bottles of distilled water, we attempted to discover what became of this compound during irradiation.

Chromatograms of these irradiated model system samples revealed about seven low boiling compounds, all present in very low concentrations. We were able to detect these compounds only with the hydrogen flame

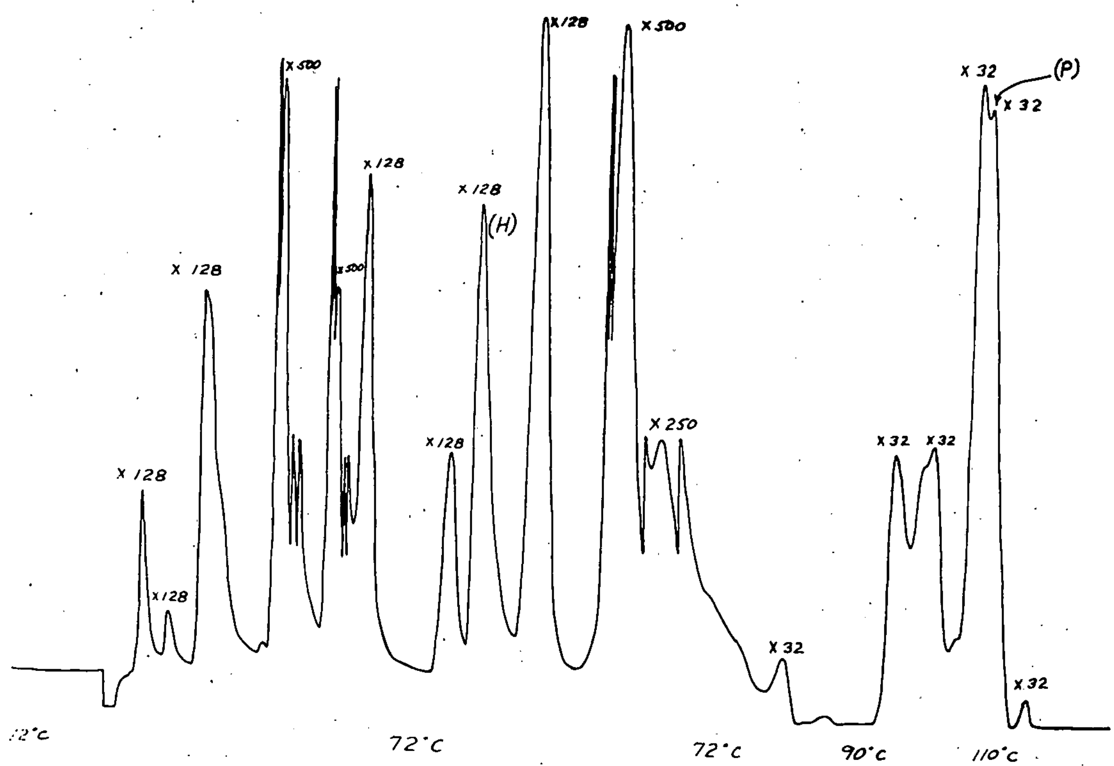

Fig. 1. Volatile compounds of fresh apple juice (0-30 mins.)

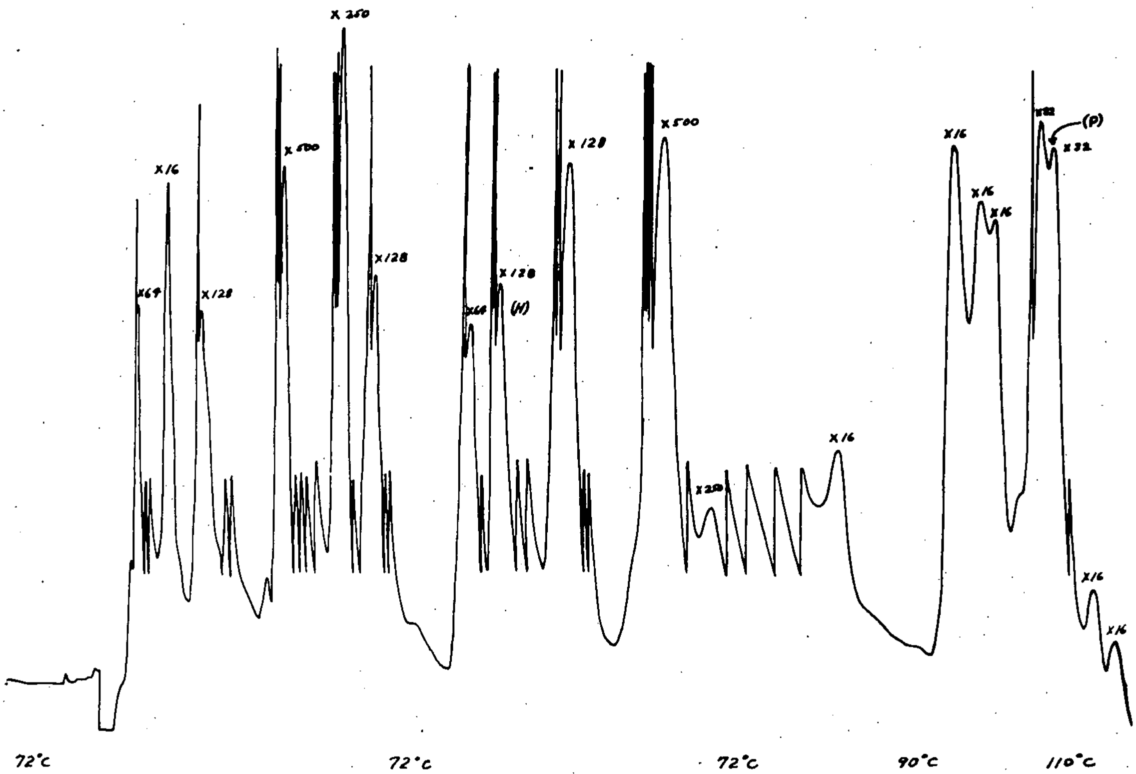

Fig. 2. Volatile compounds from irradiated apple juice (300 Krad) 0–30 mins.

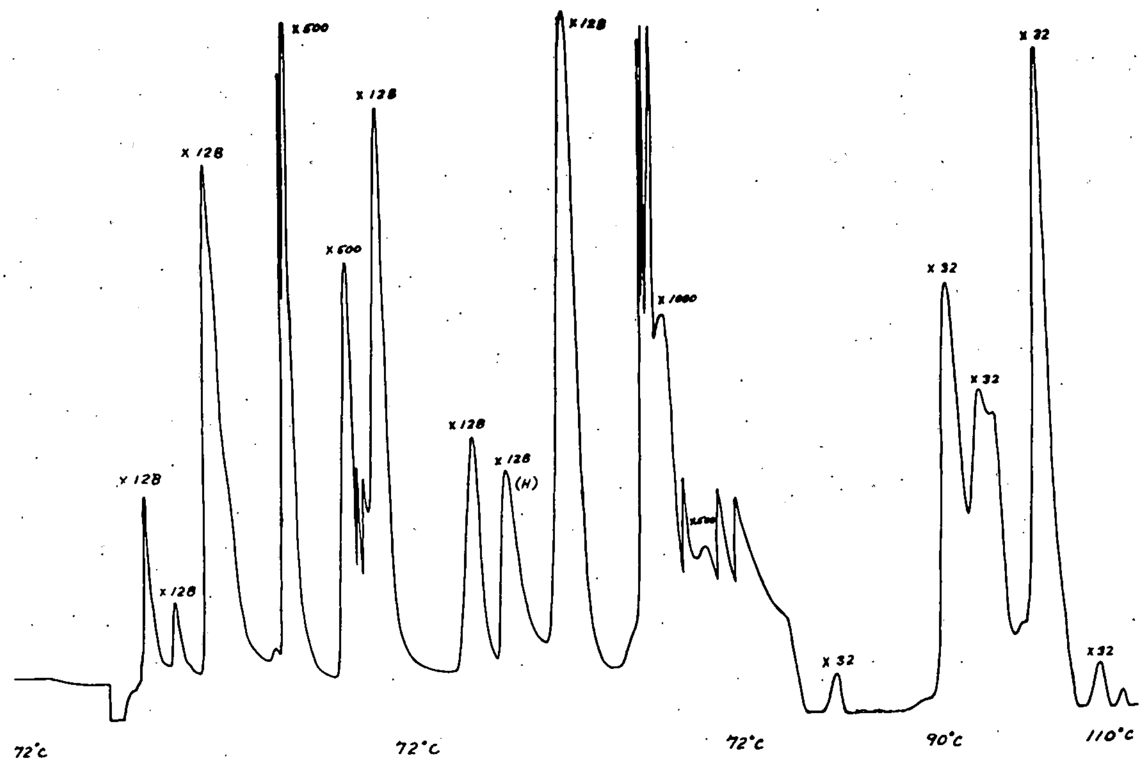

Fig. 3. Volatile compounds from irradiated apple juice (1000 Krad) 0-30 mins.

Table 1. Effect of gamma radiation on trans 2-hexenal.

Dose (Krad)	% of trans 2-hexenal remaining
0	100% (control)
300	98%
500	75%
750	38%
1000	19%

detector. Since unirradiated control samples yielded huge 2-hexenal peaks, and the irradiated samples yielded only very small peaks, we knew the irradiated 2-hexenal had been transformed primarily into a non-volatile compound. Ether extractions of the irradiated samples showed the product to be a greenish-white polymer.

We believe the second peak which decreased with increasing irradiation dose is trans 2-hexene 1-yl acetate. This compound is known to be present in apple-juice volatiles and our identification of it is based on retention time data. We observed this compound (labeled 'P' on Figs. 1-3) to behave similarly to the trans 2-hexenal. The peak corresponding to trans 2-hexene 1-yl acetate was seen clearly with 0 and 300 Krad, was vaguely evident at 500 and 750 Krad, and was not observed at 1000 Krad.

Several chromatograms were run exclusively to determine whether or not the high boiling compounds of apple juice were affected by irradiation. Three such chromatograms are shown in Figs. 4-6. It is of interest to note that at 72°C 2-hexenal has a retention time of 13 minutes, whereas at 187°C the retention time is reduced to 3 minutes. Consequently, essentially all of the peaks observed in Figs. 4-6 represent high boiling compounds. In general, we found these compounds to be very stable to irradiation. The huge peak designated in Fig. 5 (21 and 22) proved interesting in that it is always found but never in the same concentration. However, the size of this peak did not seem to be a function of the irradiation dose.

We felt it would be most important to determine whether or not the volatile compounds from irradiated apple juice would change during subsequent storage. Consequently, we held samples given 0, 300, 500, and 1000 Krad in storage at 68°F for period ranging up to three months. We were not able to demonstrate any qualitative changes. Quantitatively, it appeared that some of the compounds may have been slightly altered, but never to any appreciable extent.

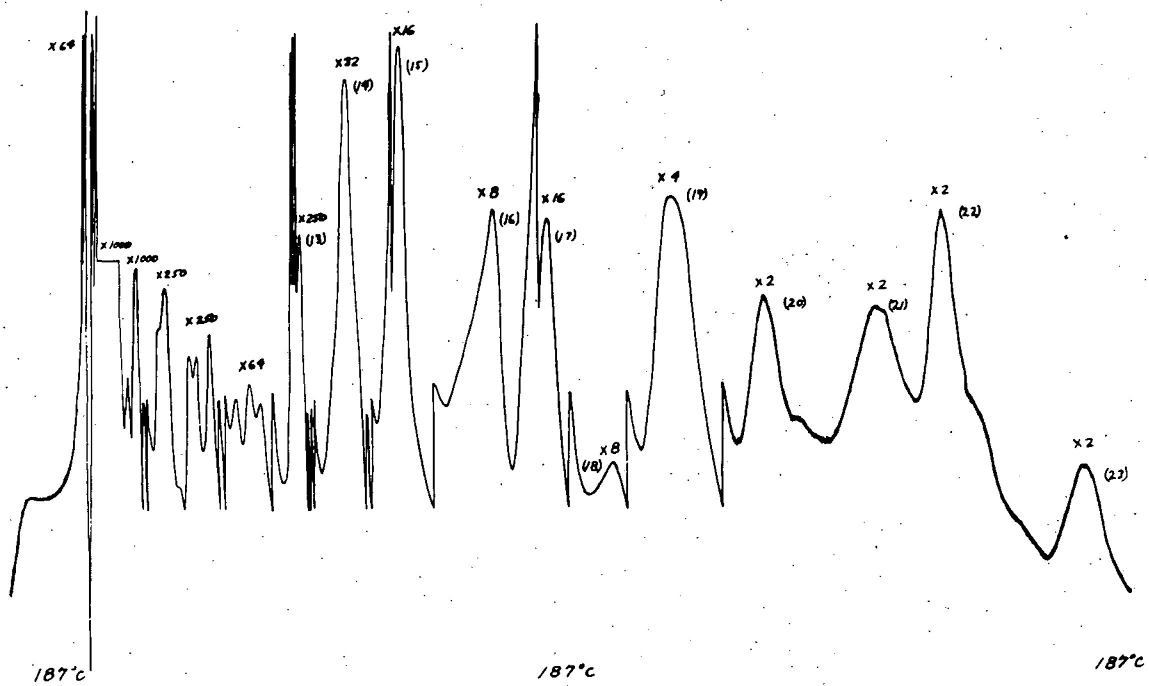

Fig. 4. High boiling volatile compounds from fresh apple juice (0-30 mins).

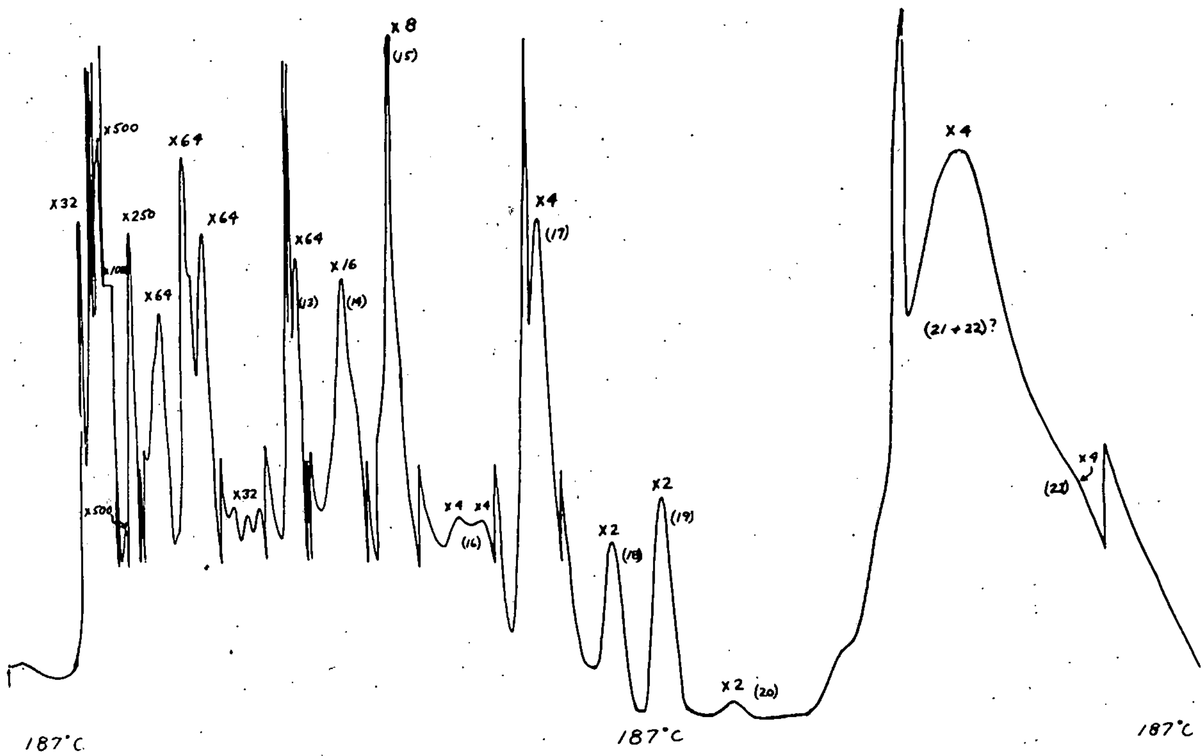

Fig. 5. High boiling volatile compounds from irradiated apple juice (300 Krad) 0–30 mins.

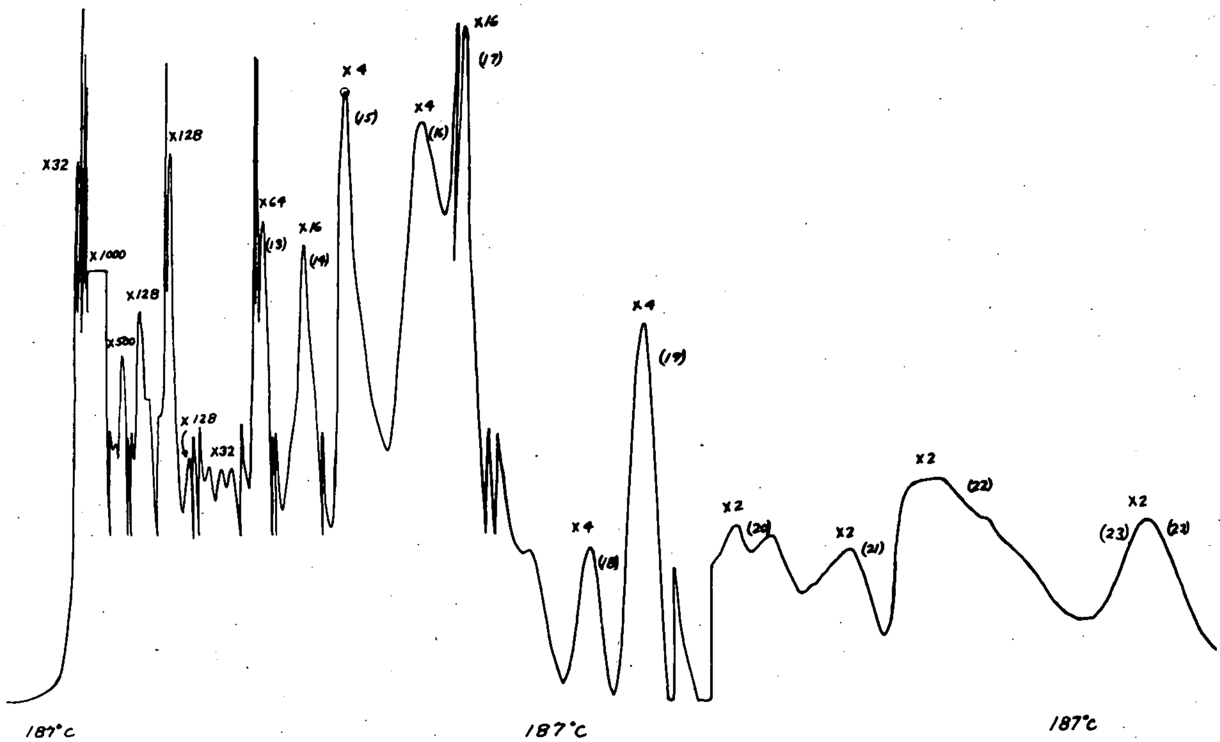

Fig. 6. High boiling volatile compounds from irradiated apple juice (1000 Krad) 0–30 mins.

CONCLUSIONS

Our findings are in good agreement with the sensory evaluations or the irradiated apple juice. It appears that the volatile components are indeed quite stable to irradiation at doses up to 300 Krad. However, at doses in excess of 300 Krad two compounds, trans 2-hexenal and trans 2-hexene 1-yl acetate, begin to break down and lead to a deterioration of aroma.

Our experiments with the model system of 2-hexenal in water indicated that greater than 99% of this aldehyde polymerized during irradiation. Whether or not this exact polymerization reaction also occurs in apple juice is difficult to say, although the evidence seems to support this idea since no new volatiles were detected. However, since much less than 99% of the 2-hexenal of normal apple juice disappears with 1000 Krad of irradiation, it seems as though the other compounds in the juice in some manner partially protect the 2-hexenal.

It is significant that the trans 2-hexenal is one of the three primary volatiles responsible for the characteristic apple aroma (Flath, R. A. 1967). Consequently, any marked decrease in this compound would probably lead to an unacceptable product. Fortunately, no significant decrease was observed at normal pasteurization doses.

Flath, R. A. Journal of Agricultural and Food Chemistry, 15, 29-35 (1967).

EFFECT OF GAMMA IRRADIATION ON MUSHROOMS

E. C. Maxie, L. L. Morris, Dale Ravetto,
Carol F. Johnson and Henry Rae

The commercial mushroom (Agaricus spp.) is a highly perishable commodity. Contributing to its short shelf life are external browning, veil opening, stem growth, and loss of turgidity. Recent work at Michigan State University, with the white mushroom (*Agaricus campestris*), indicated that gamma irradiation to 100 Krad inhibited veil opening and tended to increase external browning (1). In earlier studies using the brown mushroom (*Agaricus bisporus*), we showed an inhibition of veil opening (2). In 1967 studies were initiated to determine the effects of gamma irradiation upon: 1) visual quality, 2) external browning, 3) textural changes, 4) organoleptic attributes, 5) ascorbic-acid content, and 6) shelf life.

I. STUDIES ON VISUAL QUALITY, EXTERNAL BROWNING, AND TEXTURE.

MATERIALS AND METHODS

Brown mushrooms, from the second flush, were obtained from the Alpine Mushroom Company, Morgan Hill, California, and trucked to Davis in a refrigerated box. They were sorted into 4 lots of 40 mushrooms each, uniform in size and maturity (closed button stage). One lot was held as controls; the others were irradiated to 25, 50, and 100 Krad at a temperature of 41°F in the Mark II Experimental Co^{60} Food Irradiator. Each lot was further divided, after irradiation, into samples of 10 mushrooms for open container storage at 36°, 41°, 50°, and 59°F with relative humidities of 89.5, 84.5, 86.5, and 82.5% respectively. Each mushroom was numbered so that it could be individually scored as to quality and color changes. Another lot of similarly sorted and treated mushrooms were stored at 36°F for shear measurements.

Visual quality and color changes were evaluated every other day according to the scoring system shown in Table 1. Included in quality evaluations were cap opening, turgidity, gill and external browning, and decay. Color readings were made with a Gardner Color difference meter, Model AC-3, using the following standards: Rd = 85.1, a = -0.8, and b = +0.4. Each mushroom was numbered on the stipe and placed in the same position on the color meter at each reading.

Shear resistance was measured every other day with the Allo-Kramer shear press, with the standard shear compression cell using a 30-second down stroke. A 30-gram sample of sliced caps was used for each reading.

The effects of irradiation on cap opening were determined by visual observation only; a mushroom with 25% of its veil broken away from the annulus being considered open. Causal decay organisms were recorded where identifiable.

RESULTS

The results reported here are an average of a single lot of 10 mushrooms per treatment except the shear readings, where 2 replicates are averaged.

The quality of the mushrooms, as a function of time, temperature, and dose level is shown in Fig. 1. There was little difference in visual quality at 36° and 41°F after 2, 6, and 10 days, and at 50° and 59°F after 2 and 6 days storage. At the latter temperature, 50 Krad gave better results than either the 25 or 100-Krad treatments. At the end of the storage period, water loss and decay (*Penicillium* spp.) were the reasons for discards.

The effect of irradiation on external browning is shown in Fig. 2. The percentage figures shown were derived from the Rd (lightness) scale. There was a tendency toward increased browning

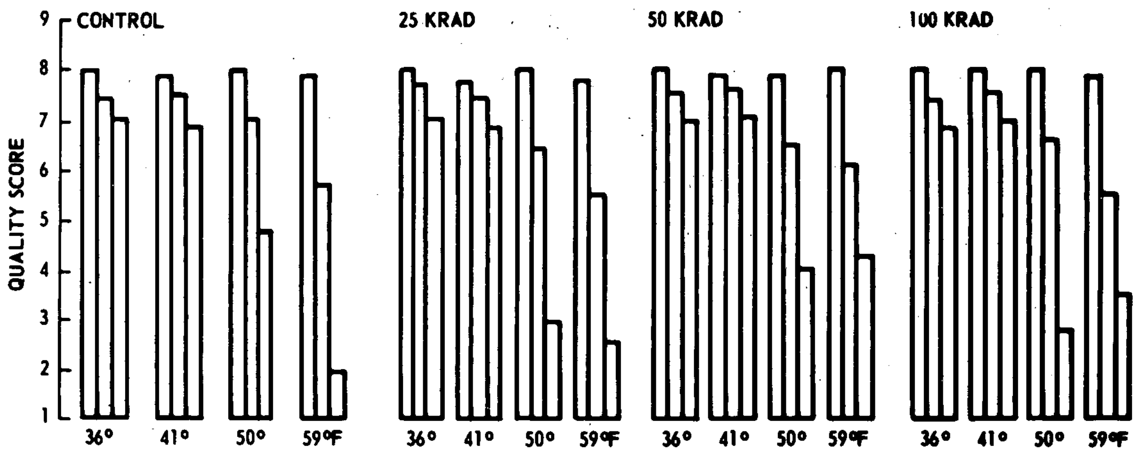

Fig. 1. Quality of mushrooms as a function of dose level and temperature after 2, 6, and 10 days storage. Bars represent 2, 6, and 10 days (left to right) at each dose.

