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Objective and Subjective Texture Evaluation of Irradiation Sterilized Meat Products

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ABSTRACT

Instrumental measures of textural properties and texture panel evaluations were obtained on several meat products irradiated using various dose-temperature conditions. Both the panel results and the instrumental data revealed several irradiation treatments that produced a tougher meat than the nonirradiated controls. Further studies indicated this toughening was due to a freezing-irradiation interaction.

INTRODUCTION

THE PRESERVATION of meat through irradiation sterilization has received considerable attention in recent years. Several reasons account for this, including savings in energy, potential benefit to developing countries as a means of long term storage without refrigeration, and now the fact that irradiation sterilization can protect against botulinum poisoning. Numerous studies have sought methods to improve the flavor and texture of irradiated meats and have provided evidence that freezing the meat prior to and during irradiation improves its flavor (Coleby et al., 1961; Harlan et al., 1967; Wadsworth and Shultz, 1966). The present study shows that freezing also improves the texture of irradiated meat.

Design of the experiment

The study was conducted in three phases:

Phase I: The first phase included measurements of color (both spectrophotometer reflectance measures at 525 nm and the percent oxymyoglobin (O_2Mb)), Kramer Shear measures, Instron Punch Shear measures and sensory panel evaluations of the acceptability of the texture and color of four meat products, all irradiation sterilized at three different dose levels and at three different temperatures. This initial phase of the study is described by Cohen et al. (1979) and only the Instron results are discussed here.

Phase II: This phase was undertaken to determine what specific sensory textural attributes are important to the description of irradiation sterilized meat and whether or not sensory panel judgments of these attributes vary with dose level or with temperature of irradiation of the products. In addition, linear correlations between the subjective and objective data were assessed.

Phase III: Based on the findings in Phase II, in which toughening in some of the frozen, irradiated products was observed, Phase III was initiated to test whether this toughening effect was directly attributable to the freezing process, or whether an irradiation-freezing interaction was responsible

EXPERIMENTAL PROCEDURE

Phase I

Sample preparation. Four meat rolls, one each of beef, pork, ham, and chicken, were prepared by the Radiation Laboratory at the U.S. Army Natick R&D Laboratories as described by Cohen et al. (1979). Briefly, uncooked muscles were trimmed of fat and gristle, mixed with 0.75% NaCl, 0.4% sodium tripolyphosphate (TPP), and 3.0% chopped ice, stuffed into cellulose casings and cooked. The cooked meat was then chilled, sliced to the desired thickness and sealed under vacuum in 404 x 309 cans. The cans were subsequently subjected to one of 10 treatments which consisted of a nonirradiated control plus all combinations of three levels of irradiation (20, 40, 60 kGy) and three temperatures of irradiation (10°, −30°, and −80°C). [The Gray (Gy) is equivalent to 1 joule of absorbed energy (from ionizing radiation) per kilogram of mass. 1 Gy = 10^2 rad.]

Instrumental measurements. An Instron Universal Test Instrument (Floor Model TT-DM) equipped with an in-house developed punch and die test cell (Segars et al. 1975) provided the objective data. This system subjected thin slices (nominally 0.6 cm thick) of the meat to punch-shear stresses by forcing a cylindrical flat-ended punch through the meat samples and into the die (hole in the plate supporting the sample) thereby cutting (shearing) a cylindrical disk from the meat slice. The force-deformation relationship required to cut out this disk was recorded. The maximum shear stress, γ_m, was calculated from the recorder trace using the equation:

$$\gamma_m = \frac{Fm}{\pi d T_o}$$

where Fm is the peak force (N) or the force at which failure occurs, d the punch diameter (cm) and T_o the sample thickness (cm).

Ten treatments each of beef, pork, ham and chicken, as described above, were evaluated using this system. Data for Phase I were obtained using a 1 cm diameter punch traveling at a speed of 5 cm/min. Twenty replicates were taken on each of the ten treatments.

In addition, color evaluations were made using Bausch and Lomb Reflectance Spectrophotometer values at 525 nm and the percent O_2Mb following the method of Kropf et al. (1974). These data are described by Cohen et al. (1979) and are not discussed here.

Sensory panel. A 12-member sensory panel evaluated the acceptability of texture using a 9-point category scale (1 = extremely poor; 9 = excellent). These data were reported by Cohen et al. (1979) and will not be repeated here.