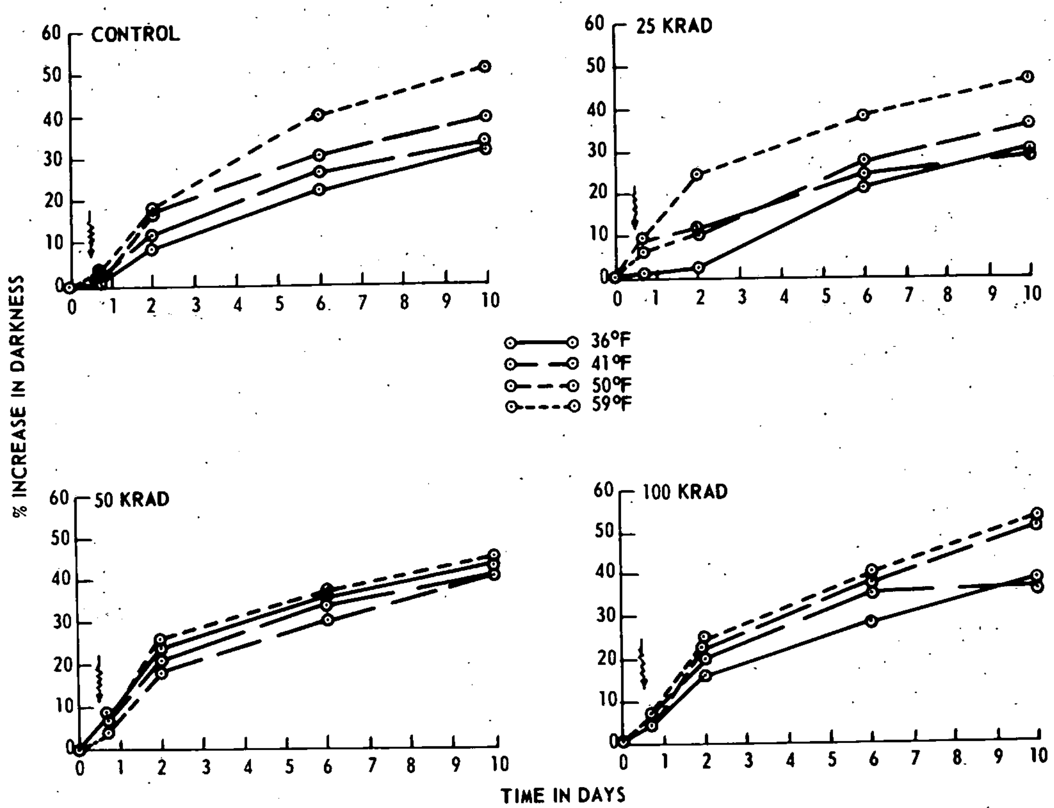

Fig. 2. Percent increase in darkness during storage as a function of time, temperature, and dosage.

immediately after irradiation. This trend persisted at all dose levels regardless of storage temperature; with 50 and 100 Krad increasing browning relative to the controls. The browning effect is masked at 59°F except immediately after irradiation.

Shear values are shown in Table 2. There is no consistent effect attributable to irradiation. The data for day 0 (6/28) showed an apparent softening at 100 Krad. The increase in shear resistance with time probably reflects an increased rate of water loss as a result of irradiation.

Cap opening, as influenced by irradiation to 25, 50, and 100 Krad, is shown in Fig. 3. There were no discernable effects at 36°F. However, at the other temperatures, doses to 50 and 100 Krad had an inhibitory effect, while 25 Krad had an apparent stimulatory effect.

II. SENSORY EVALUATION OF IRRADIATED MUSHROOMS.

MATERIALS AND METHODS

Test 1: Medium-sized brown mushrooms were obtained from Morgan Hill, California, transported to Davis, stored overnight at 41°F, and irradiated to 0 and 100 Krad the next morning. They were stored at 41°F in open commercial containers for 4 and 8 days until sampled for sensory evaluation.

Ten judges evaluated the mushrooms after 3 days preliminary testing. Over the 4-day testing period the mushroom caps remained closed in both the control and 100 Krad group. No open caps were tested. Prior to evaluation, all mushrooms were washed and those to be served cooked were steamed over boiling water for 10-15 min depending on the size, then cooled. Both cooked and raw mushrooms were sectioned into pie-shaped pieces after removing part of the stem but were served separately. Ten gm samples were used for aroma evaluation in capped glasses. A triangle difference test was used for all evaluations.

Table 1. Numerical quality scores used to evaluate irradiated mushrooms.

Score	Description
9	Field fresh, no defects
7	Good, minor defects
5	Fair, defects present, but not serious
3	Poor, major defects, unsalable but usable
1	Unusable

Table 2. Pounds force shear resistance (texture) of caps of irradiated mushrooms stored at 36°F.

Date	6/28	6/30	7/2	7/4	7/6	7/8	7/10
Control	192	214	201	214	216	249	259
25 Krad	226	213	265	243	253	250	261
50 Krad	192	204	207	231	256	252	270
100 Krad	156	244	201	202	288	271	255

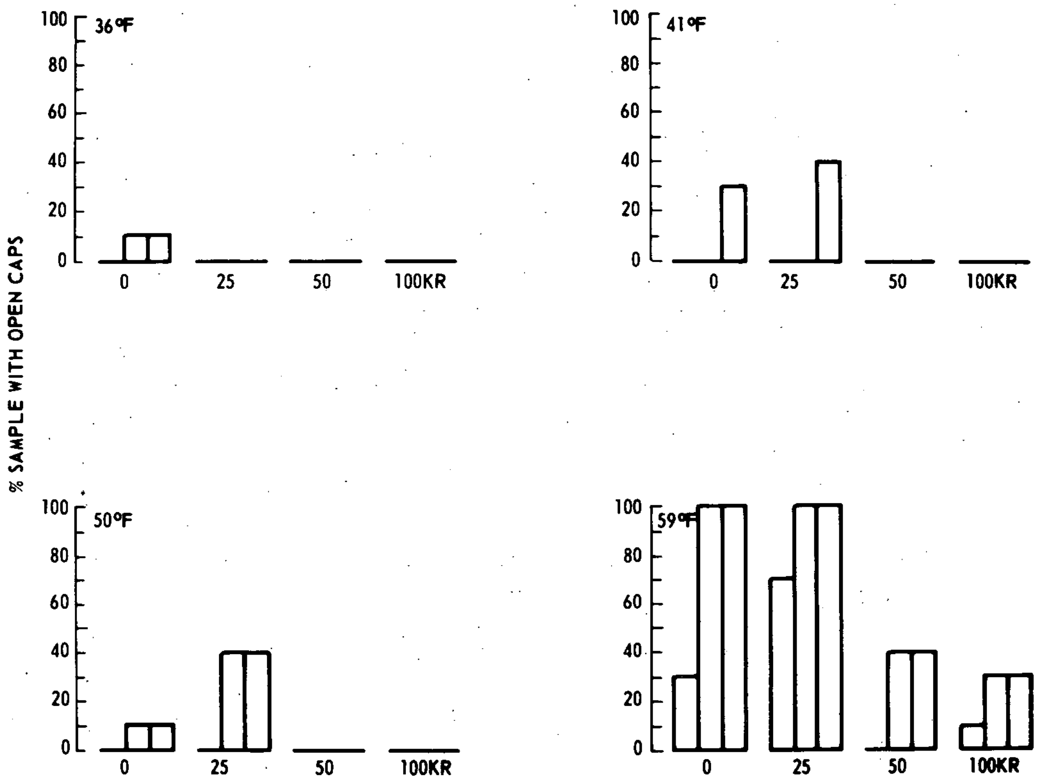

Fig. 3. Percent of sample with open caps after 2, 6, and 10 days storage at the temperatures shown.

RESULTS

The results are summarized in Table 3. There were no significant differences between 0 Krad and 100-Krad treated mushrooms.

Test 2: This test was a repeat of Test 1. The mushrooms were chosen with slightly opened caps. The source of the mushrooms and the general procedures were as described above.

The mushrooms were irradiated in the closed button stage one day following harvest. The irradiated samples were placed at 59°F (with humidifier) for about 5-6 days and control 1-2 days prior to evaluating. In neither case were many of the veils completely broken.

The comparisons were again made on both raw and steamed mushrooms. Nine-ten judges evaluated flavor and aroma using a triangle difference test.

RESULTS

The mushrooms were stronger in flavor for this test as compared to the study on tightly closed caps. Even though the irradiated mushroom veils remained unbroken at 59°F for 5-6 days, the gills had opened and darkened. The mushrooms which were irradiated tended to dry out and become porous at the end of this storage period. The texture differences noted undoubtedly influenced the judges ability to differentiate between the control and irradiated samples.

The results of the sensory evaluation are given in Table 4. A significant difference was found in the flavor (and/or texture) of the raw samples only. The judges indicated texture differences. The flavor comparisons on the cooked mushrooms were just short of being significantly different. Comments by the judges indicated a slightly stronger flavor in the irradiated mushrooms. This may possibly be accounted for by differences in the stage of button opening. According to N. Tape (Mushroom News 9(12):4-5), mushrooms with open caps have more intense flavor than the closed button stage.

Table 3. Summary of sensory evaluation of mushrooms treated with irradiation to 0 and 100 Krad.

	Raw	Steamed
Flavor[a]		
Correct number of identifications	18/40 judgments	16/40 judgments
Aroma[a]		
Correct number of identifications	16/37 judgments	16/37 judgments

[a] No significant difference using P=1/3.

Table 4. Second sensory evaluation on mushrooms treated to 0 and 100 Krad. Triangle test was made on slightly opened caps.

	Raw	Cooked
Flavor		
Number of correct identifications	28/38*** judgments	18/38 judgments
Aroma		
Number of correct identifications	16/38	17/38

*** Significant at P=0.001.

There were no significant differences in the aroma samples.

III. EFFECT OF IRRADIATION ON THE ASCORBIC-ACID CONTENT OF MUSHROOMS.

MATERIALS AND METHODS

Mushrooms were purchased at Morgan Hill, California, on January 18, 1967. After overnight storage at 32°F the mushrooms were randomly divided into 24 lots of approximately 200 gms each. After a second overnight storage at 32°F the mushrooms were irradiated, 8 lots each to 0, 50, and 100 Krad. Immediately following irradiation, half of the mushrooms were analyzed for ascorbic acid and the remainder returned to 32°F until analyzed 2 weeks later.

Whole mushrooms were washed, then 100 gms promptly blended with 250 ml of 1% HPO_3 for 3 min at full speed in a Waring Blendor. The slurry was filtered through 4 layers of cheesecloth and then a portion of this filtrate cleared by centrifugation at 10,000 rpm for 15 min.

Since previous trials had yielded only trace amounts of reduced ascorbic acid, this form of ascorbate was determined by making one composite sample per treatment. The method of Loeffler and Ponting (1942, Ind. Eng. Chem. Anal. Ed. 14:846-849) was used to assay reduced ascorbic acid. For total ascorbic acid a 5 ml aliquot per replicate for a given treatment was composited for titration with 45% K_2HPO_4 to pH 6.8 using a Beckman pH meter. Using the method of Hughes (1956, Biochem. J. 64:203-208), the same size aliquot was pipetted into a 10 ml volumetric flash and the procedure carried out making pH adjustments using the predetermined volume of 45% K_2HPO_4. One milliliter of the solution was taken for the color reading; the same as for reduced ascorbic acid. Values for dehydroascorbic acid were obtained by subtracting the average value for reduced from the average total ascorbic acid present. All data are reported as mg ascorbic acid per 100 gms mushrooms fresh weight.

RESULTS

There was a decrease in the amounts of ascorbic acid in all lots of the mushrooms after 2 weeks in storage at 32°F (Table 5). Irradiation to 50 and 100 Krad did not affect the ascorbic acid levels, either immediately after treatment or after 2 weeks storage.

DISCUSSION AND CONCLUSIONS

Gamma irradiation, under conditions of these experiments, has only a slight beneficial effect on the keeping quality of mushrooms. At the lower storage temperatures there is little quality difference among the various dose levels. As the storage temperature increases, time and the effects of high temperature tend to overshadow any beneficial effect on quality and shelf life.

Doses of 25 and 100 Krad do not appear to be as effective as 50 Krad in maintaining visual quality. Browning increases with time in brown mushrooms during storage. Gamma irradiation enhances the rate and the amount of browning, at all temperatures, and nearly proportionately to the dose. This enhancement is masked at higher storage temperatures.

The textural changes that occurred in the irradiated mushrooms are not clearly attributable to irradiation per se. The sample size was too small and variable to allow confident conclusions. The rate of water loss appears to increase, and this could cause the texture to become firmer. The fact that the irradiated mushrooms tended to dry out and become puffy more quickly than controls seems to confirm this.

Inhibition of veil opening was a definite beneficial effect of irradiation observed in this experiment, especially at the higher storage temperatures. The results do not agree with those reported by workers at Michigan State University for white mushrooms. They reported inhibition at doses as low as 7.5 Krad. We have no

Table 5. Effect of gamma irradiation on the ascorbic-acid content of mushrooms stored at 32°F. Results are expressed as mg/100 gm fresh weight.

Time after irradiation	Form of ascorbate	Treatment		
		Control	50 Krad	100 Krad
Immediate	Reduced	0.75	0.88	0.87
	Dehydro	2.48	2.58	2.80
	Total	3.23	3.46	3.67
2 weeks	Reduced	0.42	0.14	0.14
	Dehydro	2.34	2.79	2.46
	Total	2.76	2.93	2.60

explanation for the apparent stimulation at 25 Krad. It is possible that ethylene production may have been stimulated at this dose.

Beneficial effects of irradiation on the storage and keeping qualities of brown mushrooms seems limited to inhibition of veil opening. Other effects are overshadowed by increased water loss and rate of browning. With regard to browning, ionizing radiation may rupture, or otherwise modify, the permeability of the membranes thus permitting mixing of phenolase, the enzyme involved in browning, with substrates.

The observed textural changes are also not understood at this time. In other fruits and vegetables cell walls are composed in part of pectin macromolecules bound together with calcium ions. In fungi the main constituent of the cell wall is chiten. It is not known how the structure of this compound is affected by ionizing radiation.

Mushrooms are not a major source of ascorbic acid in the human diet, but nonetheless it is of interest that irradiation to 50 and 100 Krad did not reduce the amounts of this compound.

Under current marketing conditions temperature and related humidity conditions are generally not well maintained. Therefore, gamma irradiation of brown mushrooms does not seem to increase the shelf life of this species enough to justify the cost of the treatment.

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2. E. C. Maxie, Carol F. Johnson, Henry L. Rae, and Camilla Boyd. 1967. Effect of gamma irradiation on mushrooms. In: "Radiation Technology in Conjunction with Post-Harvest Procedures as a means of Extending the Shelf-Life of Fruits and Vegetables," pp. 56-64. U. S. Atomic Energy Commission Research and Development Rept. No. UCD-34P80-5.

EFFECT OF GAMMA IRRADIATION ON ASPARAGUS

Dale Ravetto and L. L. Morris

INTRODUCTION

In cool wet years Phytophthora rot of asparagus (Phytophthora cactorum (Lib.-Cohn) Schröt) often results in severe crop losses. Work reported in 1964 by Morris et al. (1) indicated that low doses of ionizing radiation could control this weak saprophyte. The spring of 1967 was exceptionally wet, creating ideal conditions for this decay organism. Another potential benefit from low dose irradiation was inhibition of elongation of treated spears. Thus, an experiment was conducted to determine the fungicidal and growth inhibiting effects of ionizing radiation on freshly harvested asparagus.

MATERIALS AND METHODS

Freshly harvested asparagus spears, taken from a Phytophthora infested field, were obtained from the Tracy area of California on April 26, 1967. They were trucked to Davis, washed, accurately cut to lengths of 7 inches, and sorted into lots of 60 spears each (3 reps of 20 spears each). Each replicate was weighed then irradiated to the desired dose in the Mark II Experimental Co^{60} Food Irradiator. Treatments were: (1) control, placed immediately at 59°F and not treated; (2) control, transported to Co^{60} source along with irradiated samples but not treated; (3) irradiated lots subjected to 0.5, 1.0, 2.0, 4.0, 8.0, 16.0, 50.0, 150.0, and 500 Krad. The spears were then placed in 5-gallon containers containing approximately one inch of water. The quality of the spears was evaluated every two days. Quality scores were based on a 9 to 1 scale as shown in Table 1. Parameters used were decay, irradiation and mechanical damage,

Table 1. Numerical scores and parameters used to evaluate quality of irradiated asparagus spears.

Score	Parameters
9	Excellent, field fresh
7	Good, only slight defects present
5	Fair, defects present, not objectionable, limit of sales appeal
3	Poor, defects present, objectionable, limit of salability
1	Unusable

turgidity, and general appearance. Quality data were taken for each lot until 50% of the spears were discarded. Elongation was determined by measuring the length of the spears after 6 days storage. The amount of growth was calculated as the difference between initial and final length.

RESULTS

The results reported here are an average of 3 replicates.

Shelf life, as a function of the applied dose, and as the number of days required to reach a quality score of 5 or less, is shown in Figs. 1 and 2 respectively. Doses of 0.5 to 4.0 Krad had no apparent detrimental effect on the asparagus and maintained shelf life comparable to that of the control lots. Doses above 4.0 Krad reduced shelf life; i.e., 7 days at 150 and 500 Krad, and 10 days at doses of 8 to 50 Krad, compared to 11 to 12 days at doses of 0 to 4.0 Krad. Spears irradiated to 50, 150, and 500 Krad showed radial splitting of the butt end; extending upward along the lower portion of the spear at the two higher doses. Other features of radiation damage included a slippery epidermis, a cooked appearance, and a darkened, dull color. The spears became flaccid after 3 to 4 days, and symptoms of mechanical damage were greatly enhanced, appearing as dull, dark green, water-soaked areas. Control of Phytophthora rot was not achieved at doses below 50 Krad. At 50 Krad or more, control was good. Bacterial soft rot entered the spears in all lots as a secondary infection after 6 days storage and quickly became the determining factor for quality scores and for discards. Phytophthora rot lesions were generally limited to the lower 1/3 of the spears, but occasionally a lesion was found on the tip or upper 2/3 of the spear.

The effect of ionizing radiation, at doses used, on postharvest growth of asparagus is shown in Fig. 3. Growth was reduced at all

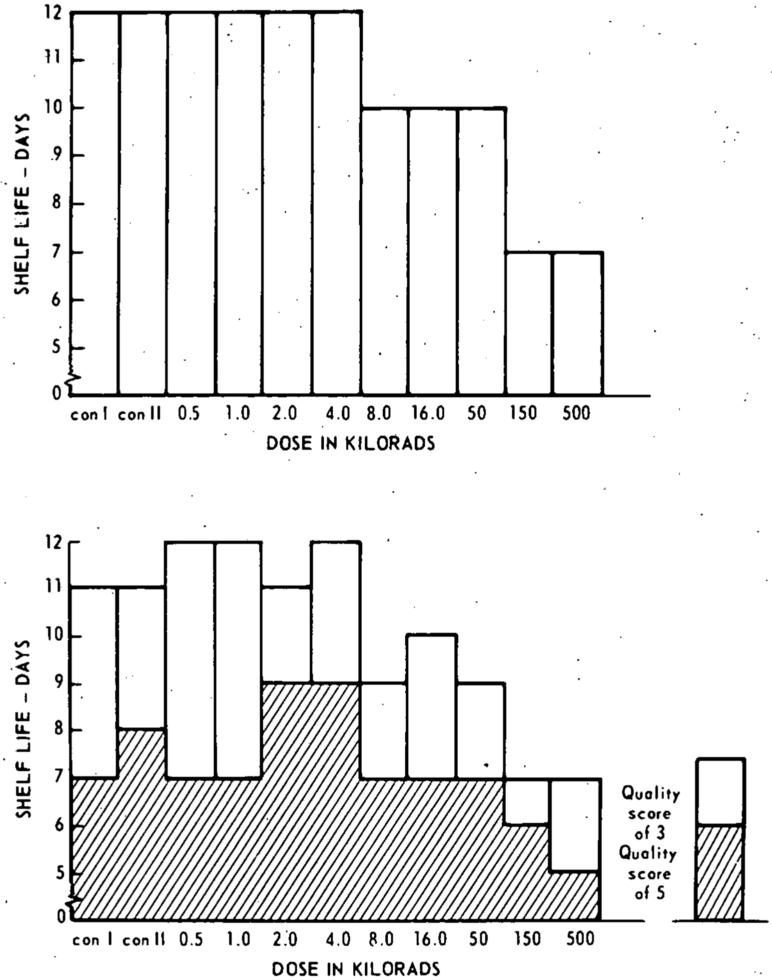

Fig. 1. Shelf life expressed as a function of dose - 59°F.

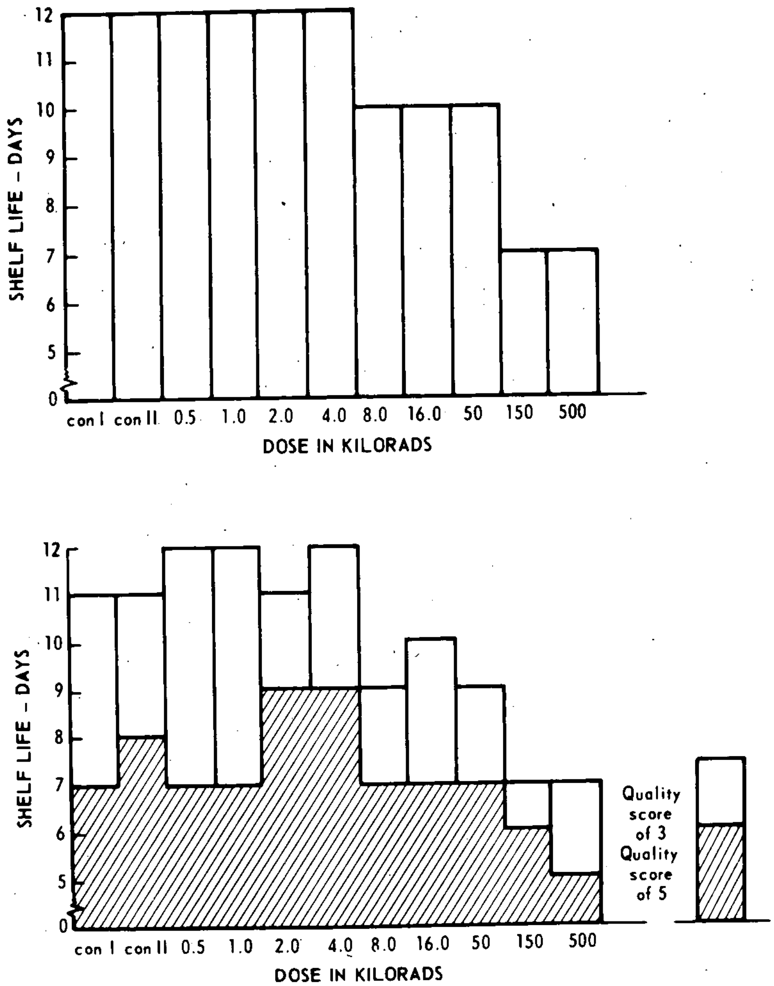

Fig. 2. Shelf life expressed as number of days required to reach quality scores of 5 and 3 or less at 59°F.

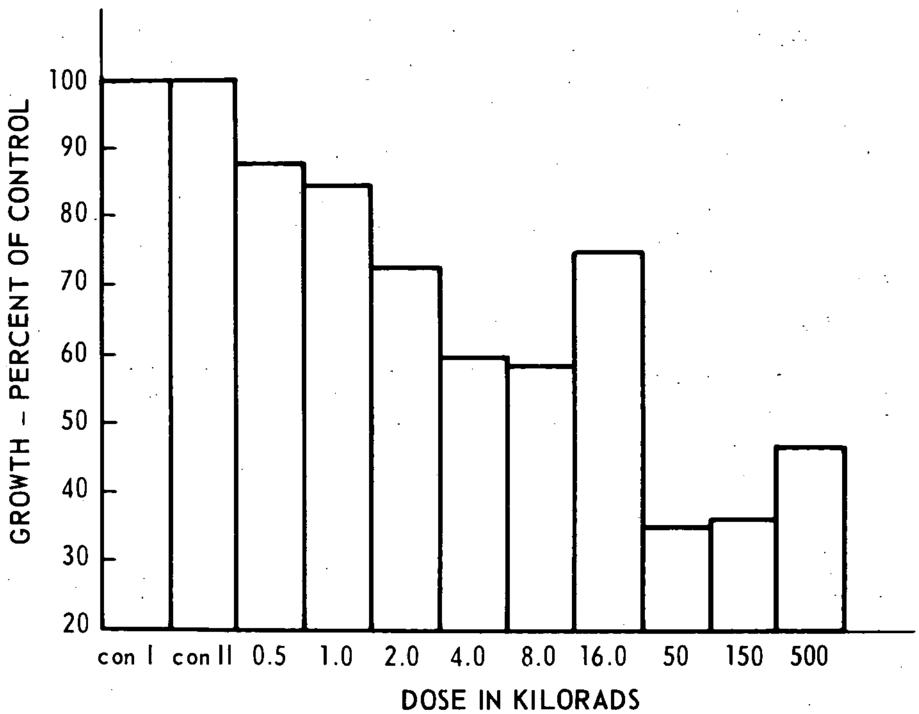

Fig. 3. Growth as percent of control of asparagus spears held at 59°F for 6 days.

levels. The decrease is nearly proportional to dose at doses up to 8.0 Krad.

DISCUSSION AND CONCLUSIONS

The results of this test did not achieve the degree of success realized by Morris *et al*. reported in 1964. The lack of *Phytophthora* rot control at low doses may have been due to varietal and/or growing area differences. When control was achieved, it was at doses detrimental to the asparagus. Reduction of shelf life was due primarily to radiation damage and an increased susceptibility to bacterial soft rot. This was especially noticeable at the higher doses. Elongation was inhibited at all doses.

Since *Phytophthora* rot is a problem only in exceptionally wet years, and with picker training to exclude infected spears, gamma irradiation does not appear to have any practical application for control of *Phytophthora* rot in California's asparagus industry.

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EFFECT OF GAMMA IRRADIATION ON THE SUSCEPTIBILITY OF TOMATO FRUITS TO TRANSIT INJURY

Dale Ravetto, L. L. Morris and E. C. Maxie

INTRODUCTION

Experiments conducted with light-pink tomatoes in 1966 indicated that the severity and incidence of transit injury was increased by gamma irradiation. However, the damage was reduced if the fruit was held tightly in place within the package. Tests were conducted in 1967 to determine the effect of gamma irradiation on transit injury and to evaluate the benefits of padding or otherwise immobilizing the fruit within the package as a means of reducing injury.

MATERIALS AND METHODS

The first two tests were similar to those reported in 1966. The remaining tests were designed to determine the effects of drops from variable heights, plus irradiation, on the respiratory behavior of tomato fruits. One test included evaluations of quality, ripeness, and weight loss.

Irradiation was done at ambient temperature in either the Mark II Experimental Co^{60} Food Irradiator or the Mobile Gamma Irradiator (MGI). Respiration determinations were made by the method of Claypool and Keefer (1) and ethylene (C_2H_4) determination by the methods of Maxie et al. (2). Quality and ripeness evaluations were based on scores shown in Tables 1 and 2 respectively. Table 3 shows the scores used to evaluate symptoms of transit injury.

TEST I.

This test was conducted to determine if the response observed

Table 1. Quality parameters and scores used to evaluate tomato fruits subjected to irradiation and simulated transit injury.

Quality score	Parameter description
9	Excellent, field fresh, no defects
7	Good, minor defects
5	Fair, defects present but not serious
3	Poor, major defects, unsalable, but usable
1	Unusable

Table 2. Ripeness classes and numerical scores used to evaluate tomato fruits subjected to irradiation and simulated transit injury.

Ripeness score	Class	Description
0	Mature green	Mature, but entirely green
1	Breaker	First appearance of pink color
2	Light pink	Approximately equal amounts of green and pink
3	Dark pink	No green, entirely pink
4	Table ripe	Fully red color, minimum eating ripeness

Table 3. Injury scores used to evaluate tomato fruits subjected to irradiation and simulated transit injury.

Injury scores	Description
0	None
1	Slight, less than 1/4 of the surface damaged
3	Moderate, up to 1/2 of the surface damaged
5	Severe, over 1/2 of the surface damaged; fruit cracked, etc.

during 1966 could be repeated. Some lots were given the simulated transit treatment various times after irradiation to see if a delay in the application of this second stress would be a factor in the responses observed.

'Ace' variety tomatoes, of light-pink maturity, were trucked to Davis from Stockton, California, on August 14, 1967. They were divided into 8 lots, each containing 4 two-layer flats (240 fruits). Treatments were as follows:

Lot #	Description
1	Control, directly to 68°F
2	Transit time control, 4 days at 55°F then 68°F; no irradiation or transit injury
3	Radiation control, 300 Krad only, no transit injury; 4 days at 55°F then 68°F
4	300 Krad + 30 vertical impacts + 8 minutes vibration at 1.1 g; 4 days at 55°F then 68°F
5	300 Krad, held at 55°F 24 hours then given 30 vertical impacts + 8 minutes vibration, returned to 55°F for 72 hours then 68°F
6	300 Krad, held at 55°F 48 hours, then given 30 vertical impacts + 8 minutes vibration; returned to 55°F for 48 hours then 68°F
7	300 Krad, held at 55°F 72 hours, then given 30 vertical impacts + 8 minutes vibration; returned to 55°F for 24 hours then 68°F
8	Transit injury control, 30 vertical impacts + 8 minutes vibration, held 4 days at 55°F then 68°F

Transit injury was inflicted by the simulating equipment located at the experiment station. The fruit were evaluated for quality, ripeness, transit injury, and decay at the end of the transit period; and except for transit injury scores, every other day until 50% of each lot was discarded. Decay organisms were identified where possible.

TEST II.

Immobilization or padding of the fruit in the two-layer flat was further evaluated in this test. Light-pink tomatoes of the 'Ace' variety were trucked to Davis from Stockton on September 18, 1967. Six lots of 4 flats each (240 fruits) were treated as follows:

Lot #	Description
1	Control, held 4 days at 55°F then 68°F
2	30 vertical impacts + 8 minutes vibration; held 4 days at 55°F then 68°F
3	30 vertical impacts + 8 minutes vibration, padded top and bottom; held 4 days at 55°F then 68°F
4	Radiation control, 300 Krad only, no transit injury; held 4 days at 55°F then 68°F
5	300 Krad + 30 vertical impacts + 8 minutes vibration; held 4 days at 55°F then 68°F
6	300 Krad + 30 vertical impacts + 8 minutes vibration, padded top and bottom; held 4 days at 55°F then 68°F

The fruit were evaluated as described above for Test I. The tomatoes in lots 3 and 6 (padded) were carefully repacked in the lugs with top and bottom excelsior pads. Lids were reinforced to insure that pressure was applied to the fruit when the lid was nailed to the box.

TEST III.

The purpose of this test was to determine the respiratory response of tomatoes treated to drops from various heights, alone and in combination with gamma irradiation. 'Ace' variety tomatoes of light-pink maturity were trucked to Davis from Stockton on September 6, 1967. The fruit were sorted into 24 lots of 10 fruit each, uniform in size and maturity. The 24 lots were then divided into 3 replicates of 8 lots each and treated as follows:

Treatment	Description
1	Control
2	300 Krad
3	One 3-inch drop per fruit
4	One 6-inch drop per fruit
5	One 9-inch drop per fruit
6	300 Krad followed by one 3-inch drop per fruit
7	300 Krad followed by one 6-inch drop per fruit
8	300 Krad followed by one 9-inch drop per fruit

The fruit were dropped onto a concrete floor taking care not to bruise the shoulder or blossom end; the bruise was marked by talcum powder and a felt pen for later evaluation. All drops were completed within one hour. The irradiated fruits were dropped immediately after treatment. The fruit were placed in respiration jars and CO_2 and C_2H_4 measurements taken after 6 hours, every 3 hours thereafter for the first 24 hours, then daily until termination of the test. The storage temperature was 68°F. At the end of the test the bruised fruit were cut open and inspected for internal damage.

TEST IV.

The purpose of this test was the same as Test III. Light-pink tomatoes, 'A-1' variety, were trucked to Davis from Patterson, California, on October 10, 1967, and sorted as noted above for Test III. The tomatoes were dropped onto concrete three times per fruit instead of only one drop per fruit. The treatments were as follows:

Treatment	Description
1	Control
2	300 Krad
3	Three 6-inch drops per fruit

4	Three 12-inch drops per fruit
5	Three 24-inch drops per fruit
6	300 Krad + three 6-inch drops per fruit
7	300 Krad + three 12-inch drops per fruit
8	300 Krad + three 24-inch drops per fruit

Storage temperature, CO_2 and C_2H_4 determinations, and terminal evaluations were the same as described above for Test II.

TEST V.

The experimental conditions of this test were similar to those described above for Tests III and IV. Breaker-stage fruits of the 'A-1' variety were trucked from Tracy to Davis, California, on November 3, 1967. Only 6 and 12-inch drops were used both before and after irradiation. Carbon dioxide and C_2H_4 determinations were made as described earlier. A second group of sorted fruit was divided into 8 lots of 25 fruits each for quality, ripeness, and water-loss evaluations. The treatments were as follows:

Treatment	Description
1	Control
2	300 Krad
3	Three 6-inch drops per fruit
4	Three 12-inch drops per fruit
5	300 Krad + three 6-inch drops per fruit
6	300 Krad + three 12-inch drops per fruit
7	Three 6-inch drops per fruit + 300 Krad
8	Three 12-inch drops per fruit + 300 Krad

The results reported here are averages of 3 or 4 replicates for all tests and the average of 25 fruits for quality, ripeness, and water loss in Test V.

RESULTS

TEST I.

Figure 1 shows the effects of irradiation and simulated transit injury, alone and in combination, on the ripening of tomato fruits. Both stresses, separated by a few hours or as much as 3 days, delayed ripening from 4-6 days. The 2-day delay seen in lot 2 is a temperature effect due to storage at 55°F. Fruit receiving transit injury, alone or in combination with irradiation, did not ripen as the control fruit; often appearing blotchy or failing to ripen at all. There was no benefit to separating the two stresses by 1, 2, or 3 days. Lots 5 and 6 received the transit-injury treatment 1 and 2 days after irradiation and ripened 2 days earlier than lot 7, which received the injury 3 days after irradiation. Fruit irradiated only ripened 5 days later than the control fruit.

Figure 2 shows the number of days at 68°F required for 50% of the fruit in each lot to become unmarketable. When the two stresses were combined, regardless of the time interval between application, the shelf life was reduced 3-4 days (lots 4, 5, 6, and 7). Either treatment alone reduced the shelf life by 1 day.

Transit-injury scores for each lot at the end of the simulated transit period are shown in Fig. 3. The severity and magnitude of injury was significantly higher in those lots receiving simulated transit injury, alone or in combination with irradiation (lots 4-8). Injury was slightly more severe in lots 5, 6, and 7 treated after 1, 2, or 3-day delays, but no consistent trends could be seen.

Figure 4 shows the percent of marketable fruit after 6 days at 68°F. Transit injury and irradiation both reduced the number of marketable fruit, but when combined the effect was more severe. The delay in application of the two stresses seemed to have a more adverse effect, for fewer fruit were marketable.

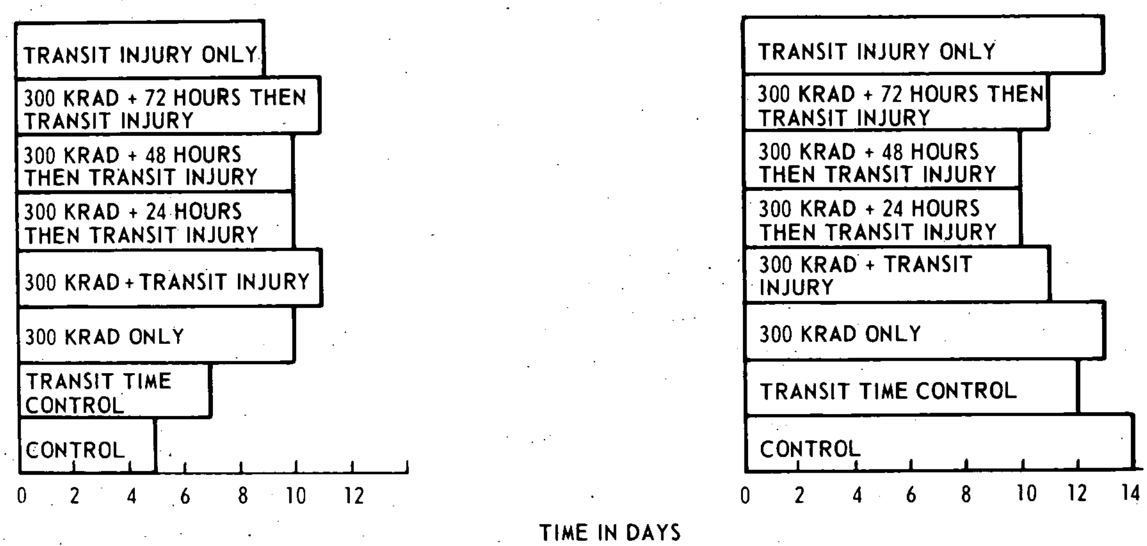

Fig. 1. Effects of gamma irradiation and simulated transit injury, alone and in combination, on the number of days required for 'Ace' tomatoes to reach table ripeness at 68°F.

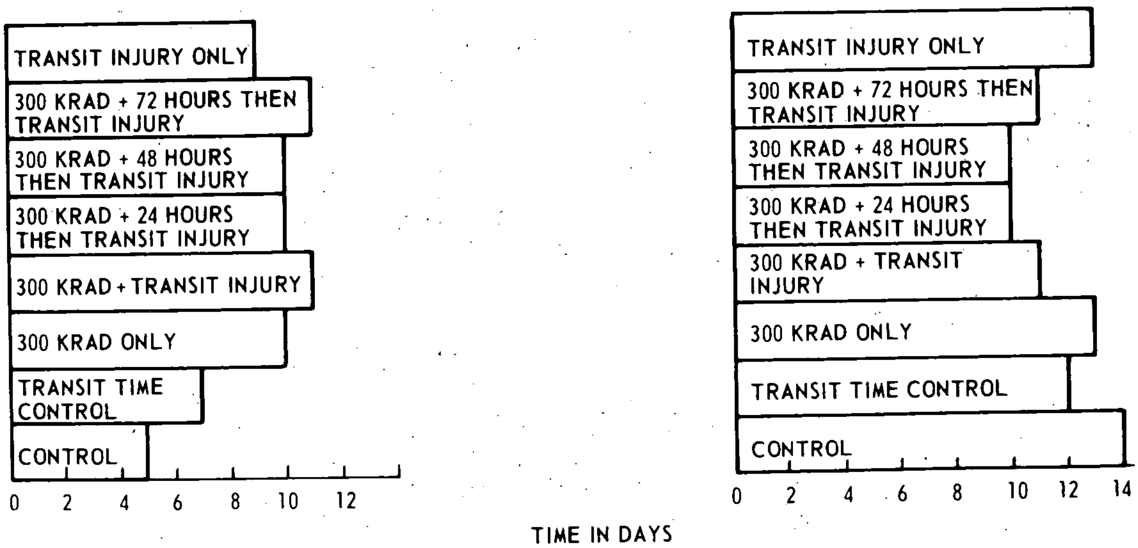

Fig. 2. Effects of gamma irradiation and simulated transit injury, alone and in combination, on the number of days required for 50% of each lot to reach an unmarketable condition at 68°F.

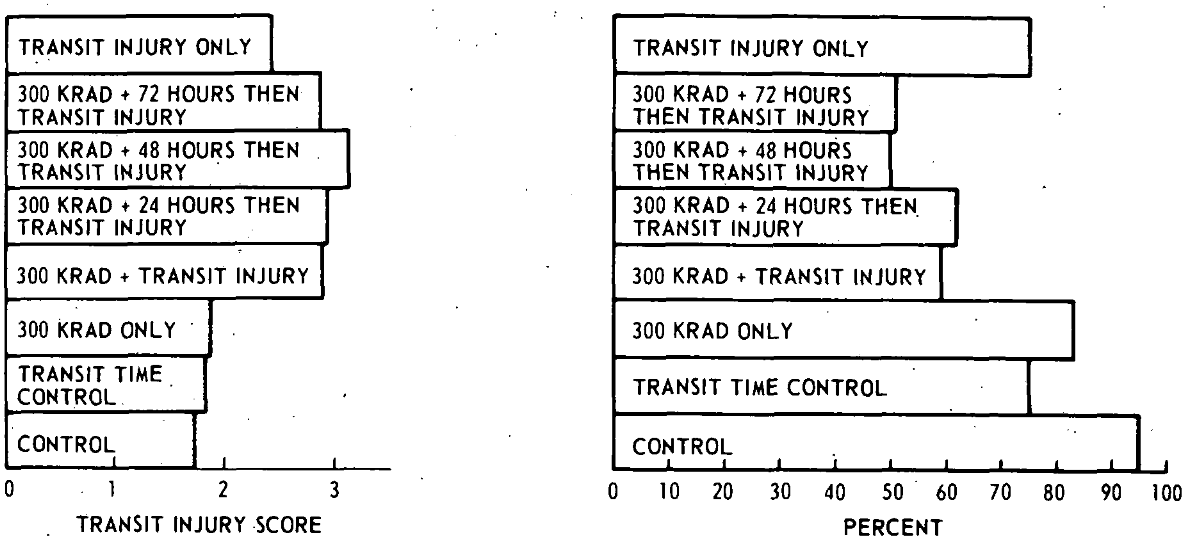

Fig. 3. Effects of gamma irradiation and simulated transit injury, alone and in combination, on the level of transit injury on 'Ace' tomatoes at the end of the transit period.

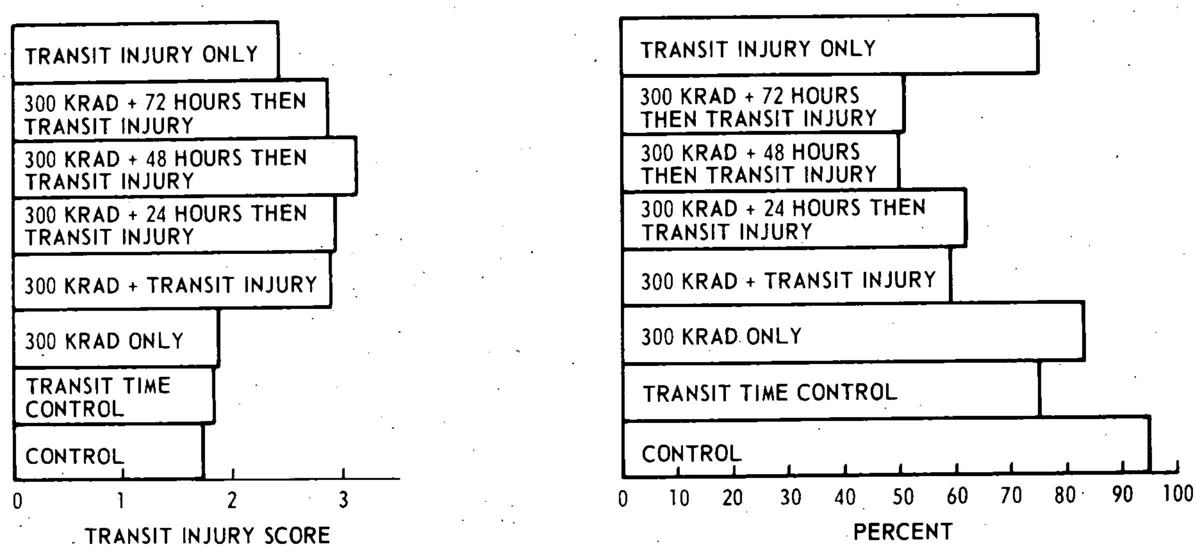

Fig. 4. Effects of gamma irradiation ans simulated transit injury, alone and in combination, on the percent marketable fruit after 6 days at 68°F.

Decay was the major cause of cullage. Causal organisms and frequency of occurrence were as follows: Rhizopus stolonifer (Ehrenb. ex Fr.) Lind. - 47.8%; Penicillium spp. - 4.9%; Alternaria tenuis (Nees) - 3.9%; Erwenia carotovora (bacterial soft-rot organism) - 2.4%; Cladosporium spp. - 0.9%; Botrytis cinerea (Per. ex Fr.) - 0.3%. Other causes of cullage included sunburn - 0.7%; shrivel - 0.5%; combinations of blotchy ripening, excessive softness, and split fruit - 8.5%. The internal condition of the treated fruit was similar to that reported last year. There was complete description of locular organization; the jelly-like matrix became a watery fluid.

TEST II.

Figure 5 shows the time required at 68°F for fruits in Test II to reach table ripeness. The simulated transit treatment delayed ripening 1 day. When the fruit were immobilized by padding, there was no delay. Irradiation alone delayed ripening 1 day, but when followed by the injury, the delay was 4 days. If the fruit was immobilized, irradiation gave the only delay in ripening.

The days required for 50% of each lot to become unmarketable is shown in Fig. 6. The simulated transit treatment, alone or in combination with irradiation, reduced shelf life by 2 days (lots 2 and 5). When the fruit was immobilized by padding, shelf life was increased by 1-2 days (lots 3 and 6). Irradiation alone increased the shelf life by about 2 days (lot 4).

The transit-injury scores at the end of the simulated transit period are shown in Fig. 7. Padding or immobilizing the fruit reduced the severity of the injury (lots 3 and 6). Irradiation increased the susceptibility of the fruits to transit injury (lot 5). In both tests the level of damage observed did not preclude sale of the fruit in all cases, but did increase the susceptibility to decay via infection ports caused by the combination treatments.

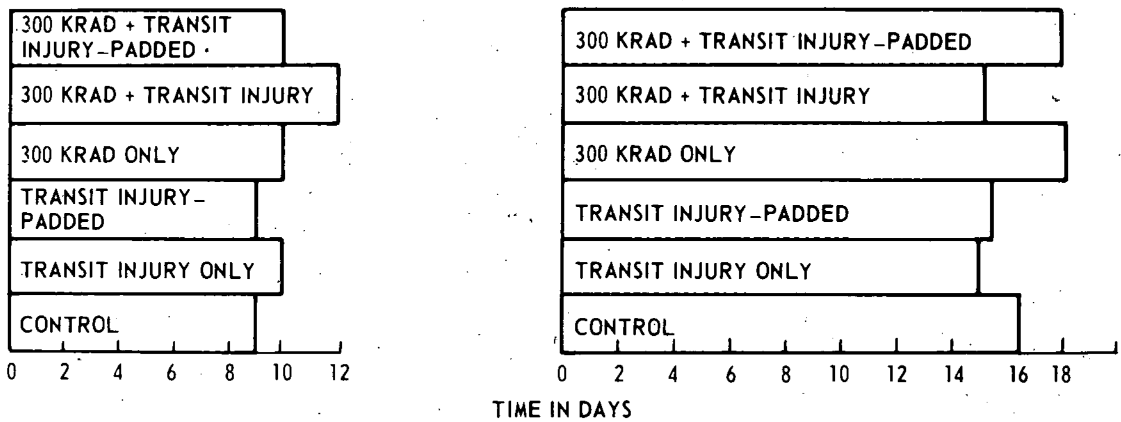

Fig. 5. Effects of gamma irradiation and simulated transit injury, alone and in combination, on the number of days required for 'Ace' tomatoes to reach table ripeness at 68°F.

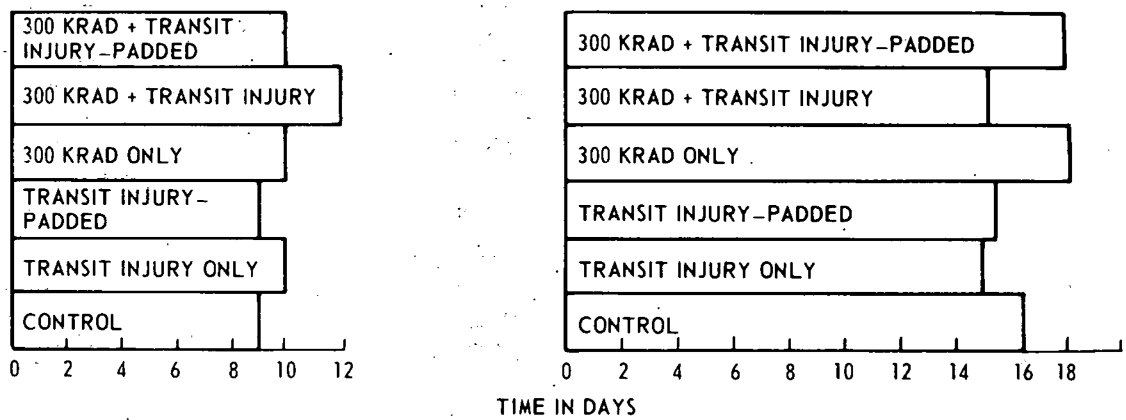

Fig. 6. Effects of gamma irradiation and simulated transit injury, alone and in combination, on the number of days required for 50% of each lot to reach an unmarketable condition at 68°F.

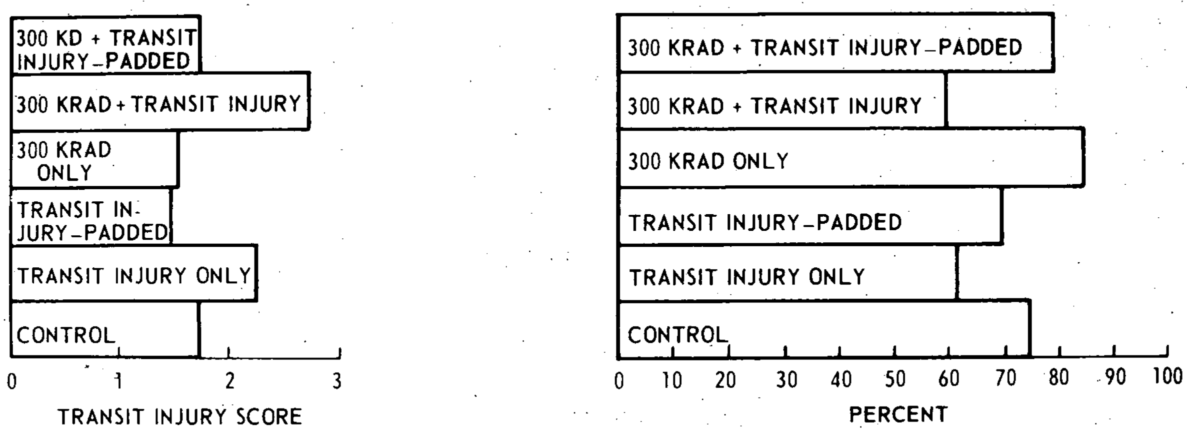

Fig. 7. Effects of gamma irradiation and simulated transit injury, alone and in combination, on the level of transit injury on 'Ace' tomatoes at the end of the transit period.

The percent marketable fruit after 15 days at 68°F is shown in Fig. 8. Irradiation increased the number of marketable fruit, even when the simulated transit treatment was applied, if the fruit was padded.

Cullage was largely due to decay. The most prevalent decay organism was _R. stolonifer_ - 59.4%; followed by _A. tenuis_ - 4.5%; _E. carotovora_ - 3.9%; _Penicillium_ spp. - 2.8%; _Cladosporium_ spp. and _B. cinerea_ - 0.5% each. Shrivel accounted for 1.1%; sunburn - 0.4%; combinations of excessive softness, split fruit and blotchy ripening amounted to 1.3%. The internal condition of damaged fruit was similar to that described above for Test I.

TEST III.

Carbon dioxide and C_2H_4 production of tomatoes subjected to one drop of 3, 6, or 9 inches, 300 Krad, alone and in combination, are shown in Figs. 9, 10, 11, and 12. All treatments increased the rate of carbon dioxide production during the initial 24-hour period. The rates remained higher than in the control fruit for fruits subjected to 6 and 9-inch drops, but were lower than in the control fruit after 4 days. Fruit subjected to irradiation alone had an initial increase in carbon dioxide production but the rate fell below that of the control fruit after 2 days. The increase in carbon dioxide production in dropped fruit was not proportional to height of the drops. When drops were administered after irradiation, the carbon dioxide production was markedly increased again, but not proportionately to the drops. The rate remained higher for the irradiated fruits subjected to 3 and 6-inch drops but those irradiated then dropped 9 inches showed a rate below that of the control fruits after 2 days.