Phase II

Sample preparation. Beef rolls prepared following the procedure outlined in Phase I and subjected to the same ten treatments provided the samples for Phase II.

Instrumental measurements. The Instron system described in Phase I was used in this second study with only minor modifications. A punch of smaller diameter, d = 0.5 cm, was used to permit the measurement of a greater number of replicates (50 replicates for Phase II). The punch speed was 5 cm/min as in Phase I.

Sensory panel. Samples of control beef were first submitted to a trained texture profile panel for preliminary evaluation. This panel was composed of six members who had been trained in the General Foods Texture Profiling Method and who had prior experience in the evaluation of meat texture. A texture profile was developed for these meat products and the panel then evaluated each of the profile attributes in order to select the most salient textural attributes for further study. The attributes selected were the *hardness, cohesiveness*, and *chewiness* of the meat.

The ten experimental beef samples were then evaluated by a larger sensory panel. This panel was composed of 12 members, all of whom had extensive experience in sensory evaluation of food, but who had varying experience in judging the specific textural attributes of concern. In order to mitigate these panelist differences, all panelists were provided with definitions of the three textural at-

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tributes to be judged, were provided a demonstration of the specific methods of making these evaluations by a profile panel leader, and were observed in preliminary trials to insure that judgements were made in accordance to the prescribed definitions. The definitions of the three attributes were as follows:

Hardness–The force required to bite through the sample.

Cohesiveness–The degree to which the sample holds together during biting.

Chewiness–The total effort required to chew the sample until it is ready to be swallowed.

Evaluations of hardness and cohesiveness were made using the incisor teeth and chewiness was evaluated using the molar teeth.

In addition to the above attribute training, all 12 panelists had prior experience in the use of the psychophysical method of magnitude estimation.

Testing was conducted in individual sensory testing booths. The ten samples were presented in random order to each panelist. Panelists evaluated the samples for the above three attributes as well as for overall acceptability of texture. The order of evaluation of the attributes was held constant for each subject with hardness evaluated first, followed by cohesivenses, chewiness, and overall acceptability, in that order. All evaluations were made using the method of modulus-free magnitude estimation. This scaling method requires that judgments of the intensity of sensory attributes be based on the ratios of intensity among stimuli. Thus, when the first sample was presented, the panelist assigned an arbitrary number to indicate the degree of hardness, cohesiveness, etc., of that sample. Subsequent samples were judged with reference to the first, so that if the second sample was twice as hard as the first, the panelist assigned a number to it that was twice as large as the number assigned to the first sample. If, on the other hand, the second sample was one-half as hard as the first then he/she assigned a number one-half as large as that assigned to the first, and so forth. This procedure continued until all samples were evaluated for all attributes.

During this experiment a 30-second interval was maintained between the last judgment of a sample and presentation of the next sample (interstimulus interval). In addition, panelists were instructed to rinse their mouth with tap water after each sample.

Phase III

Sample preparation. As mentioned previously, this phase of the study was designed to test whether or not the toughening observed in Phase II could be produced by freezing alone. Ham and beef rolls prepared as described in Phase I were exposed to the same temperature conditions as the irradiated samples of Phase I and II; however, none of the samples was irradiated. In addition, each of the three temperature lots (+10°, –30°, –80°C) was halved, and each half maintained at the test temperature for either 2 or 4 hr before being placed into 0°C storage.

Instrumental measurements. Instron test conditions were the same as for Phase I (1 cm diameter punch, punch speed of 5 cm/min). Thirty replicates were obtained on the beef samples and 16 replicates on the ham.

Sensory panel. Each of the six beef and ham samples were evaluated by sensory panels (n = 15 for beef; n = 14 for ham) that had identical training as the panel in Phase II.

The testing procedure for these tests was identical to that described in Phase II, with the exception that on any one trial, only one judgment was made. Thus, all six samples were presented in random order during one series, and only hardness was judged. During the next series of samples, only cohesiveness was judged, etc. Overall acceptability was not judged during this phase of testing. Magnitude estimation was used and no modulus assigned. A 30-second interstimulus interval was maintained and subjects rinsed between each sample.