Ethylene production did not correspond to the responses seen for carbon dioxide production. There were little differences between

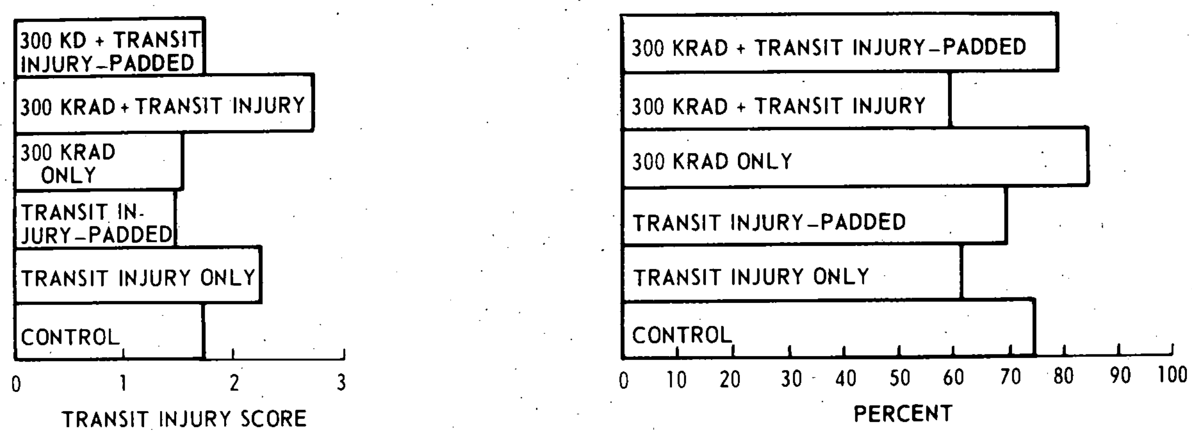

Fig. 8. Effects of gamma irradiation and simulated transit injury, alone and in combination, on the percent marketable fruit after 15 days at 68°F.

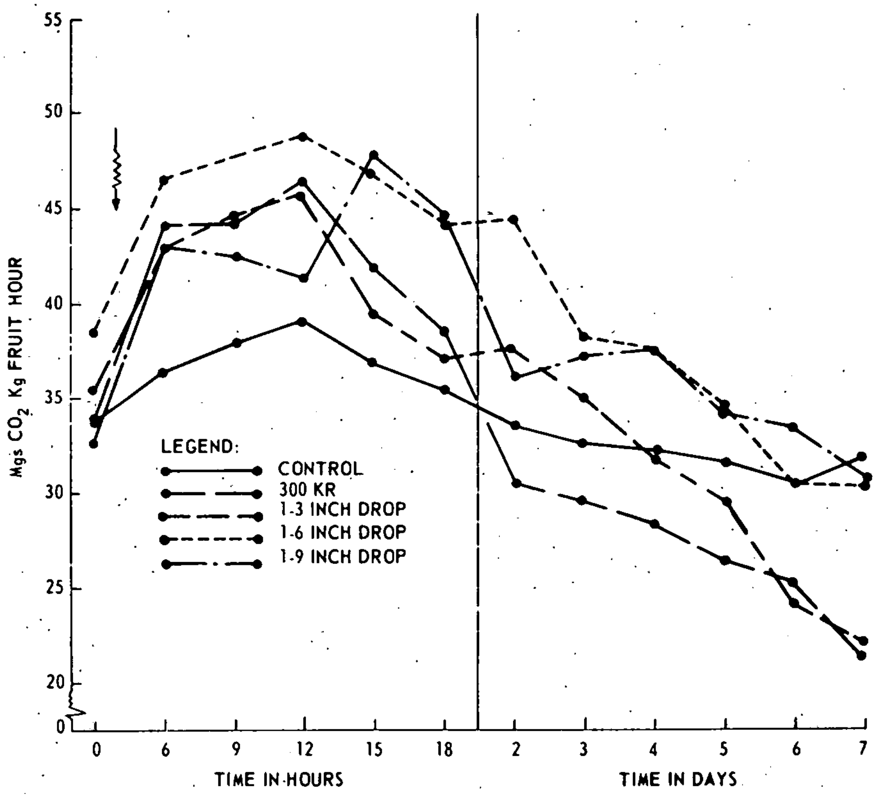

Fig. 9. Effects of gamma irradiation and single drops from various heights on the respiration of 'Ace' tomatoes held at 68°F.

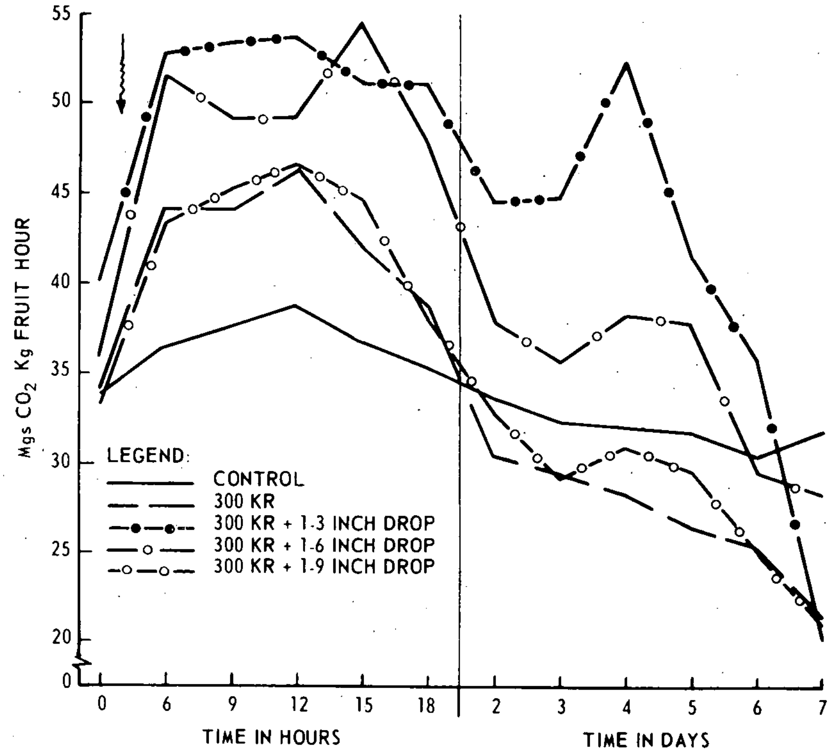

Fig. 10. Effects of combined treatments of gamma irradiation and single drops from various heights on the respiration of 'Ace' tomatoes held at 68°F.

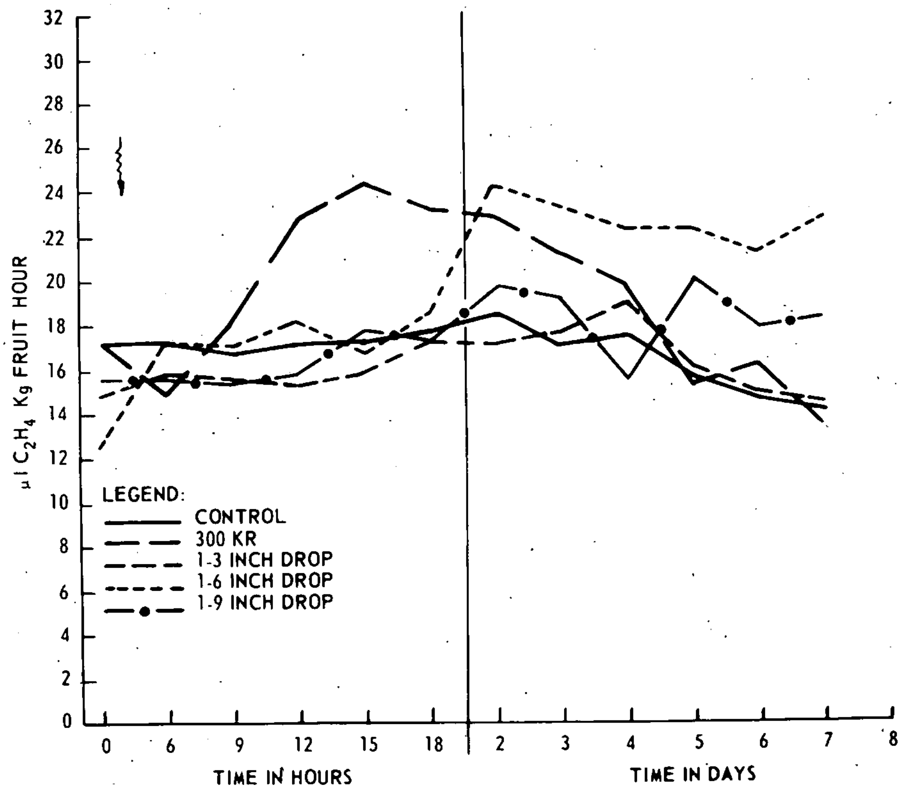

Fig. 11. Effects of gamma irradiation and single drops from various heights on ethylene (C_2H_4) production of 'Ace' tomatoes held at 68°F.

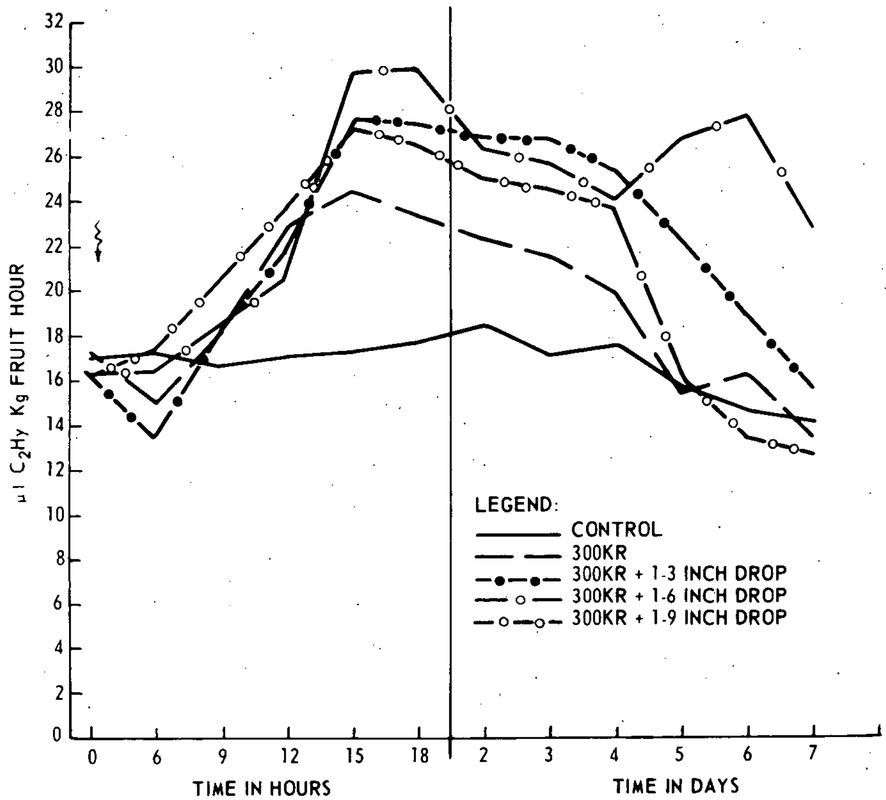

Fig. 12. Effects of combination treatments of gamma irradiation and single drops from various heights on C_2H_4 production of 'Ace' tomatoes held at 68°F.

the control fruit and the unirradiated but dropped fruit for the duration of the test, except for those subjected to 6-inch drops. In this lot the rate increased after 2 days and remained higher thereafter. Irradiation alone stimulated C_2H_4 production for 4 days then fell to a rate similar to that of control fruit. When the two treatments were combined, the rate of C_2H_4 production was increased dramatically. This rate remained above that of the control fruit for nearly all lots. Only those fruits subjected to 300 Krad and a 9-inch drop fell below the rate of the controls. The magnitude of the stimulation was not proportional to the treatment.

TEST IV.

Carbon dioxide production by fruit treated to 300 Krad and three drops of 6, 12, or 24 inches is shown in Fig. 13. A stimulated rate was observed only in the 6 and 24-inch treatments. No stimulation was observed in the other treatments. As shown in Fig. 14, the carbon dioxide production was stimulated when irradiated fruit were dropped, but not proportionately to the height. The increased rate lasted only 2 days. Thereafter there was no difference between control and treated fruit.

Ethylene production by treated fruit was similar to that shown in Figs. 11 and 12 for Test III (this test Figs. 14 and 15). There were only minor differences between dropped fruit and the controls. The irradiated fruit produced more C_2H_4 throughout the test. However, when the treatments were combined, C_2H_4 production was stimulated, although not proportionately.

TEST V.

Figs. 17 and 18 show the carbon dioxide production of breaker-stage tomatoes irradiated and dropped from various heights, alone and in combination. The rate increased immediately after the

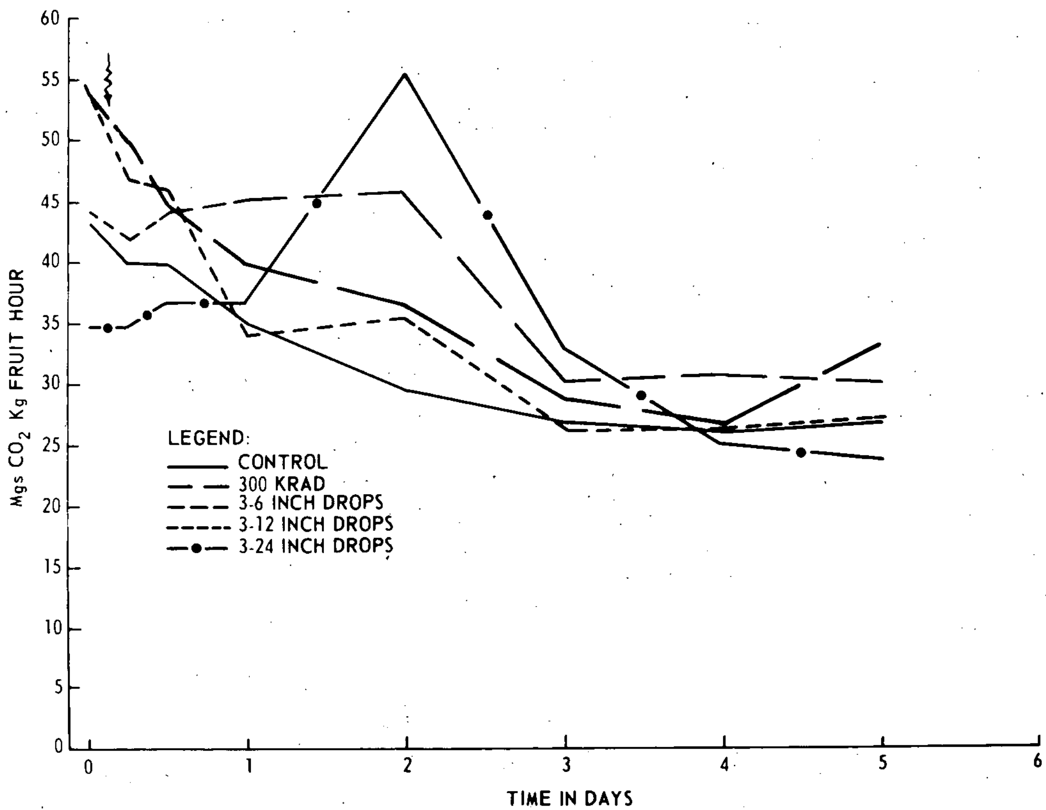

Fig. 13. Effects of gamma irradiation and multiple drops from various heights on the respiration of 'A-1' tomatoes held at 68°F.

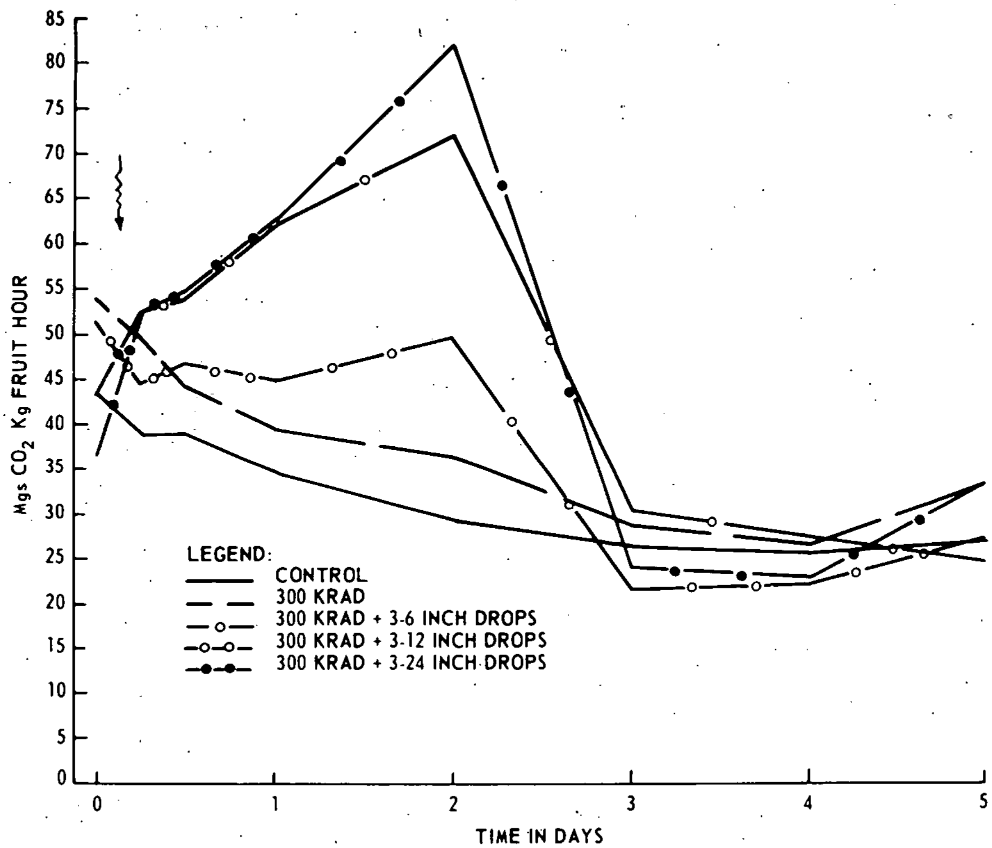

Fig. 14. Effects of combination treatments of gamma irradiation and multiple drops from various heights on the respiration of 'A-1' tomatoes held at 68°F.

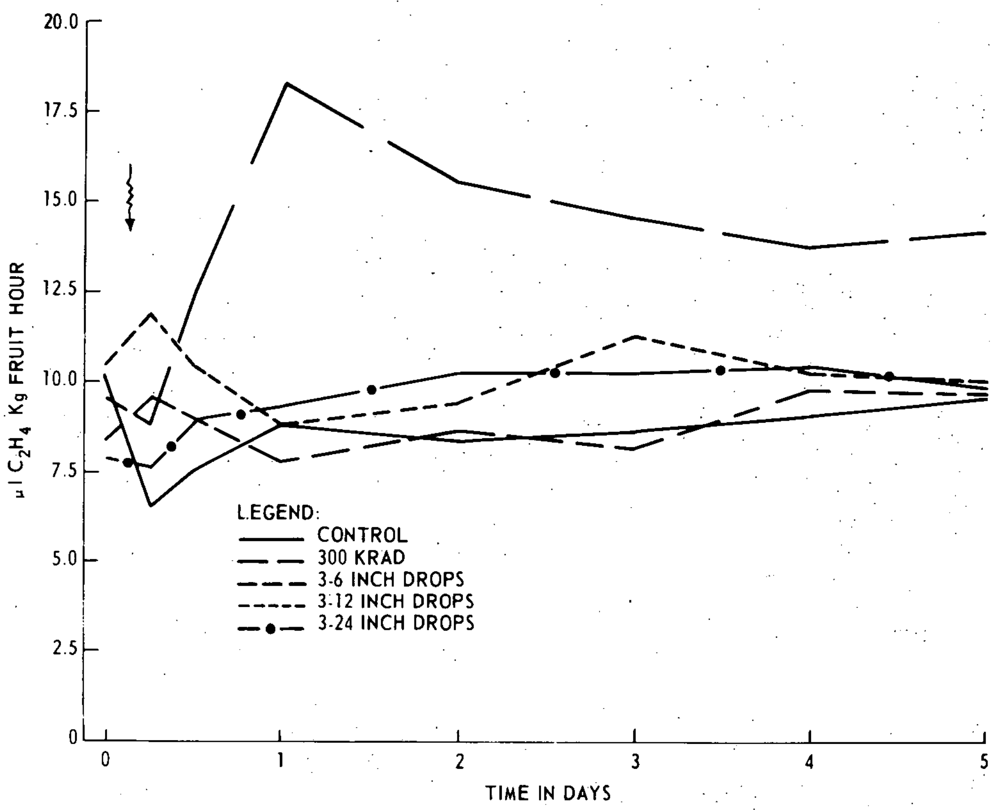

Fig. 15. Effects of gamma irradiation and multiple drops from various heights on C_2H_4 production of 'A-1' tomatoes held at 68°F.

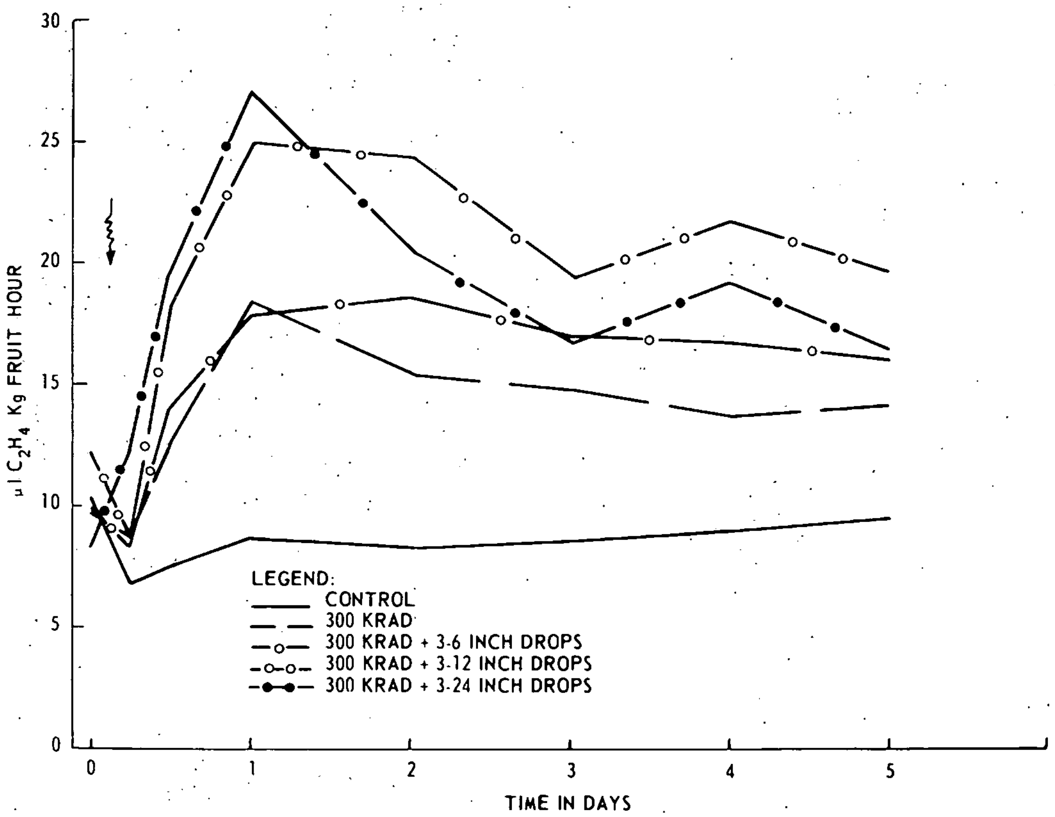

Fig. 16. Effects of combination treatments of gamma irradiation and multiple drops from various heights on C_2H_4 production of 'A-1' tomatoes held at 68°F.

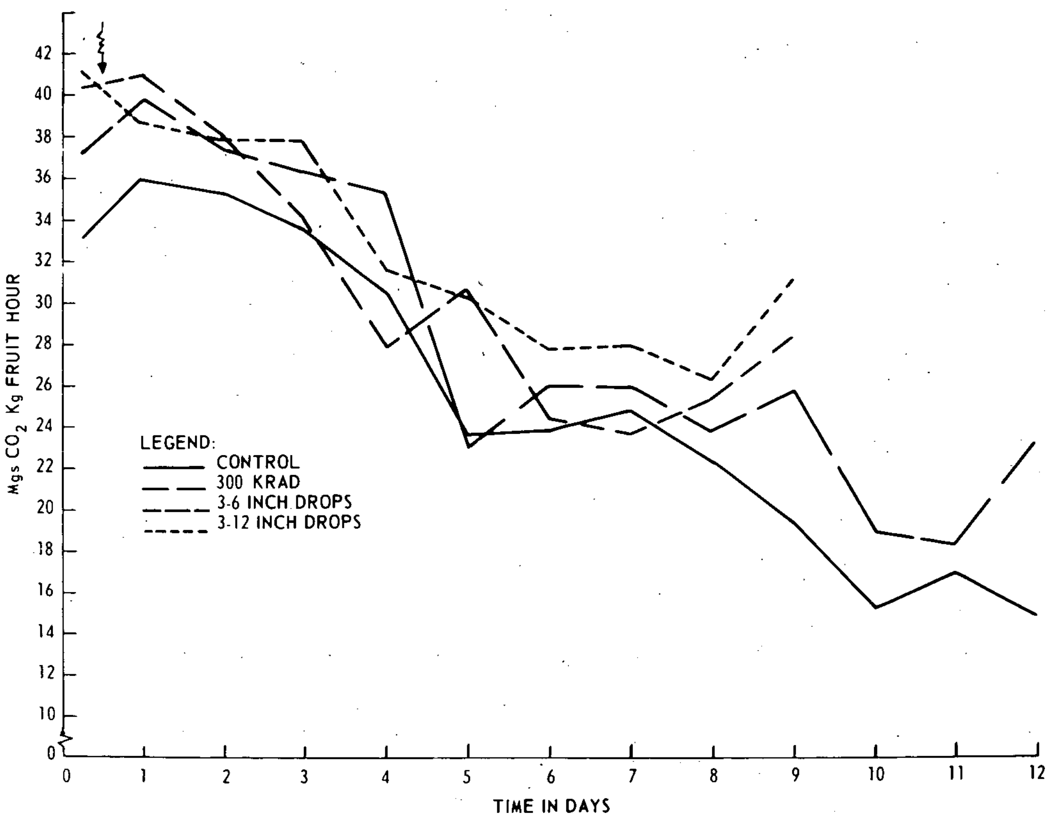

Fig. 17. Effects of gamma irradiation and multiple drops from various heights on the respiration of 'A-1' tomatoes held at 68°F.

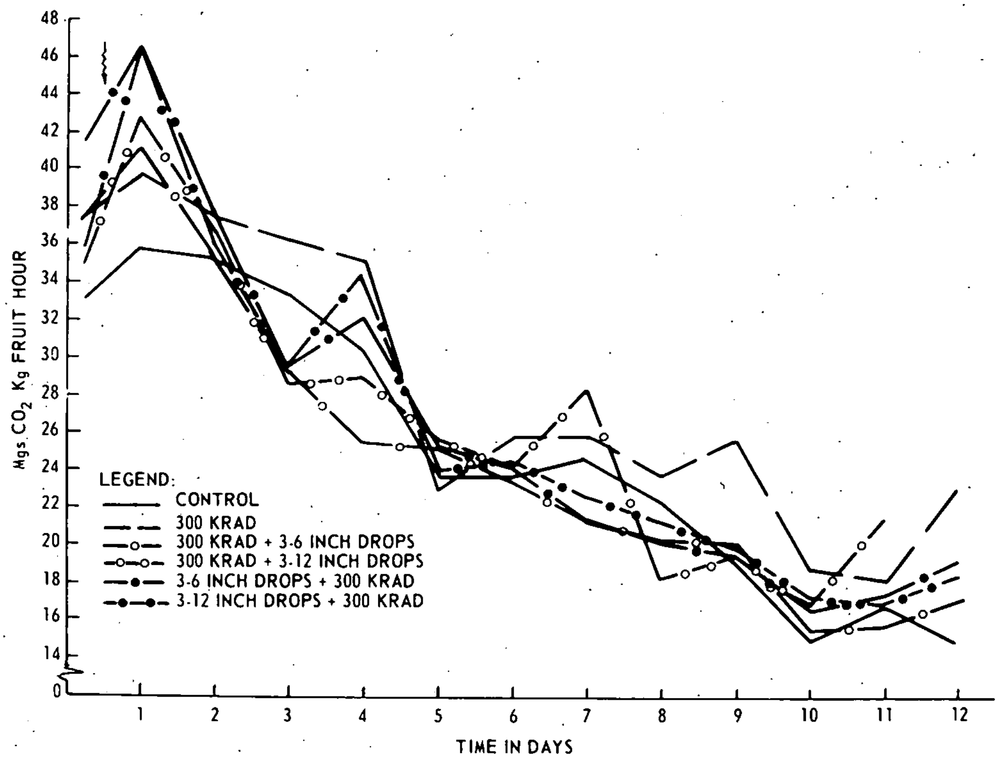

Fig. 18. Effects of combination treatments of gamma irradiation and multiple drops from various heights on the respiration of 'A-1' tomatoes held at 68°F.

combined treatments, and for fruits subjected to 300 Krad, 6-inch drops alone. The stimulated rate lasted no more than 2 days then fell to a level approximating that of the control fruit.

The rate of C_2H_4 production is shown in Figs. 19 and 20. Stimulation was more evident in treated fruit. The peak increase in rate occurred 2 days after treatment. The response was proportional to height of drop (Fig. 19), but when irradiation preceded the drops the increase in rate was not proportional to treatment. As C_2H_4 production increased in the control fruit, differences due to irradiation and/or drops were less evident.

Figure 21 shows the percent weight lost by breaker-stage tomatoes at 68°F after 3, 7, 10, 20, and 23 days storage when treated to 300 Krad, three drops of 6 and 12 inches, alone and in combination. Fruit receiving 300 Krad either alone or with drops generally lost more weight. However, fruits receiving the three 12-inch drops lost more weight than any other lot.

The number of days at 68°F required for the fruit to reach table ripeness is shown in Fig. 22. Irradiation alone delayed ripening by 3 days. The fruit dropped but unirradiated ripened 7 days earlier than untreated fruit. Drops administered after irradiation also stimulated ripening, thus overcoming the inhibitory effect of 300 Krad. However, when irradiation followed the drops, delay in ripening was as pronounced as for 300 Krad alone.

Figure 23 shows the number of days at 68°F for the fruit in each lot to reach a quality score of 3. Irradiation to 300 Krad increased the shelf life by 3 days. The shelf life was reduced by 3 and 6 days by the three 6 and three 12-inch drops respectively. When the two treatments were combined, only the fruit receiving three 12-inch drops after irradiation showed a reduced shelf life.

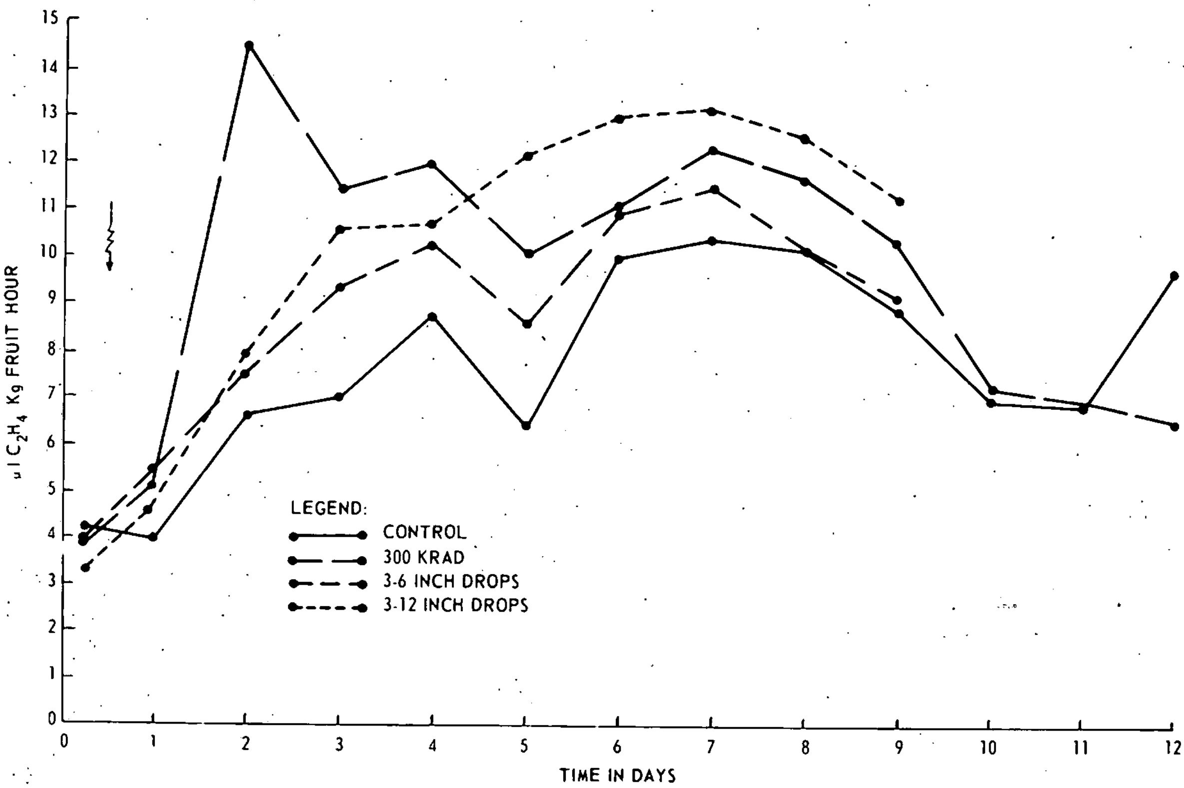

Fig. 19. Effects of gamma irradiation and multiple drops from various heights on C_2H_4 production of 'A-1' tomatoes held at 68°F.

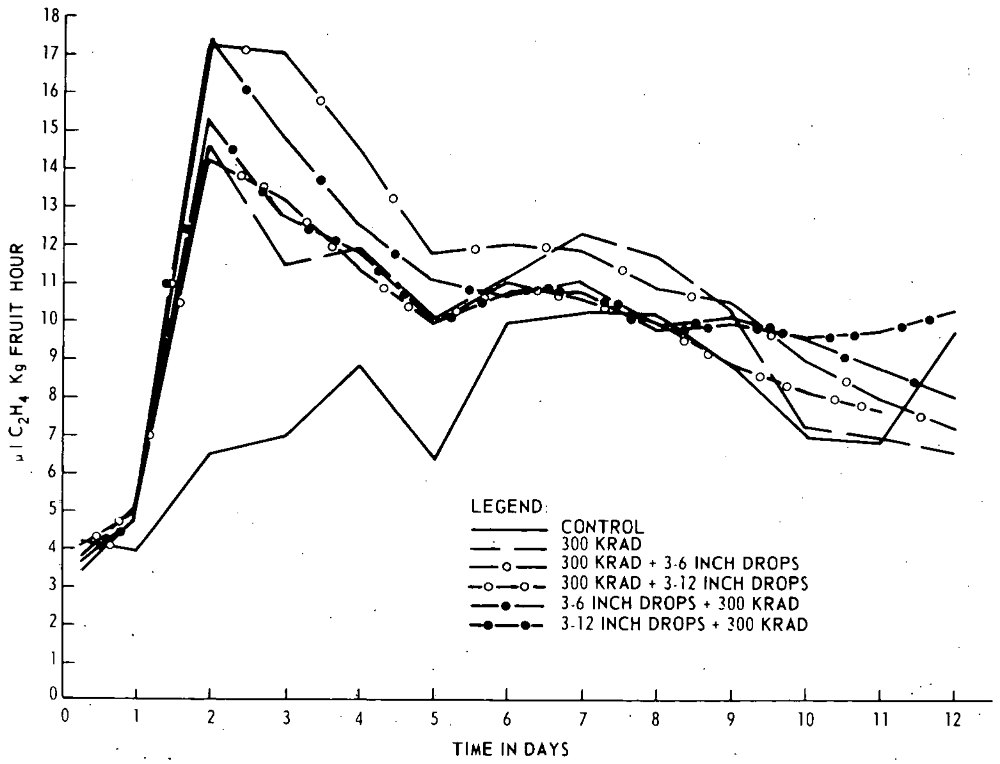

Fig. 20. Effects of combination treatments of gamma irradiation and multiple drops from various heights on C_2H_4 production of 'A-1' tomatoes held at 68°F.

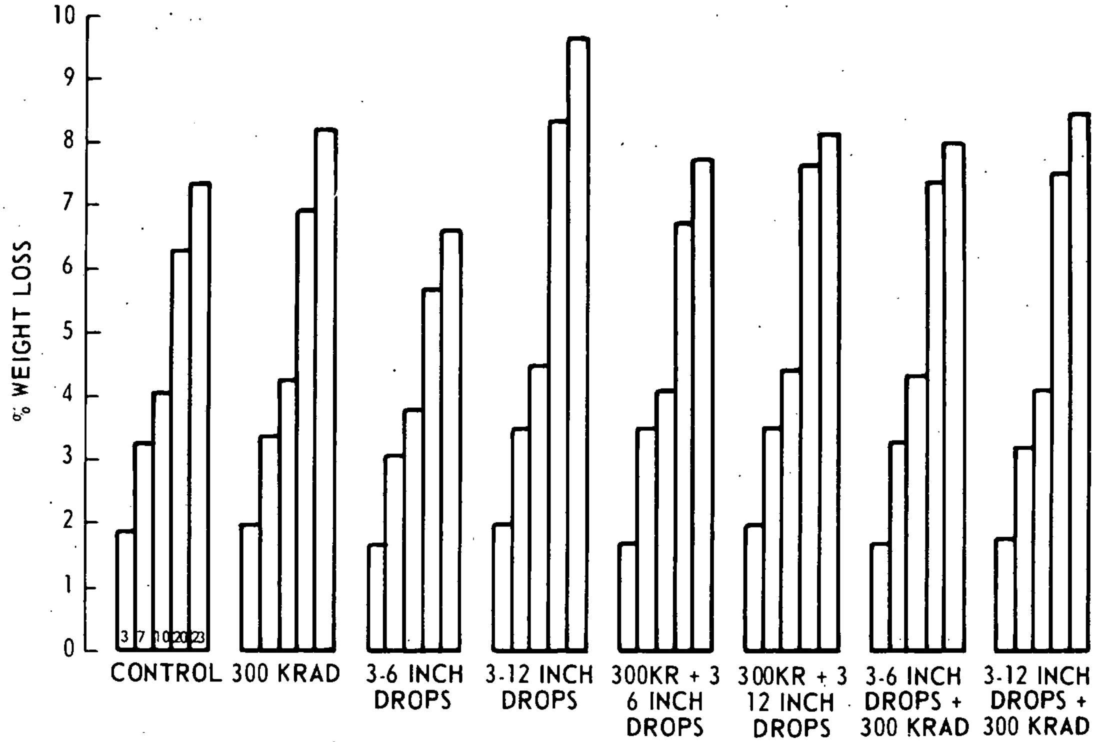

Fig. 21. Effects of gamma irradiation and multiple drops from various heights on the weight loss of 'A-1' tomatoes after 3, 7, 10, 20, and 23 days at 68°F.

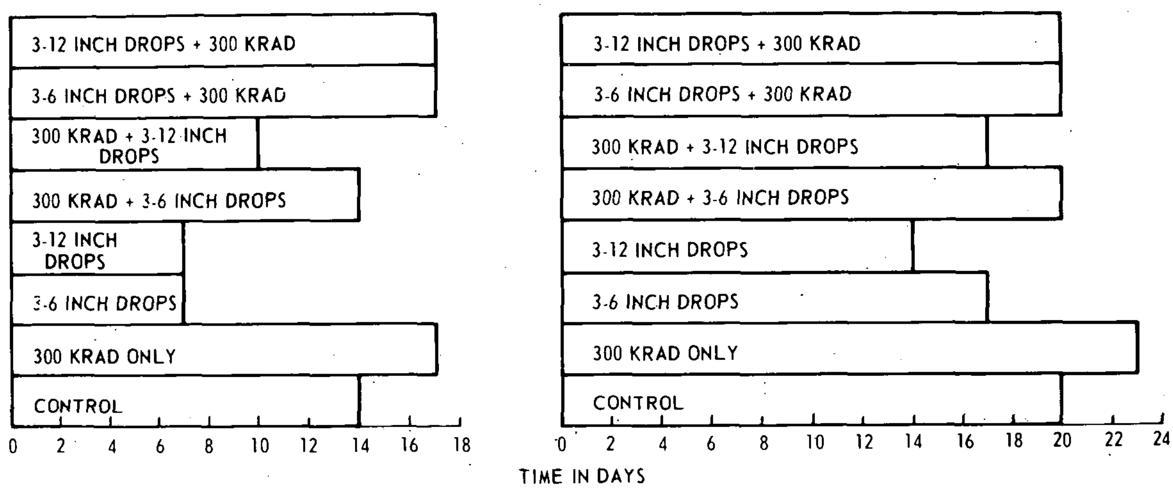

Fig. 22. Effects of gamma irradiation and multiple drops on the number of days required for 'A-1' tomatoes to reach table ripeness at 68°F.

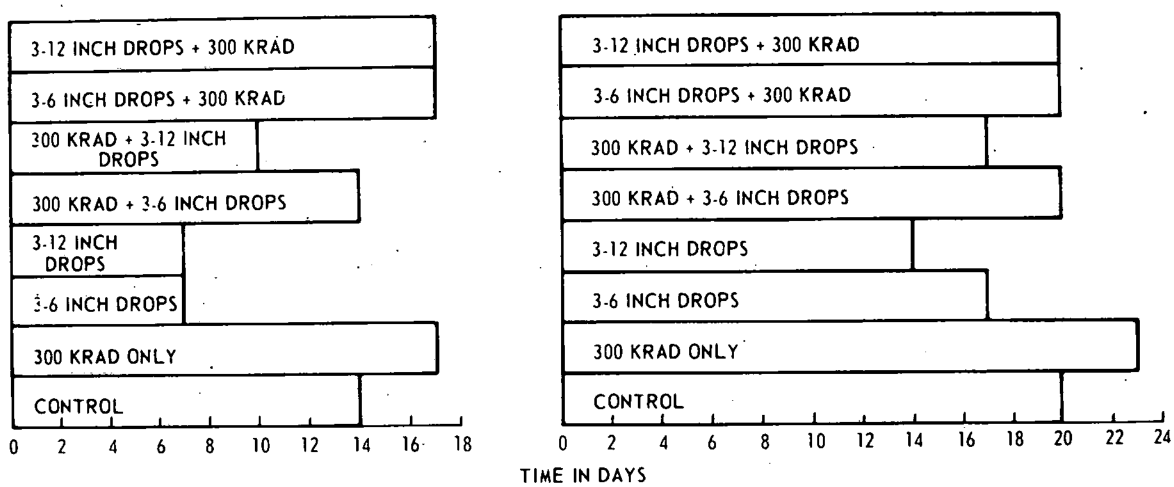

Fig. 23. Effects of gamma irradiation and multiple drops on the number of days required for 'A-1' tomatoes to reach a quality score of 3 at 68°F.

DISCUSSION AND CONCLUSIONS

The results of Tests I and II confirm those reported for similar tests conducted last year. The combined effects of the two stresses, whether applied within a short time span, or separated by 3 days are detrimental to the tomato fruit. Ripening is delayed by either treatment alone, but when combined the delay is more pronounced. Overall quality of the fruit subjected to combined treatments is reduced. Susceptibility to transit injury is increased following irradiation. A consequence of the increased susceptibility to transit injury is an increase in decay via numerous infection ports created on the surface of the tomatoes.

If the tomatoes are held tightly in place within the package, the effects listed above are held to a minimum. Transit injury is nearly eliminated even when irradiation is introduced into the system. Compression bruising was not significantly increased and would not be a serious problem if maturity selection and packaging techniques were done carefully.

Irradiation and bruising each have been shown to increase internal damage and respiration rate of tomatoes. When these two treatments were combined the respiration rate was markedly increased, as was C_2H_4 production. This could result in a higher number of ripe fruit upon arrival and also a larger number of decayed fruit via ripe fruit rots.

Water loss is another important feature of postharvest behavior to consider. Irradiation alone increases water loss in tomatoes. Data presented here indicates that bruising alone and in combination with irradiation increases water loss as well. Perhaps a closed container of the type necessary to minimize transit injury may minimize the increased water loss resulting from irradiation.

The physiological response of tomatoes to irradiation and transit injury, alone and in combination, is difficult to predict.

The maturity range of tomatoes that can tolerate beneficial doses of irradiation is limited to light pinks and more mature fruit. Physiologically these are "ripe" fruits in that they are at, or beyond, the climacteric peak, but they are visibly not "ripe". The delay in ripening may then be only a delay in lycopene development and/or chlorophyll degradation and not a physiological delay *per se*. The varietal and seasonal differences seen in response to the two stresses may be manifestations of the stage of the climacteric at which the tomatoes were treated. Data is needed from actual shipments of irradiated tomatoes before any general conclusions can be made.

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TIGHT FILL PACKING OF TOMATOES

Dale Ravetto, L. L. Morris and E. C. Maxie

Within the last decade a new packing method has been developed by research workers at the Davis experiment station (1). Termed "Tight Fill" this technique has reduced the mechanical damage of some commodities during transit. This method consists of volume filling corrugated cartons to a predetermined fill weight, vibrating the carton for a few seconds to settle the fruit, covering the fruit with a compression pad, then stapling, under pressure, a telescoping lid to the box. The fruits are held tightly in place within the package, precluding movement. Vibration injury resulting from scuffing of one fruit against another and against the box surfaces is substantially reduced.

Commodities packed successfully include; apricots, pears, plums, peaches and nectarines. These commodities have the following features in common: 1) they are harvested when mature, but not ripe; 2) their flesh is relatively firm, and thus adaptable to volume filling; and 3) they all are highly susceptible to transit injury which reduces their marketability. The "mature green" tomato has these features. Inspection of arrivals at eastern wholesale and retail outlets during the past two years indicated a need for improving the handling, packing, and shipping of tomatoes. This is particularly important in attempting to use gamma irradiation with this fruit because decreased texture of irradiated fruits markedly increases their susceptibility to transit injury. Therefore, two tests were conducted with tomatoes during the summer of 1967 using "tight-fill" techniques.

MATERIALS AND METHODS

TEST I.

Mature-green tomatoes of the 'Ace' variety were trucked to Davis from Stockton on September 6, 1967. They were packed in commercial 40-pound wire bound crates. Four crates were held as controls, another 4 were given a simulated transit treatment consisting of 30 vertical 2-inch drops, 30 horizontal impacts each equivalent to a 2.5 m.p.h. impact, and 30 minutes vibration at 1.1 g. Both lots were held at 55°F for 4 days then evaluated for transit injury on a 0-5 scale shown in Table 1. Fruit in the top, middle, and bottom layers of the crate were segregated for evaluation of compression and vibration injury.

TEST II.

Twelve 40-pound cartons of mature-green tomatoes were trucked to Davis from Patterson on October 6, 1967, and treated as follows: Four cartons were held as controls, 4 were treated as per Test I. The fruit in the remaining 4 cartons were placed in vented, waxed, corrugated cartons similar to those used in commercial tight-fill operations with other fruits. Each carton was filled to 35.5 pounds, expanding excelsior pads were placed in the bottom and top of the cartons, the cartons vibrated for 7 seconds for settling and closed by side staples in the lid while the lid was under pressure, and treated as per Test I. All 12 cartons were held at 55°F for 4 days then evaluated for transit injury as per Table 1.

RESULTS

The results reported here were analyzed statistically. Averages are derived from the scores of each individual fruit for 4 replicates of each treatment. Generally if a fruit receives a score of 3 or

Table 1. Transit injury scores used to evaluate mature-green tomatoes subjected to a simulated transit injury treatment.

Score	Injury description
0	None
1	Slight - less than 1/4 of the surface damaged
3	Moderate - up to 1/2 of the surface damaged
5	Severe - over 1/2 of the surface damaged; fruit cracked, etc.

higher, it is not considered marketable.

The results for Test I are shown in Tables 2 and 3. Tables 4 and 5 give the results of Test II. When comparisons were made between control and treated lots, the treatment effect was also highly significant except in the case shown in Table 6.

DISCUSSION AND CONCLUSIONS

In interpreting the results of this study, one must keep in mind that both of the tests were preliminary assessments of the potential benefits that might be accrued from "tight-fill" packing of mature-green tomatoes. Tomatoes subjected to simulated transit conditions in commercial packages were significantly damaged in all cases when compared to untreated control fruit. When tomatoes were "tight-fill" packed and then subjected to simulated transit there was no significant difference in injury levels as compared to control lots (Table 6).

In nearly all cases there was a significant effect of positioning the fruit within the package. The top layer had the least amount of damage, whereas the middle (2 or 3 fruit diameters) and bottom layers, in order, had increasing levels of damage. The position effect on level of injury is more or less consistent regardless of treatment. Thus, control fruit not subjected to simulated transit showed an increasing injury level from the top to the bottom layers.

The data presented here indicate less transit injury can be realized by tight-fill packing of mature-green tomatoes and hopefully would reduce the amount of transit injury to irradiated fruits. However, there are many questions that need answering. For example, the size of fruit used in these tests was 5 x 6 or larger. Smaller sizes may not respond in the same way. Also fill weight, size of container, handling in the field, packing house operations, vibration time for settling, padding and lidding, and cooling all need additional study.

Table 2. Summary of analysis of variance for tomatoes subjected to simulated transit injury.

Main effect	Mean squares	F values Observed	Required 5%	1%
Treatment	0.96	48.00**	4.38	8.18
Positioning	0.81	40.50**	3.52	5.39
(Treatment x Positioning)	0.04	2.00	3.52	5.39
Error = 0.35	0.02			

** Significant at P = 0.01.

Table 3. Average transit injury scores for each carton.

	Control				Treated			
Rep	1	2	3	4	1	2	3	4
Top	1.24	1.02	1.02	1.38	1.60	1.89	1.71	1.53
Mid.	1.53	2.05	1.50	1.83	2.18	2.08	1.84	1.79
Bot.	1.81	2.05	1.60	1.86	2.48	2.12	2.21	2.26
Avg.	1.54	1.83	1.43	1.73	2.14	2.10	1.90	1.86

Table 4. Summary of analysis of variance for tomatoes subjected to transit injury.

Main effect	Mean squares	F values Observed	F values Required 5%	F values Required 1%
Treatment	0.62	47.69**	3.32	5.39
Positioning	0.10	7.69**	3.32	5.39
(Treatment x Positioning)	0.47	3.61*	3.32	5.39
Error = 0.41				

* Significant at P = 0.05.

** Significant at P = 0.01.

Table 5. Average transit injury scores for each carton.

Rep	Control				Treated				Tight fill			
	1	2	3	4	1	2	3	4	1	2	3	4
Top	0.80	0.93	0.88	1.17	1.84	1.50	1.57	1.27	1.18	1.00	1.20	1.00
Mid.	1.10	1.15	1.19	1.15	1.58	1.50	1.51	1.35	1.09	1.02	1.32	1.44
Bot.	1.35	1.39	1.31	1.41	1.62	1.31	1.65	1.52	1.04	1.05	1.12	1.10
Avg.	1.10	1.18	1.16	1.21	1.62	1.50	1.56	1.38	1.10	1.02	1.25	1.25

Table 6. Summary of analysis of variance for tomatoes held as controls vs. tight fill and treated.

Main effect	Mean squares	F values Observed	F values Required 5%	F values Required 1%
Treatment	0.01	1.00	4.38	8.18
Positioning	0.09	9.00**	3.52	5.93
(Treatment x Positioning)	0.10	10.00**	3.52	5.93
Error = 0.19	0.01			

** Significant at P = 0.01.

EFFECT OF GAMMA IRRADIATION ON POSTHARVEST BEHAVIOR OF BELL PEPPERS[1]

Dale Ravetto, L. L. Morris, and E. C. Maxie

INTRODUCTION

Gamma irradiation markedly inhibits ripening in bananas and stimulates the rate of yellow color development in lemons (1, 2) and the rate of ripening in peaches (3).

The bell pepper (Capsicum frutescens var. grassums Bailey) is a large, thick walled, non-pungent pepper with a ripening sequence similar to that of the tomato. When harvested as "greens" they subsequently ripen to a deep red color, passing through various stages of yellows and reds. They are marketed in one of two ways: 1) as "greens" where red coloration is generally undesirable, and 2) as "reds" for canning where green coloration is undesirable. Thus, an inhibition or a stimulation of color change in peppers by gamma irradiation might be beneficial; "degreening" at a uniform rate for canning, or a delay of red color development for the fresh market. An experiment was conducted in the fall of 1967 to determine if either of the above responses might occur with bell peppers.

MATERIALS AND METHODS

"Green" bell peppers were trucked to Davis from the Tracy area of California on November 4, 1967. They were sorted into 24 lots of 11 fruit each for uniformity of size and maturity, weighed, and placed in respiration jars for overnight aeration at 68°F. The following morning an initial CO_2 determination was made by the

[1] Not a major contract project. Conducted as a survey of potential application of irradiation of perishables.

Claypool-Keefer method (4). Then 3 replicates each were irradiated as follows: 0, 50, 100, 200, 300, 400, 500, and 600 Krad. After irradiation the fruit were returned to the jars and CO_2 determinations made daily. Upon termination of the experiment each fruit was evaluated for quality, ripeness, internal condition, and decay using the quality and ripeness classifications described for tomatoes.

Four lots of 25 fruit each were prepared as above for visual evaluation of quality, ripeness, and decay in open container storage at 68°F. Doses were 0, 100, 200, and 400 Krad.

RESULTS

Figures 1 and 2 show the CO_2 production of the irradiated peppers over the 11-day storage period. Carbon dioxide production was stimulated at all dose levels albeit not proportionately to the dose. The respiratory rate of irradiated fruits remained higher than the controls for the duration of the test. The rate of fruits subjected to the lower dose declined with time to a level just slightly higher than the control fruit. The rates gradually declined for 10 days after irradiation. After 10 days, decay caused by Botrytis cinerea (Per. ex Fr.) precluded further CO_2 readings. The severity of decay in terms of abundance of aerial mycelium increased with increasing dose levels. This is reflected in the respiration readings for day 11.

Table 1 gives the terminal quality and ripeness scores for the fruit used in the respiration phase of this test.

The visual quality of the peppers was not substantially reduced by the irradiation. However, increased susceptibility to decay would have precluded sale of the fruits. At doses of 200 Krad and above, the peppers were yellowed. The degree of yellow color increased from a light pale yellow-green at 200 Krad to a medium dark yellow at 600 Krad. The yellow color extended throughout the wall of the fruit.

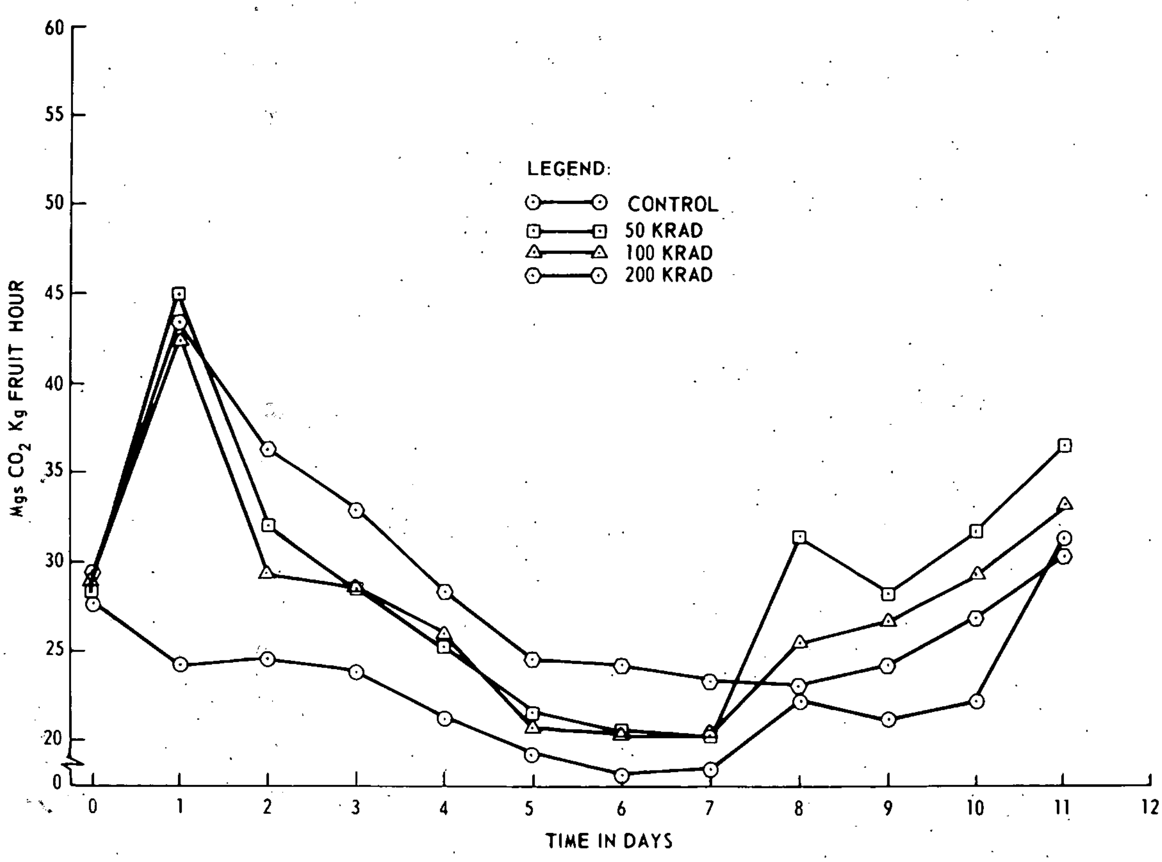

Fig. 1. Effect of gamma irradiation on the respiration of "green" bell peppers held at 68°F.

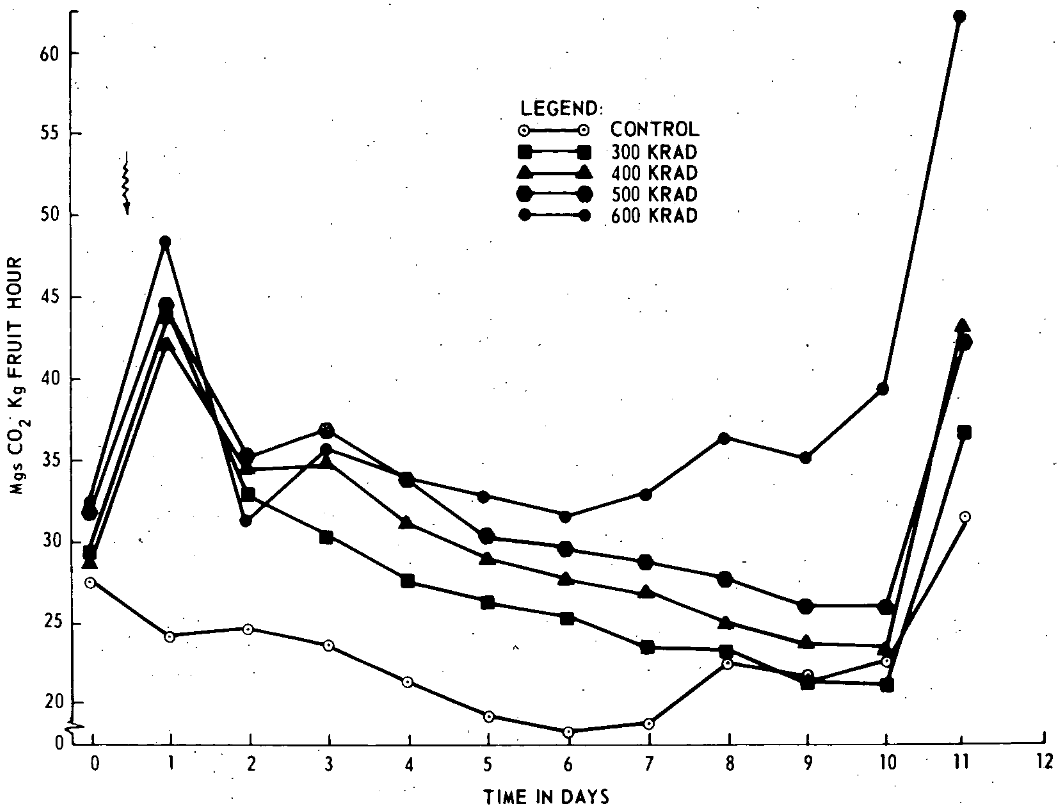

Fig. 2. Effect of gamma irradiation on the respiration of "green" bell peppers held at 68°F.

Table 1. Quality and ripeness scores after 11 days storage at 68°F.

Treatment	Quality	Ripeness
Control	6.2	1.8
50 Krad	5.5	1.5
100 Krad	5.8	2.0
200 Krad	5.9	0.9
300 Krad	5.5	0.8
400 Krad	4.4	1.1
500 Krad	4.1	0.9
600 Krad	1.1	0.9

Ripening was inhibited at doses above 100 Krad as compared to fruit subjected to 0, 50, and 100 Krad. The calyx was not affected at any dose level and the placentae and seeds did not show any abnormalities.

Table 2 gives the quality and ripeness scores for the peppers held in open storage for 8 days.

The peppers were shriveled, soft, and some showed decay. The texture of the irradiated peppers was noticeably softer than the control fruit, but no objectionable flavors or aroma were evident. There was an inhibition of color development at all dose levels, with 400 Krad being the most effective. The yellowing observed in the respiration studies was not evident in this test. The internal condition of the peppers was not affected by irradiation.

DISCUSSION AND CONCLUSIONS

The respiratory response of peppers is typical of non-climacteric type fruits. Irradiation to doses as low as 50 Krad induces a pseudoclimacteric. The high levels of CO_2 produced by the peppers on day 11 is due to respiratory activity of both the peppers and the decay organism (*B. cinerea*). The amount of aerial mycelium on the peppers increased with dose level.

The texture of the fruit was reduced by all levels of irradiation. The peppers held in open storage shriveled much more than those under a nearly saturated atmosphere in the respiration jars.

The appearance of the peppers was not materially affected by irradiation until shrivel and/or decay started, the quality deteriorated rapidly. Ripening was inhibited, but the levels that were most effective were most injurious to the peppers. Of interest is the completely different responses observed in fruit held in a high relative humidity and those held in open storage with a relative humidity of approximately 90%. The peppers held in the respiratory jars "yellowed" at doses above 200 Krad, yet peppers treated to

Table 2. Quality and ripeness scores for bell peppers subjected to 0, 100, 200, and 400 Krad and held in open containers for 8 days at 68°F.

	Quality				Ripeness			
	Date				Date			
Treatment	11/5	11/7	11/9	11/13	11/5	11/7	11/9	11/13
Control	8.36	7.56	6.85	2.87	0	0.4	1.2	2.7
100 Krad	8.36	7.60	6.05	2.67	0	0.3	0.4	1.2
200 Krad	8.32	7.64	6.40	2.67	0	0.5	0.8	1.3
400 Krad	8.28	7.44	6.35	3.00	0	0.5	0.6	0.9

400 Krad and held in open containers did not yellow. Chlorophyll degradation by irradiation is not a new response, but that none of the red colors developed might indicate that degradation was not limited to chlorophyll but may also have been extended to include lycopersicum and the xanthophylls responsible for red pigmentation.

Increased susceptibility to decay and softening of peppers precludes irradiation in the postharvest handling of bell peppers. Inhibition of ripening occurs, but at levels above those tolerated by the peppers.

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2. Maxie, E. C., I. L. Eaks, and N. F. Sommer. 1964. Some physiological effects of gamma irradiation on lemon fruit. Rad. Bot.. 4:405-411.

3. Maxie, E. C. (Unpublished data.)

4. Claypool, L. L. and R. M. Keefer. 1942. A colorimetric method for CO_2 determination in respiration studies. Proc. Amer. Soc. Hort. Sci. 40:177-186.

A LABORATORY UNIT FOR STUDY OF PASTEURIZATION OF FRUITS OR VEGETABLES WITH SATURATED AIR

OCTOBER 1967

Rene Guillou

Three trays of strawberries -- about 40 pounds net -- or equivalent samples of other fruits -- were chosen as being an adequate maximum load for the type of tests anticipated, with provision for smaller loads down to half a tray, or about 7 pounds net. For accurate measurements of the relation of temperature and time to fruit injury and survival of decay, the air temperature should come up quickly after insertion of a load of cold fruit and hold close to the set point. Air flow through the fruit sample and static head across it should be measured to provide engineering data for commercial pasteurizers if needed.

Direct steam admission was chosen to heat and humidify the air in the research unit because the absence of inertia in this system facilitates quick response and close control. Also, for quick response and close control, a small thermistor in the fan blast was connected to a solenoid valve in the steam line through an electronic indicating controller with an on-off sensitivity adjustable down to 0.01F. Cycling in the control system is regulated manually by a needle valve in series with the solenoid, to control the rate of air temperature rise when the solenoid is open, and a second needle valve in parallel with the solenoid, to control the rate of air temperature fall when the solenoid is closed. By occasional readjustment of the needle valves as the load changes the temperature swings can be held to plus or minus 1/2F or less from the set temperature.

Air flow is measured by a gage reading differential pressure across an orifice plate and a second gage measures differential pressure across the fruit. Air is circulated by a centrifugal fan, with a damper in its discharge to regulate the flow.

The pasteurizer, complete with its instruments, is mounted on casters. Steam at 15 psi is supplied by a separate 6 kw portable electric boiler. Fruit temperature is measured, when desired, by thermocouples connected to a separate 12-point recorder. The three units can be used in the laboratory or rolled into a pickup truck and taken to the irradiator site.

ACCESSORIES

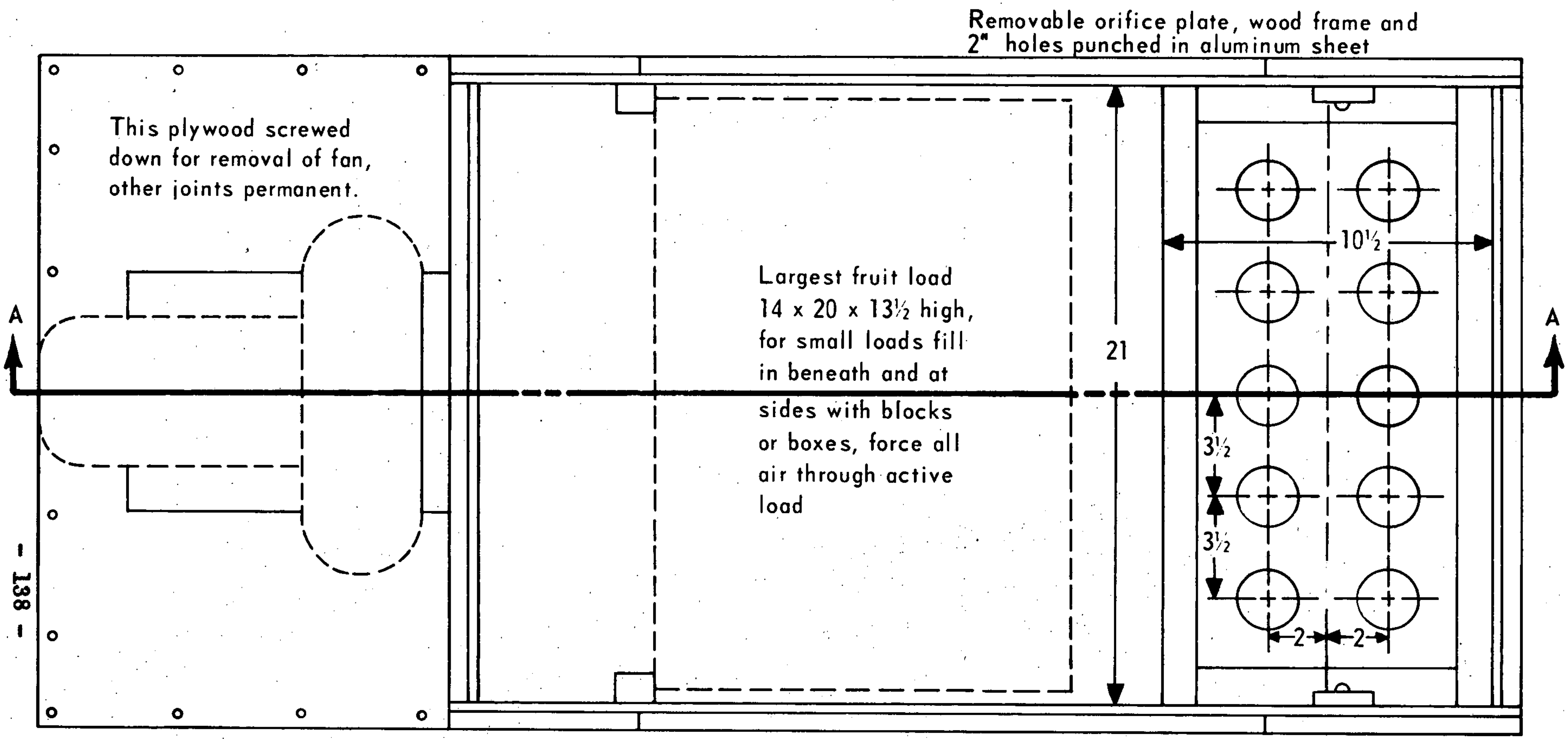
Steam boiler, portable electric, 6 kw, operated at 15-20 lb/sq in by thermostatic control which also provides low water protection, 22 lb/sq in safety valve, water level maintained manually by hose connection to hydrant. (Sussman Hot Shot, Model MB6L, Automatic Steam Products, New York 23, N.Y.)

Fan, 1/4 hp radial flow, 327 cfm at 1/2" static, 258 cfm at 2" static. (ILG Size PE 4, ILG Electric Ventilating Co., 2870 North Pulaski Road, Chicago 41, Illinois.)

Air-pressure gages, 0 to 1.0 inches differential water head, needle magnetically coupled to diaphragm. (Magoahelic Model 2001, F. W. Dwyer Manufacturing Co., P. O. Box 373, Michigan City, Indiana.)

Electronic temperature indicator and controller with small thermistor in fan blast, opens and closes solenoid steam valve on about 0.1F differential. (Tele-Thermometer Model 73, Yellow Springs Instrument Co., P. O. Box 279, Yellow Springs, Ohio, 45387.)

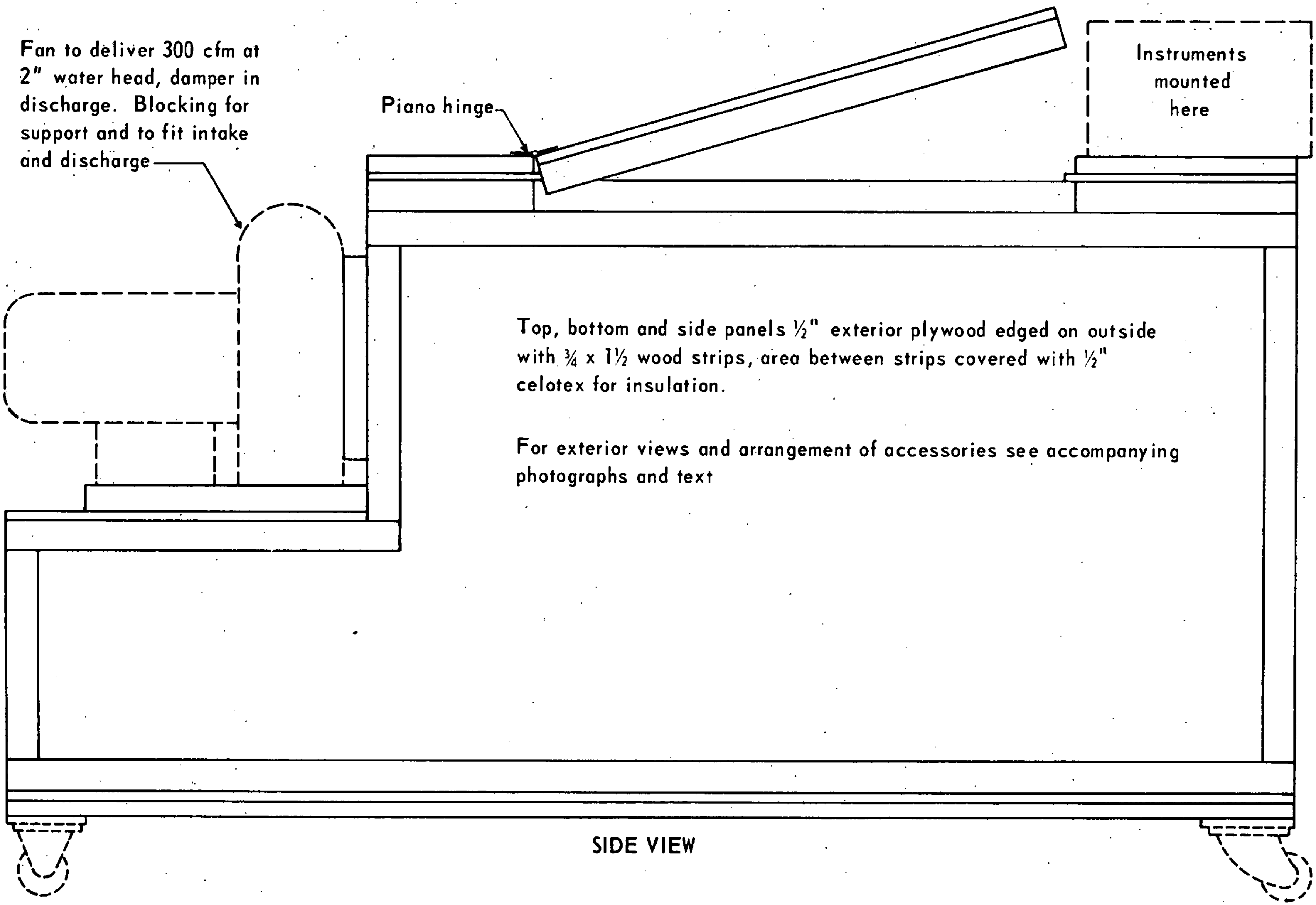
Recording potentiometer, 12 point, chart speed at least 4 inches per hour, using copper-constantan thermocouples of No. 24 wire or finer. (Honeywell Electronik, Honeywell Inc., Industrial Products Group, Ft. Washington, Pa., 19034.)



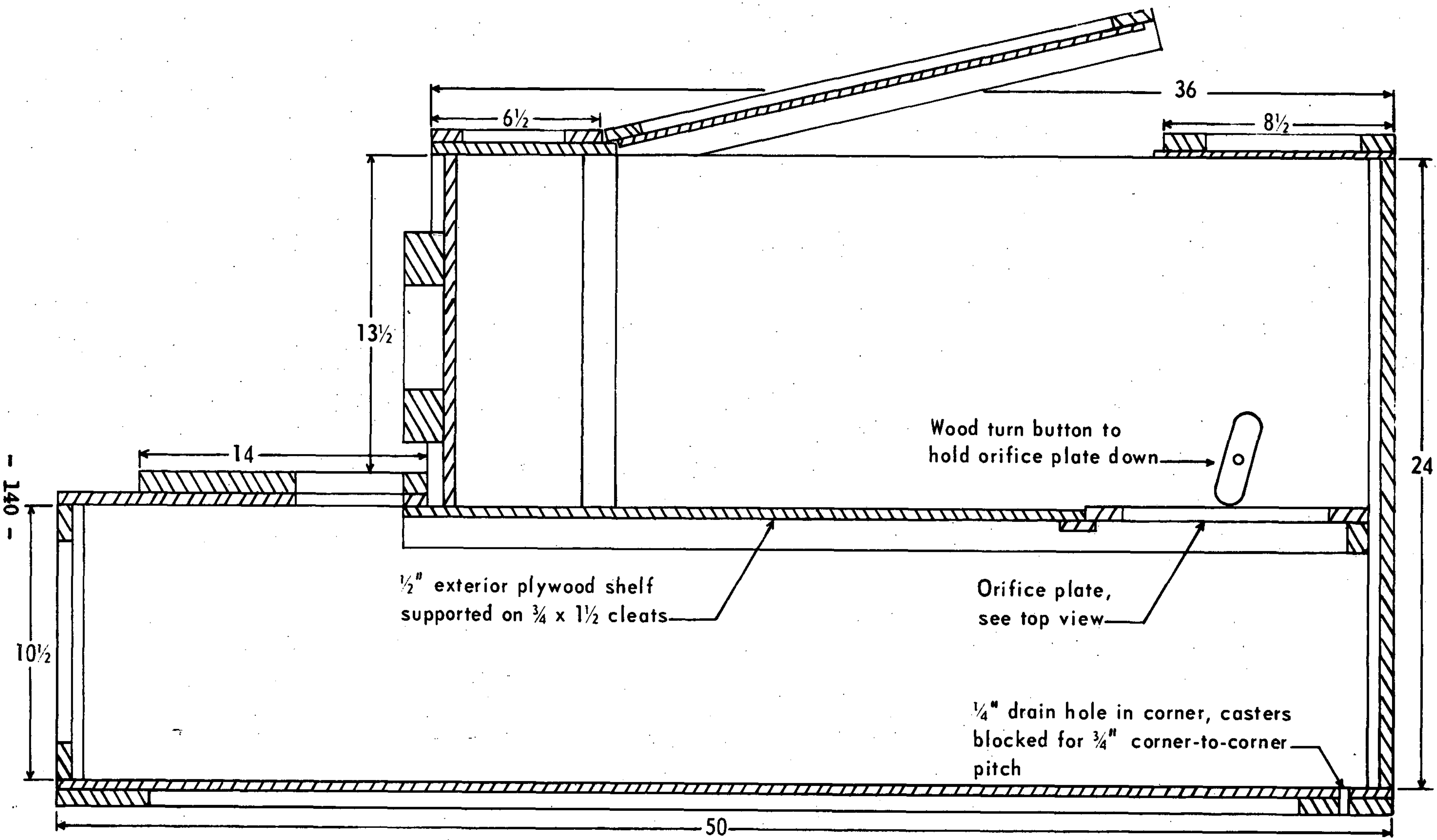
TOP VIEW WITH TOP PANELS REMOVED

FRUIT PASTEURIZER
University of California, Department of Pomology
Davis, California
July 1967

RG 7/67


Fan to deliver 300 cfm at 2" water head, damper in discharge. Blocking for support and to fit intake and discharge
Piano hinge
Instruments mounted here
Top, bottom and side panels ½" exterior plywood edged on outside with ¾ x 1½ wood strips, area between strips covered with ½" celotex for insulation.
For exterior views and arrangement of accessories see accompanying photographs and text

SIDE VIEW


36
6½
8½
13½
14
24
10½
50
Wood turn button to hold orifice plate down
½" exterior plywood shelf supported on ¾ x 1½ cleats
Orifice plate, see top view
¼" drain hole in corner, casters blocked for ¾" corner-to-corner pitch

SECTION A - A

SUMMARY OF ENGINEERING STUDIES OF FRUIT PASTEURIZATION APRIL-OCTOBER 1967

Rene Guillou

PHYSICAL OBJECTIVES IN HEATING FRUIT.

Whether heat treatment is used alone or in combination with ionizing radiation, success appears to depend on production of a temperature history that controls decay without serious injury to the fruit. Satisfactory decay control presumably requires that the coolest regions in which treatment is required should experience at least some minimum time-temperature history. Avoidance of fruit injury, on the other hand, presumably requires that the warmest regions subject to injury should experience at most some maximum time-temperature history.

It seems, therefore, that an essential feature of any heat treatment is the spread in temperature history between the coolest regions in which decay is to be controlled and the warmest regions that are subject to injury. Where these regions are, and the allowable differences in their temperature histories, are questions of horticulture rather than engineering. However, a review of some engineering considerations may be helpful in planning and interpreting horticultural studies.

Temperature sensing devices on the surfaces of fruits or in their flesh tend to disturb the conditions that are to be measured. Also it is difficult to locate sensing devices at exact positions in the undisturbed flesh. Finally, irregular positioning combines with irregularities among individual fruits and irregular flow patterns of the heating medium to produce a wide scatter in observed temperature histories. This may give an impression that the measurements are so unreliable as to have limited value. Perhaps it should be considered, on the contrary, that the scatter in temperature histories may be the most important characteristic of a treatment. Even imperfect estimates of the range of temperature histories in the fruit may be more helpful in explaining decay control and fruit injury than are exact measurements of the temperature of a heating medium and the time of exposure.

MEASUREMENTS IN THIS STUDY.

Measurements of fruit temperature in this study were made with No. 24 wire thermocouples inserted to estimated depths in the fruit. Close to the surface and early in the heating operation, there appeared to be roughly a linear relation between depth below the surface and remaining fraction of initial temperature difference between fruit and heating medium. This was used to extrapolate surface temperatures from measurements beneath the surface. The temperature of strawberry surface cells subject to heat injury was measured by threading very fine wire thermocouples a fraction of a millimeter beneath the surface, but this was not attempted with nectarines. Thermocouples in the fruit and others to measure temperature of the heating medium were connected to a recording potentiometer to obtain time-temperature histories.

Measurements were made at the most exposed locations, where most heat injury would be expected; in stem cavities, where slowest heating in fully exposed fruits would be expected; and beneath points of contact when the fruits were not fully exposed.

Velocity of the heating medium relative to the fruit was made as uniform as possible and was measured or estimated. Heat transfer from a fluid to a solid varies roughly with the square-root of the velocity and can be an important factor in the temperature history of the solid surface.

Graphs of the most significant measurements are appended.

HEATING BY IMMERSION IN WATER.

Nectarines were heated by moving pairs of fruits in a water bath at an estimated velocity of 20 feet per minute relative to the water. All exposed surfaces, including those in stem cavities, were estimated to come virtually to water temperature within 2 or 3 minutes. Times for other points to come to 10 percent of the initial fruit-to-water temperature differences were:

Coolest exposed areas	
1 mm below surface	5 min
3 mm below surface	20 min
Coolest fruit-to-fruit contacts	
Surface	15 min
1 mm below surface	20 min
3 mm below surface	30 min

This emphasizes the difference to be expected between immersion of moving fruits, with no fixed fruit-to-fruit contacts, and fruit in containers in which fruit-to-fruit contacts are fixed.

Relative water velocity of 90-feet per minute reduced these heating times by about one-half, as would be expected. On the other hand, a relative velocity of 5-feet per minute, which could exist at some places in a tank with random agitation rather than controlled flow, could double these times.

No tests were made of showering fruits with water, as opposed to immersion. Experience with hydro-cooling indicates that showered water often does not reach the under sides of fruits, and that it tends to channel through the lower layers. This behavior would be expected to produce differences in temperature history that would be objectionable in heat treatment.

HEATING WITH SATURATED AIR.

Heat is released from saturated air to the surface of heat-treated fruits chiefly by condensation of water, at a rate of about one percent of the weight of the fruit for each 13°F or 7°C rise in the mass-average temperature of the fruit. In short treatments of large fruits the mass-average temperature rise is much less than the temperature rise near the surface and total condensation on fruit initially at field temperature is of the order of one percent of its weight, but may be considerably more on refrigerated fruits or on small fruits. Forced-air cooling of strawberries, immediately after heating, has evaporated the condensed moisture without injury to the berries or to corrugated paper trays in which they are commonly packed.

Nectarines in screen-sided boxes were heated by saturated air moving at a velocity of 400 feet per minute in the gross section. Times to reach 10 percent of the initial fruit-to-air temperature difference were:

Warmest exposed surface	3 min
At fruit-to-fruit contacts	
Coolest surface	17 min
Coolest 1 mm below surface	22 min
Coolest 3 mm below surface	30 min

Exposed surfaces are evidently heated much faster by water immersion than by saturated air, but at fruit-to-fruit contacts the two methods are nearly equal.

Strawberries were heated in a common commercial pack, of small ventilated plastic baskets in corrugated paper trays, with saturated air flowing over and through the fruit mass at a velocity of 350 feet per minute, measured in the gross section. Times to reach 10 percent of the initial fruit-to-air temperature difference were:

Most exposed surfaces	4 min
Most protected surfaces	12 min
Most protected centers	15 min

Heating times for small test samples in saturated air varied about inversely with the square-root of the air velocity. In commercial scale operations the air might be cooled considerably in passing through the fruit at lower velocities and there could be a greater variation of heating rate with velocity.

Temperature and saturation of air were maintained in these tests by direct admission of low pressure steam, which is convenient for small, intermittent operations. Air initially at 100°F and 5 percent relative humidity is heated to 109°F when brought to saturation by admission of saturated steam at 20 pounds per square inch. If the air is initially warmer or dryer, or if the steam is at higher temperature. Such conditions were not approached however. Saturation is maintained by any contact of the air with cold surfaces and admission of steam to maintain the temperature. In commercial operations consideration should be given to humidifying and heating the air by contact with hot water in a counterflow tower, which could be combined with immediate cooling by changing to cold water.

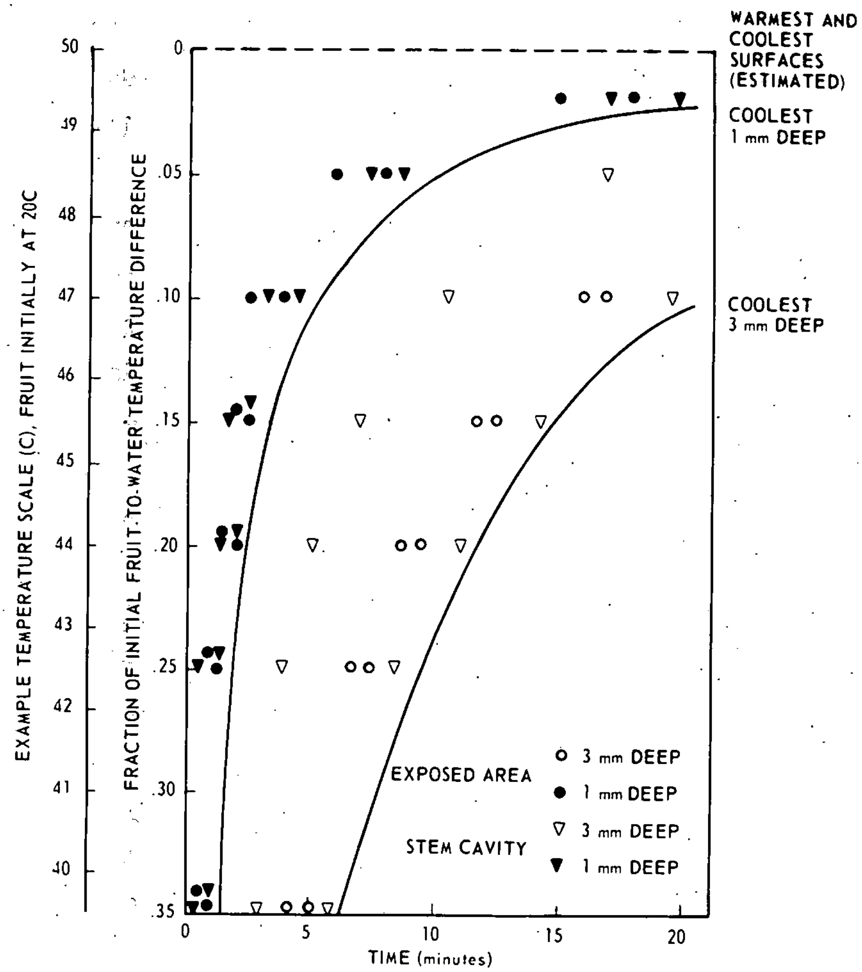
SUGGESTED ADDITIONAL STUDY.

Engineering of heat-treating facilities depends on an understanding of the relation of decay control and fruit injury to time-temperature histories in the fruit. The connection between these time-temperature histories and the means of producing them is essentially an engineering one. Probably it is to this aspect that engineering can make its most useful contribution.

Obviously, the regions that should be heated and the maximum and minimum temperature histories that are allowable are the keys to development of satisfactory treatments. Possibly it would be useful to construct a chart of estimated time-temperature histories for each test treatment, and then to compare this with the horticultural evaluation of the fruit and with the results that might have been anticipated from _in vitro_ tests. This suggestion is made with some hesitation by an engineer who may be quite ignorant of its horticultural aspects.

Analogy with other operations suggests that the relative costs of short and long treatments cannot be reliably predicted for the various conditions likely to be encountered. Effects on the fruit and relation to subsequent cooling may be decisive considerations. Tests covering a wide range from high-temperature short-time to low-temperature long-time seem likely to be of value.

Temperature differences in different parts of the heating fruit are about the same fraction of the initial fruit-to-heating medium temperature difference, _irrespective of the initial fruit temperature_. Differences in temperature history could be reduced by first heating the fruit to a relatively uniform, non-injurious temperature, and then applying the final heat treatment. This might be tried on a laboratory scale. It could be accomplished commercially by a two-stage continuous process or by automatic sequence in a batch operation. Cooling might follow in a third continuous stage or in a third sequence.

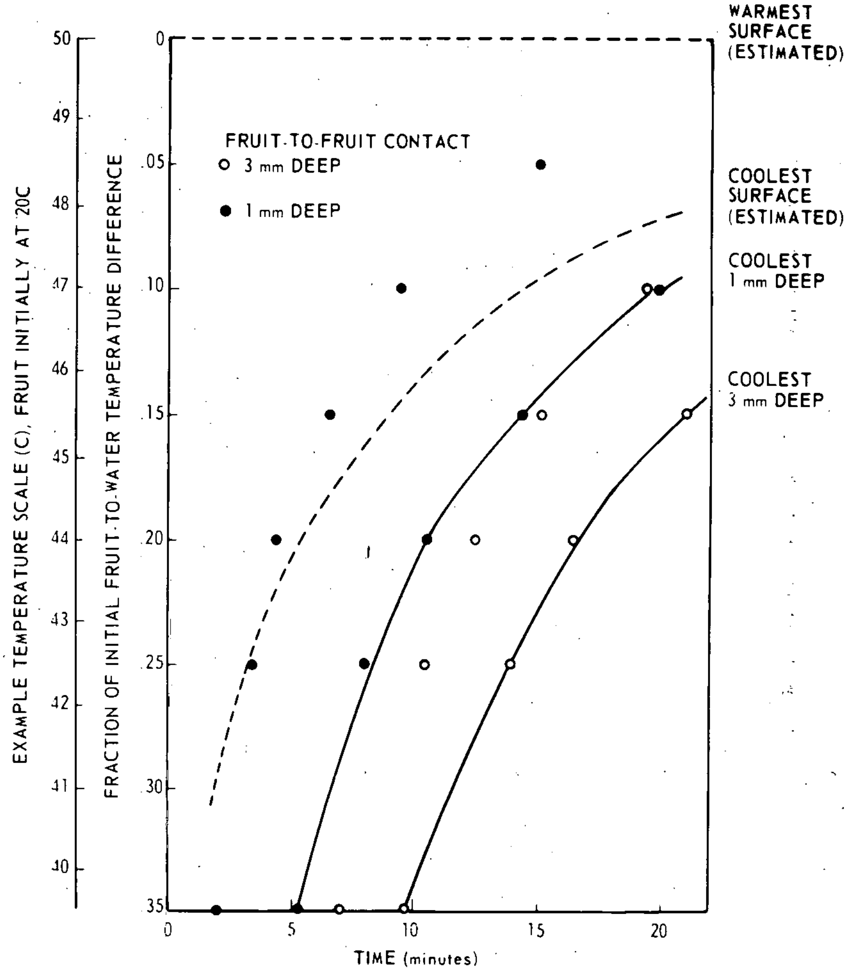


Heating nectarines by immersion in water

Single fruits fully exposed.

Water velocity relative to fruit estimated at 20 ft/min (90 ft/min reduced cooling times at 1 mm depth by 30 to 50%, little difference at 3 mm).

Size 64 nectarines, average weight 156 grams = 0.342 lb.

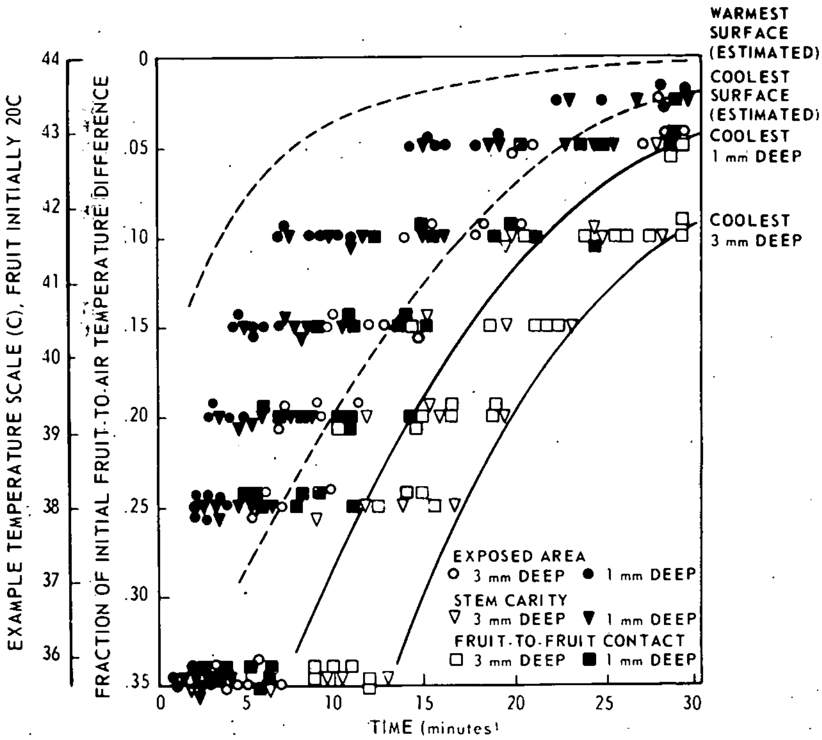


Heating nectarines by immersion in water

Two fruits held in contact.

Water velocity relative to fruit estimated at 20 ft/min (90 ft/min did not significantly speed heating at points of contact).

Size 64 nectarines, average weight 156 grams = 0.342 lb.



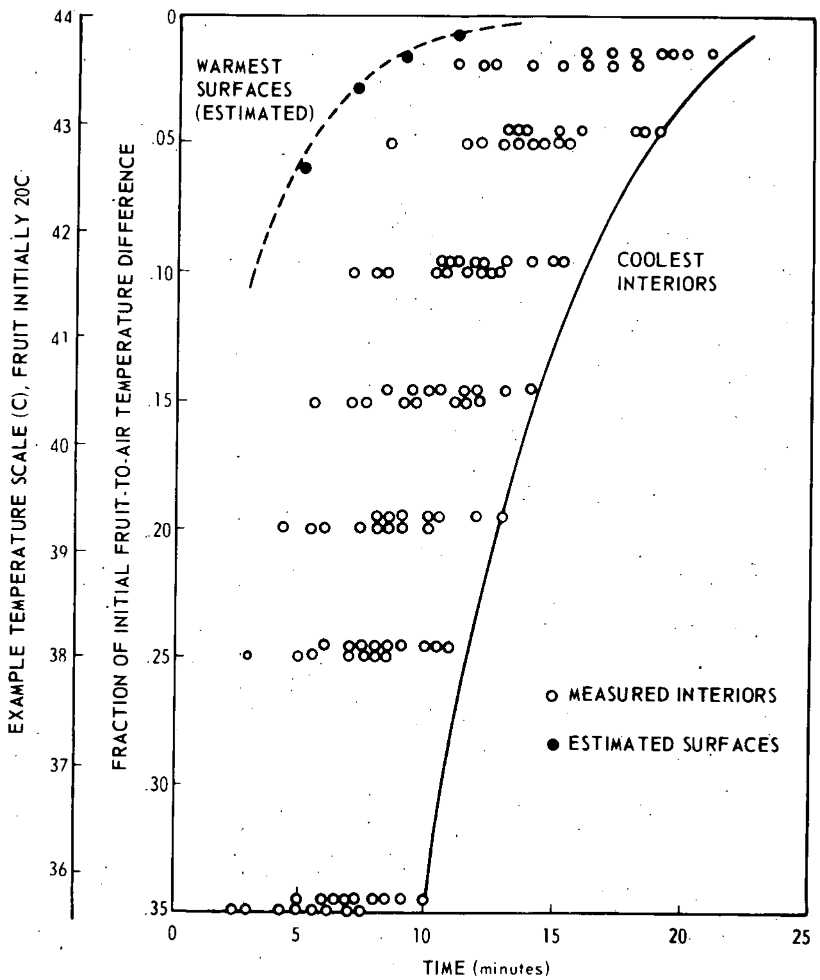
Heating nectarines in saturated air

Thirty nectarines in fruit-to-fruit contact in screen-sided box.

Air velocity in gross section 400 ft/min (heating times about doubled at 100 ft/min).

Static head across box (13 1/2") 0.35 to 0.46 inches water.

Size 64 nectarines, average weight 156 grams = 0.342 lb.

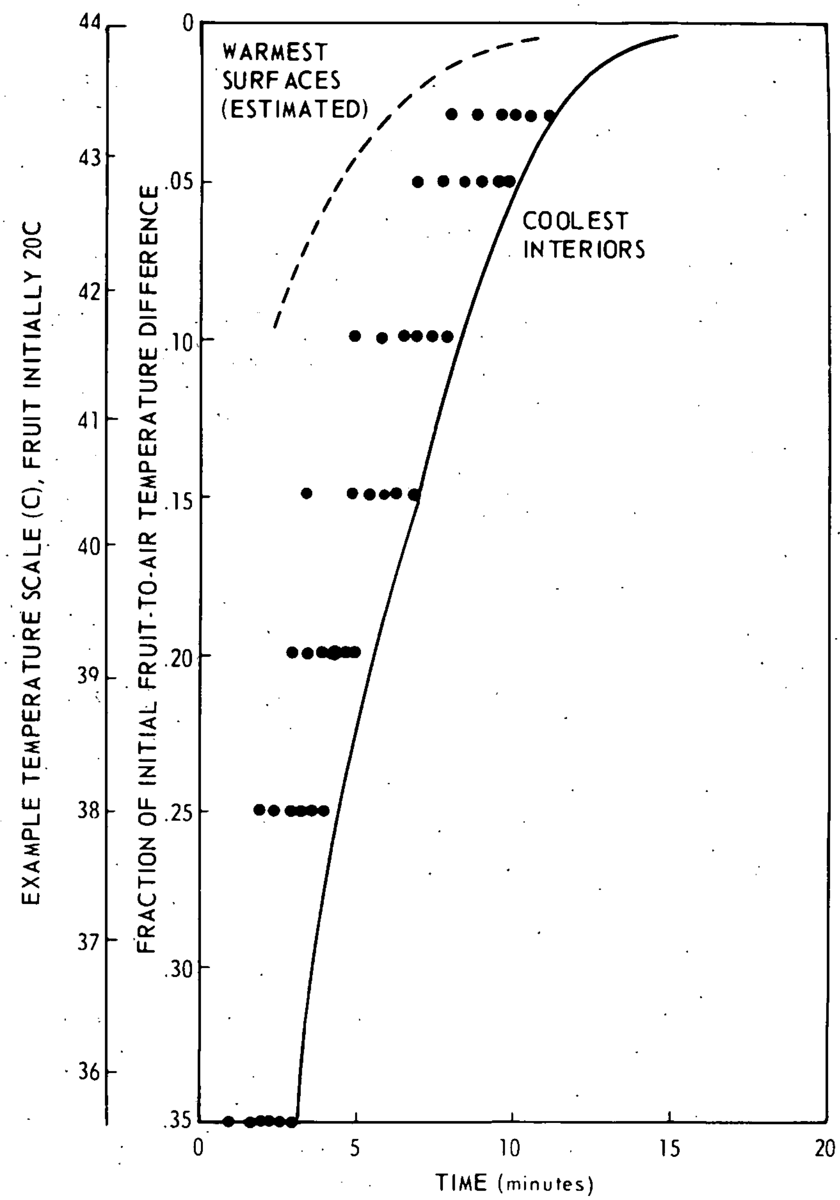


Heating strawberries with saturated air

Vented plastic baskets in corrugated paper trays.

Air velocity in gross section 350 ft/min.

Static head across 1 tray 0.3 to 0.5 inches water.

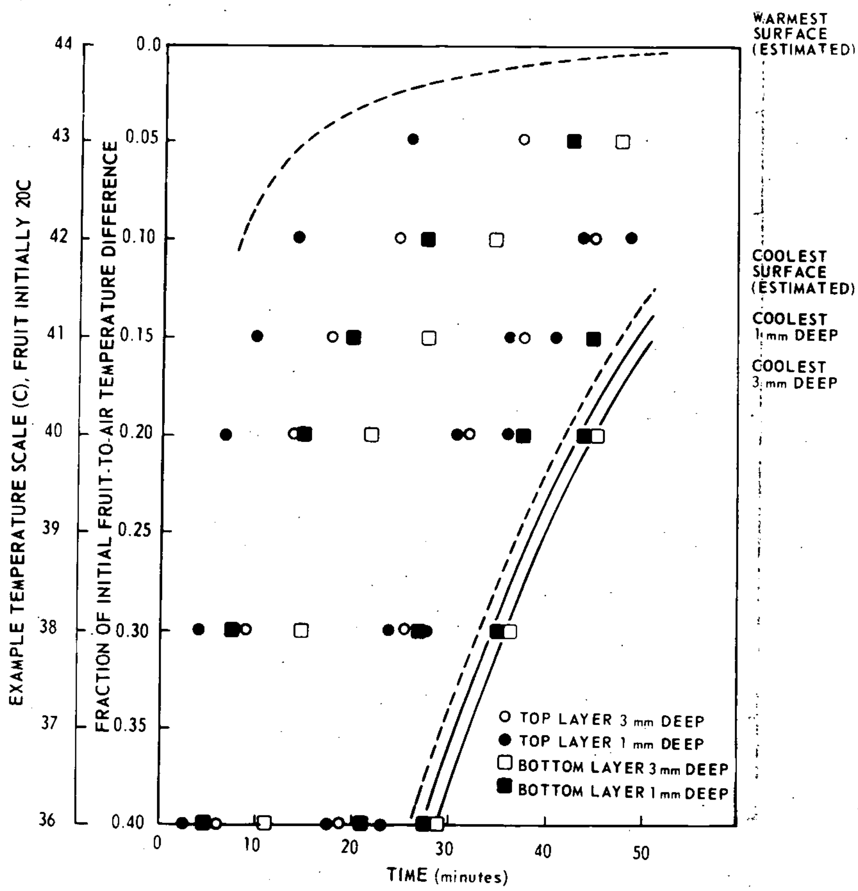


<u>Heating cherries with saturated air</u>

28 lb fruit in bulk in screen-sided box.

Air-flow 10.7 cfm/lb fruit = 490 ft/min in gross section.

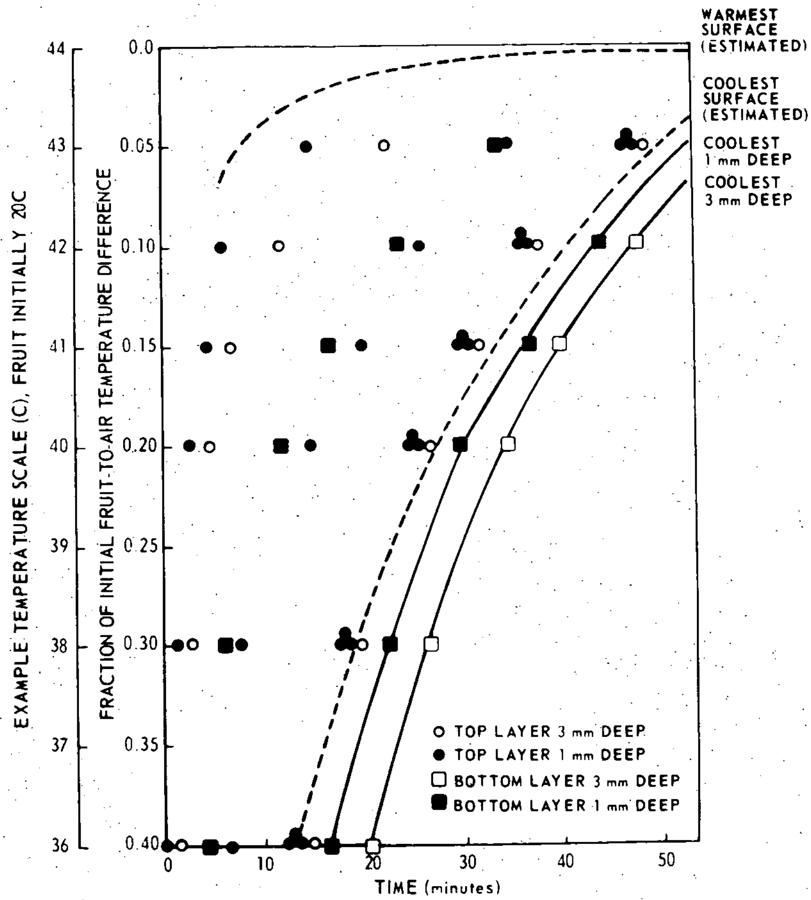
Static head across fruit 0.70 inches water.



<u>Heating nectarines in saturated air</u>, **plastic trays in wooden LA lug**

Air velocity in gross section 400 ft/min.

Static head across 1 box (13 1/2") 0.57" H_2O.



Heating nectarines in saturated air, plastic trays in screen-sided box

Air velocity in gross section 400 ft/min.

Static head across 1 box (13 1/2") 0.54" H_2O.

HEAT SENSITIZATION FOR CONTROL OF GREY MOLD OF STRAWBERRY FRUITS BY IRRADIATION*

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D. A. Coon, E. C. Maxie and F. G. Mitchell

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INTRODUCTION

Losses of harvested strawberries from grey mold (Botrytis cinerea Pers.) during transit and marketing in the United States have been estimated at 15% or more (7). Since the disease occurs during distribution and marketing, computation of actual losses must include, besides costs of production, the costs of packaging, handling, and transport. Such distribution costs may substantially exceed the costs of production and harvesting. In addition, orderly marketing is disrupted when impending losses result in distress sales or transfer of the loss to unwary customers. Marketing losses would probably be even greater if extreme spoilage hazards were not often anticipated and the fruit diverted to processing channels, which are usually less remunerative.

Infection by B. cinerea commonly occurs at blossoming. Senescing floral parts are colonized, followed by growth of the fungus into the base of the young berry. In the young berry, the growth rate of the fungus may be slow until the fruit matures and ripening starts (4). A satisfactory control in the field by conventional protective chemical fungicides would require effective coverage of the flowers.

* This research was supported in part by the U. S. Atomic Energy Commission, Contract AT(11-1)-34, Projects 73 and 80. Report No. UCD-34P73-22.

Since, however, blossoming is continuous from early spring through autumn in the principal growing areas of California, effective fungicidal coverage would require an unrealistic frequency of applications.

At harvest, disease lesions may be almost entirely or partially internal or hidden by the calyx, and many diseased berries are harvested. Once in the package, the fungus grows from diseased to adjacent berries by extension of fungus mycelium at points of fruit-to-fruit contact. The constantly enlarging "nests" ot diseased berries will eventually involve all fruits in the container. The fungus growth is only slowed by refrigeration, for the pathogen can still grow at temperatures far below the freezing point of the host (2). Growth may be further slowed by using atmospheres of elevated carbon dioxide in transit vehicles, but the fungus resumes normal growth when fruits are removed from the modified atmosphere.

A postharvest therapeutic treatment that would inactivate lesions or delay "nesting" should yield important benefits. The potential benefits of gamma irradiation from cobalt-60 have been demonstrated by Maxie _et al_. (3), but irradiation at doses the host can withstand, does not inactivate all lesions. Tests have shown that irradiation delays the progress of "nesting" in refrigerated transit (_ca_. 5°C) by 3 days or more, long enough to reduce losses materially. An alternative therapeutic treatment with hot, moist air was suggested by Smith (5) and Couey (1). The possibility of combining heat and radiation was suggested by the finding that some postharvest pathogens could be sensitized to irradiation by heat treatments that did not injure the host (6). The investigations reported here were made to evaluate the potential use of combined heat and radiation treatments for control of the grey mold disease of strawberry fruits.

MATERIALS AND METHODS

The isolate of B. cinerea used was selected for unusually abundant sporulation in culture though it appeared typical in other respects (pathogenicity, temperature relations, responses to heating and irradiation). Procedures used in culturing the fungus (harvesting, washing, and adjusting concentrations of spore suspension; in vitro heat and irradiation treatments; and plating methods) have been described in detail (Sommer et al. 1967).

Survival after tests was determined by plating spores on potato-dextrose agar in petri dishes and incubating at room temperature. A failure to develop a small colony within 48 hours of plating was considered presumptive evidence that the colony-forming potential of the conidium had been destroyed. After that period, only an occasional spore germinated and produced a colony.

Determining colony formation required special precautions because the rapid mycelial growth merged quickly, obscuring the outlines of individual colonies. Consequently, 10 X magnification was used to determine survivors while colonies were still small. It is true that some irradiated spores will germinate and grow for a short time even though they have lost their colony-forming potential. These germinants can usually be recognized, however, by their abnormal appearance. Slow germination, resulting in hyphae with swollen tips, sometimes accompanied by excessive branching, is invariably followed by a cessation of growth and failure to form a colony. Tests involving the removal and observation of single spores demonstrated that these spores of abnormal germination could be distinguished visually from normal initiating colonies with a high degree of reliability.

Since the disease spreads in harvested berries primarily by fungus growth from diseased to healthy berries, the primary goal of treatments is prevention of contact infection. Ideally, the prevention of contact infections and "nesting" would be accomplished by inactivating the fungus in lesions of diseased berries. Failing that objective, the secondary objective would be to delay contact infections and the onset of "nesting" until near the end of the market life of the strawberry. To measure the effectiveness of treatments in preventing or delaying contact infections, a paired-berry technique was used in a series of tests. Fifteen carefully selected healthy "receptor" berries were each placed against the lesion of diseased "donor" berries. Breaking contact between paired berries during treatment and handling was avoided by positioning the fruits carefully in troughs formed from hardware cloth. The treated berries were held at 5°C in a humid atmosphere within closed polethylene-coated corrugated paper cartons and examined every third day or oftener. Contact infection bound "donor" and "receptor" berries together by mycelium.

Uniform berries with lesions of near-equal size were obtained by the following procedure. Potato-dextrose agar, in large (26 x 26 x 2 cm) stainless-steel petri dishes, was inoculated by spreading ca. 10^7 conidia over the surface. After 8 hours at room temperature the medium was covered by young, fast growing mycelium. Berries were selected carefully for size and freedom from infection and placed on the mycelial mat. Lesions developed in 24 hours at room temperature, with mycelium occupying 1/4 to 1/3 of each fruit.

To test the effect of certain treatments under semicommercial conditions, recently harvested fruits were obtained in trays containing 12 one-pint baskets. All baskets were removed from trays and completely randomized. Eighteen baskets of fruits constituted each treatment. Data were recorded after a 7-day simulated transit period at 5°C.

Radiation at a dose rate of approximately 5 Krad/min was applied in a Cobalt-60 AEC Mark II food irradiator as previously described (Sommer et al. 1967). Fruits were heated in a specially fabricated chamber to the desired temperature by air, humidified by steam, forced around and among the berries at a pressure of 12 mm of water. Temperatures were monitored by thermocouples placed in the center of certain fruits. A constant temperature was maintained for 10 minutes after the fruits had reached the desired temperature. Generally, 20 to 25 minutes were required to warm the fruits to the test temperature.

RESULTS

Tests with nongerminating conidia have shown that *B. cinerea* responds to combinations of heat and radiation in a manner similar to most other postharvest pathogens tested. Thus, lethality is greater if heat treatments precede irradiation (6). After heat treatments (Fig. 1) of 0 to 30% lethality (i.e. 44°C/4 min), survivors were noticeably more sensitive to irradiation than their unheated counterparts. The synergistic interaction between irradiation and heating is noticeably less when irradiation precedes heat treatment. In repeated tests with a variety of temperature-time combinations, synergism was greater when heating was first. In either sequence, delays between heating and irradiation reduced the effectiveness of the combined treatments. This adverse effect of delays was demonstrated in tests with a heat treatment of 42°C for 20 minutes and a radiation dose of 90 Krad. During delays the spores were held in water at 0°C to prevent germination. When heating preceded irradiation by 6, 3, and 0.5 hours, survival was 3.8, 2.1, and 0.4%, respectively. When heating followed irradiation after delays of 3 and 6 hours, survival was 3 and 11%, respectively.

Tests with strawberry fruits used the paired-berry technique to determine the effects of treatments on contact infections and "nesting". Figure 2A, B, illustrates the effects of combining heat and irradiation and the advantages of applying heat before irradiation. In untreated fruits stored at 5°C, "nesting" was noticeable by the fourth day and proceeded rapidly thereafter.

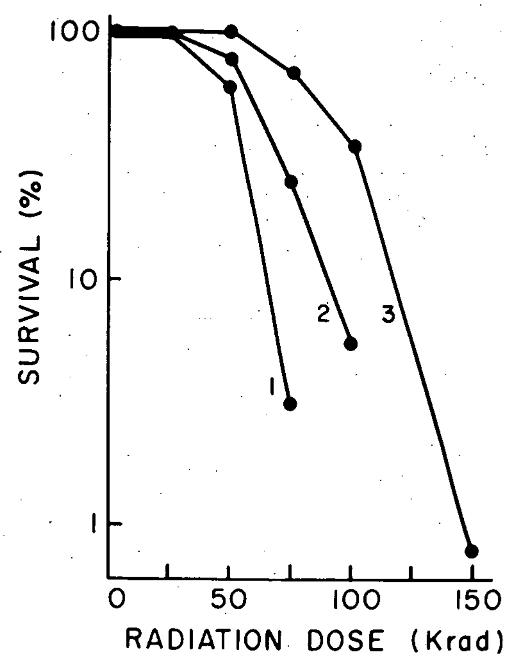

Fig. 1. Survival of nongerminating conidia of <u>Botrytis cinerea</u> after heating (44°C/4 min) and/or irradiation. 1) Heating followed by irradiation. 2) Irradiation followed by heating. 3) Irradiation only.

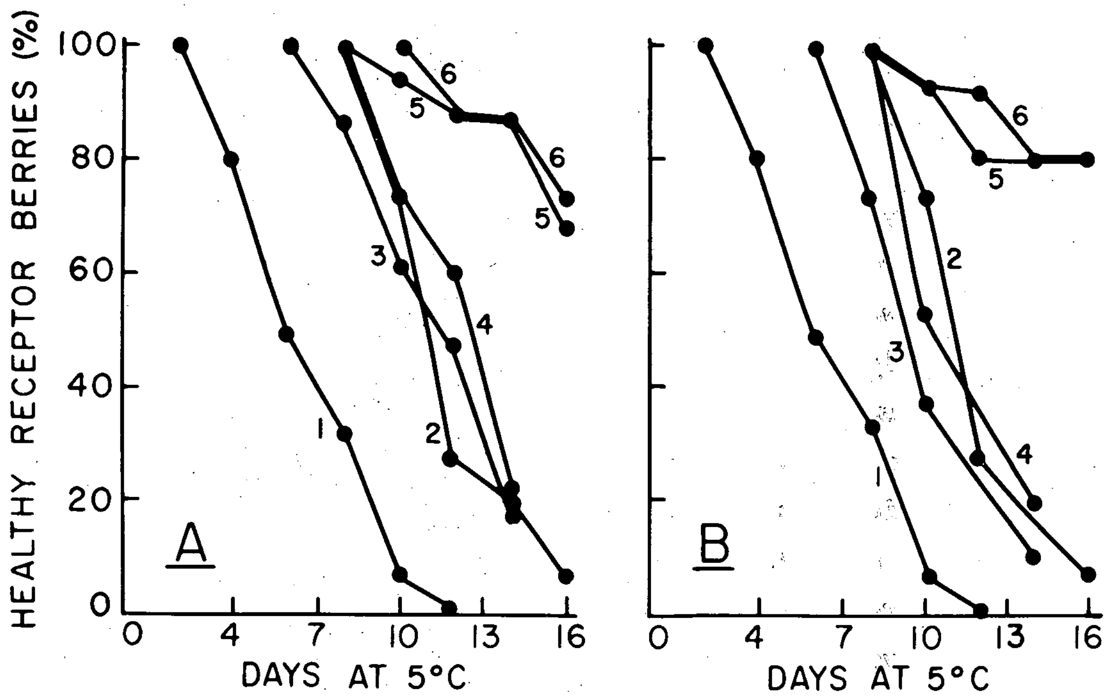

Fig. 2. Effect of sequence of treatments and delays between treatments on contact infections by <u>Botrytis cinerea</u> in diseased "donor" berries to healthy "receptor" berries (14 pairs). Heat treatments were at 39°C for 10 minutes. Irradiation was at 100 Krad.

A) 1. Control (no treatment).

2. Irradiation only.

3. Irradiation followed by a 24-hour delay at 5°C before heating.

4. Irradiation followed by a 4-hour delay at 5°C before heating.

5. Heating followed by a 24-hour delay at 5°C before irradiation.

6. Heat followed by a 4-hour delay at 5°C before irradiation.

B) Same as A except that delays between treatments were at 0°C.

If irradiation preceded heating with a delay of 4 or 24 hours (at 5°C) between treatments, disease control did not greatly exceed that expected from irradiation alone. The lesions were only delayed, not completely inactivated, since in most cases, given time, the fungus grew from diseased berries into the adjacent healthy fruit. When heating was first, however, the delays in onset of "nesting" were strikingly larger. In fact, in the majority of diseased berries the fungus had not yet caused contact infection after 16 days at 5°C, a time exceeding the usual market life of the fruit. Thus, for all practical purposes most lesions were effectively inactivated.

Although nonlethal heating sensitizes B. cinerea to radiation, the most rigorous treatment that did not cause fruit injury would presumably give a greater advantage. When paired berries were heated for 10 minutes at 39, 40, and 41°C, "nesting" was delayed about 5 days by 41°C, but delayed only slightly by 40°C (Fig. 3A). Accompanying tests to evaluate strawberry tolerance to heat indicated that about the maximum temperature that could be used in 10-minute treatments was 41°C. At 42, 43, and 44°C, the ripest fruits exhibited detectable injury: a softening of the entire fruit, sometimes accompanied by exterior bleaching. At the highest temperatures, ripe or overripe fruits sustained considerable injury, while adjacent firm ripe fruits exhibited no evidence of injury.

Figure 3B shows how different temperatures (for 10 min) combined with different irradiation doses affected contact infections present after 16 days post-treatment storage at 5°C. After that time, contact infections had occurred in all cases in which the berries had been heated but not irradiated. At all doses, the addition of irradiation dramatically decreased contact infections. Figures 3C and 3D illustrate the progress of contact infections during 16 days of storage at 5° following treatment. At 10 days, generally considered about the limit of the marketable life of strawberries held at 5°C, no contact infections had occurred in berries heated at 41°C and

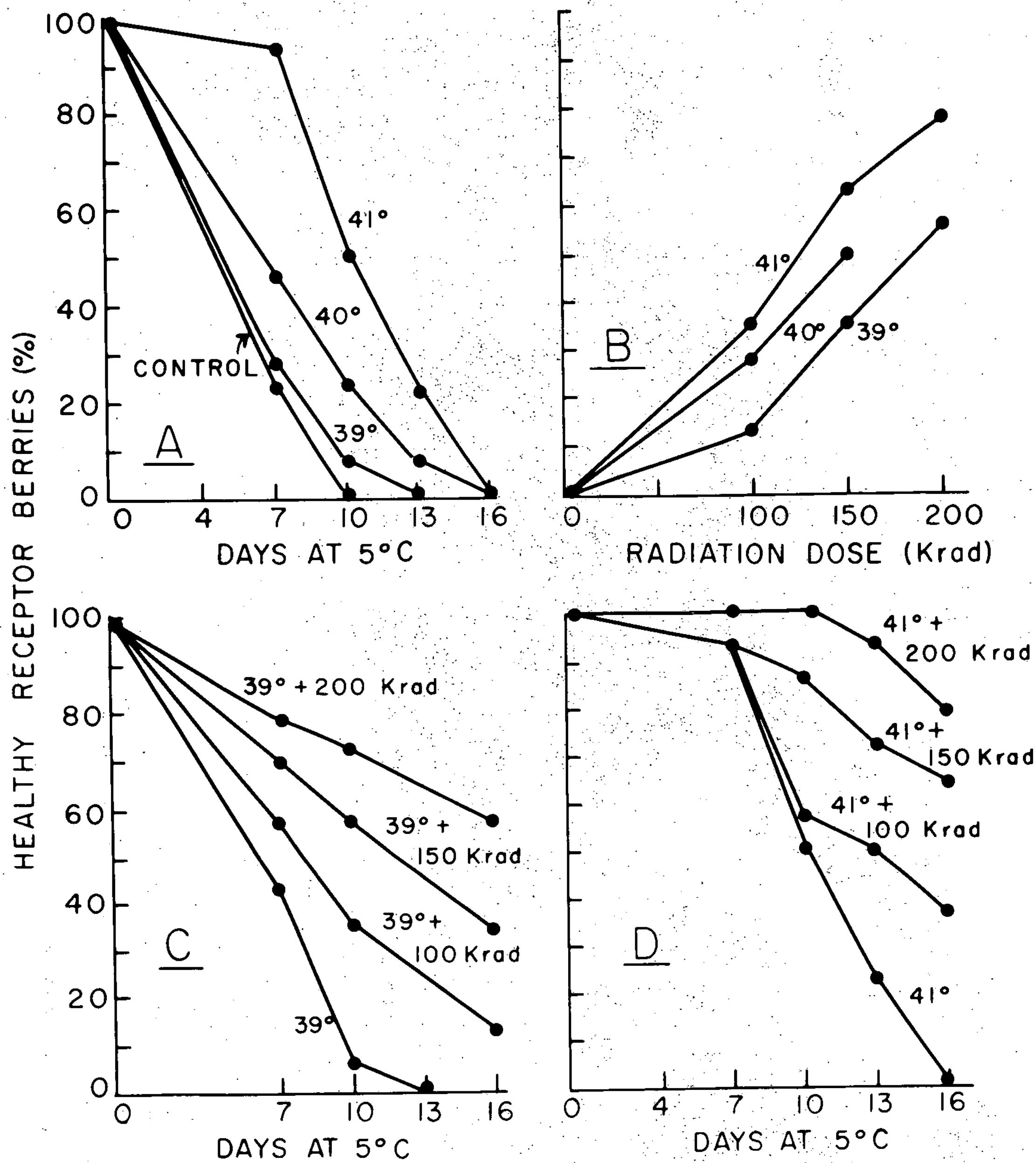

Fig. 3. Effects of heat and radiation on contact infection from Botrytis cinerea in infected "donor" berries to paired healthy "receptor" berries (14 pairs). In all heat treatments, berries were held for 10 minutes after reaching indicated temperatures. If irradiated, the irradiation followed heating within 2 hours.

irradiated with 200 Krad. With lower irradiation doses or lower temperatures, some contact infections had occurred by the tenth day. Often, however, these contact infections were so delayed that the consequences of their activity would likely be minor under commercial conditions. Without treatment, in contrast, contact infections had occurred in all cases by the end of the tenth day (Fig. 3A).

The advantage of preheating was confirmed in tests conducted on commercial berries harvested at a time when many fruits contained disease lesions (Table 1). With heating followed by irradiation, the incidence of rotted berries remained at a low level. Furthermore, a 100-Krad dose preceded by heating was more effective than a 200-Krad dose without prior heating.

DISCUSSION

Results from tests of commercially harvested berries are inherently variable because of differences in the number of diseased berries and sizes of lesions. Further, the fate of individual disease lesions can seldom be observed. As an alternative, individual berries with disease lesions can be treated and then observed for evidences of post-treatment lesion enlargement or the growth of aerial hyphae. Determining if or when lesions have become active is sometimes difficult, however. Some apparent post-treatment lesion enlargement evidently results from continued pectinase production after the fungus has lost its potential for indefinite growth. Further, inactivation by irradiation may be followed by a limited growth of aerial hyphae before fungus growth stops completely. The aerial hyphae may then be mistakenly interpreted as indicating that fungus activity has resumed although infection does not result. Much of the subjectivity of the tests was eliminated by using the

Table 1. Effect of radiation and heat-radiation treatments on grey mold rot of strawberry fruits. Data obtained after a simulated transit period of 7 days at 5°C following treatments. In combined treatments, heating preceded irradiation.

Treatment		Grey Mold Rot
Heat	Radiation (Krad)	$\bar{x}$(%)
0	0	44 ± 6
0	100	15 ± 6
0	200	8 ± 2
39°C/10 min	100	5 ± 1
40°C/10 min	100	2 ± 1
41°C/10 min	100	2 ± 2

paired-berry technique. Here, the sole measure of treatment effect was the ability of the treated fungus to infect a healthy berry in contact with the lesion.

The paired-berry technique provides an objective measure of the ability of *B. cinerea* to infect by mycelial contact, accurately determining in small-scale experiments the relative effectiveness of treatments on the fungus *in vivo*. Thus, the results of the effects of different treatment sequences or environmental conditions are highly reproducible by the paired-berry technique, in contrast to the high variability of results with commercial berries. The amount of rot developing in untreated commercial fruit depends upon such factors as the number of infected fruits initially present, the average size of the lesions, and the number of lesions that happen to be in contact with healthy fruits. Thus, the amount of rot that will develop in commercial fruits is not predicted precisely by paired-berry experiments. For example, if 30% of the "receptor" berries in a paired-berry experiment become infected, it might appear that the treatment was not very effective. However, at this rate, if 6% of the commercial berries contained lesions at the time of harvest, only 2% would remain infective after treatment. Since, however, each berry containing a lesion at harvest may eventually involve 10, 20, or more rotting fruits in a "nest," the treatment benefits may actually be great.

The effectiveness of gamma irradiation as a therapeutic fungicidal treatment for the control of grey mold of strawberry fruits is limited by the tolerance of the fruit. Above a dose of about 200 Krad, irradiation causes excessive fruit softening. An even higher dose would be desirable, however, from the standpoint of disease control. With heating to sensitize the pathogen, though, it appears that the radiation dose can be reduced to 150 or 100 Krad. Such a dose reduction should increase the capacity of irradiators while presumably reducing, somewhat, radiation-induced fruit softening.

Evidently, heating in advance should be far more effective than similar heating after irradiation. Simultaneous heating and irradiation is reported to be even more effective than sequential application. However, temperatures must be carefully controlled during heating, and the time that strawberry fruits can be exposed to elevated temperatures without adverse physiological effects is short. Unfortunately, with fresh fruits such as strawberries, problems of heat transfer exist. Rapid heat addition or removal could be accomplished if water were used as the heat-transfer medium, but wetting strawberry fruits destined for fresh consumption is undesirable. Microwave heating, in our tests, has lacked uniformity from fruit to fruit. Evidently, heating can be applied best by forcing hot, moist air through spaces around fruits in packages. Precise and rapid heating within irradiation chambers might require costly modification of irradiation equipment. By contrast, heating prior to irradiation and cooling afterward can be accomplished with relatively simple forced-air equipment.

The tolerance of strawberry fruits to heating has been observed to vary with fruit ripeness. In our experience, the ripest fruit have suffered damage with heat treatments that have not affected other berries. It is likely that tolerance to heat treatments may vary widely among different varieties of strawberries. Possibly growing conditions will similarly affect tolerance. The experiments here reported were conducted with strawberries of the Shasta variety grown in the Central Coastal District of California. Other varieties produced under different growing conditions might, therefore, respond differently to treatment. Furthermore, the extent of disease control achieved by heat and radiation treatments might differ in strawberries from other producing areas. California berries are usually promptly cooled and are refrigerated for several days during transport to market. Under refrigeration the "leak" disease [*Rhizopus stolonifer* (Ehrenb. ex Fr.) Lind.] usually does not develop. Without refrigeration, however, "leak" may be the most serious postharvest disease present. Since _R. stolonifer_ is more resistant than _B. cinerea_ to both heat and radiation, it might be expected that the treatments would not be highly effective in controlling "leak." Consequently, heat and radiation treatments should not be expected to overcome problems of inadequate refrigeration.

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