RESULTS & DISCUSSION

Phase I

Instron data. Data obtained on slices of beef, pork, ham and chicken irradiated at various temperatures are shown in Table 1. The data for beef showed that, in general, increasing the dose level decreased the maximum shear stress which, according to all previous experience, indicates a tenderization of the meat. The student-t test was used to compare the mean for each treatment with the mean for the control. This test for significant differences showed that samples irradiated at +10°C with either 40 or 60 kGy and at –80°C with 60 kGy produced shear values that are significantly lower (indicating a softer meat) than the controls at the 99% confidence level. Shear values for samples irradiated at –30°C with 60 kGy were significantly lower than the controls at the 95% confidence level. The onset of tenderization occurred at lower dose levels with the unfrozen (+10°C) product; increasing the dose above 40 kGy had no significant effect on the unfrozen product, but produced additional softening in both frozen samples. The softening is not significant for the –30°C samples, but is significant at the 99% level for the samples irradiated at –80°C.

Decreasing the temperature at which the pork samples were irradiated increased the maximum shear stress, i.e. toughened the product; differences between the –30°C and the –80°C samples are significant at the 99% level. When irradiated at –80°C all dose levels investigated produced pork that was tougher than the unirradiated control. However, this toughening is significant (99% level) only for samples irradiated at –80°C with 40 kGy. An irradiation dose of 20 kGy produced tenderization (significant at the 99% level) in samples held at –30°C and greater tenderization in samples held at +10°C. Increasing the dose level above 20 kGy had very little effect on the texture of pork.

With ham there appears to be a significant dose-temperature interaction; the –30°C data is the extreme treatment (toughest product) at all irradiation levels. This toughening, when compared with either the +10°C or the –80°C samples, is significant at the 99% level in nearly all cases. Ham irradiated at –30°C with a dose of 20 kGy is tougher (significant at the 95% level) than the controls. Ham irra-

Table 1—Instron punch and die shear stress at failure (γ_m, N/cm^2) for th cooked meats tested in Phase I

Treatment	Beef	Pork	Ham	Chicken
	γ_m	γ_m	γ_m	γ_m
Control	14.8 ± 3.7	11.0 ± 1.8	11.3 ± 1.9	6.91 ± 1.70
20 kGy, + 10°C	14.6 ± 4.7	7.40 ± 2.38	9.68 ± 2.49	6.73 ± 1.17
20 kGy, –30°C	14.4 ± 1.8	9.10 ± 1.50	14.5 ± 5.0	7.60 ± 1.45
20 kGy, –80°C	15.6 ± 6.0	11.1 ± 2.2	11.5 ± 2.7	7.57 ± 1.89
40 kGy, +10°C	9.32 ± 1.78	8.66 ± 2.21	7.84 ± 3.36	6.47 ± 0.94
40 kGy, –30°C	13.5 ± 2.6	9.94 ± 2.81	11.7 ± 3.3	7.66 ± 1.12
40 kGy, –80°C	13.6 ± 2.6	14.1 ± 4.2	9.28 ± 2.34	7.97 ± 1.62
60 kGy, +10°C	9.40 ± 2.38	8.48 ± 2.78	8.10 ± 2.43	5.98 ± 1.51
60 kGy, –30°C	12.6 ± 3.0	8.85 ± 2.44	11.2 ± 3.3	7.72 ± 1.61
60 kGy, –80°C	9.76 ± 1.90	12.1 ± 2.8	9.31 ± 1.39	8.02 ± 1.11

diated at −30°C with either 40 kGy or 60 kGy or at −80°C with 20 kGy is similar to the control. Increasing the dose level above 40 kGy had no effect on the texture of ham.

All treatments of irradiated chicken were observed to be tougher based on Maximum Shear Stress values than the controls, except those irradiated at the highest temperature (+10°C). However, this toughening is significant (95% level) only for samples irradiated at −80°C with 60 kGy. When irradiated at −80°C, increasing the dose always increased the toughness; however, the change is not significant; at −30°C, toughening occurred at 20kGy (not significant), but further increases in dose had very little effect. At +10°C almost no effect was observed until the dose level reached 60 kGy where some tenderization (significant at the 90% level) occurred.

Other results. The color data, Kramer Shear measurements, and sensory data are described in detail by Cohen et al. (1979) and only the sensory panel results will be summarized here. In general, the nonirradiated controls received the highest ratings of acceptability. Increasing the dose level decreased the panel scores in all products except chicken, although the highest dose was often rated similar to, but higher, than the intermediate dose. Lowering the temperature at which irradiation occurs increased the ratings of the acceptability of texture slightly, except for chicken, where the intermediate temperature (−30°C) produced the lowest panel scores. For chicken, the extreme temperature samples and the control received similar ratings.

Phase II

Instron data. Experimental data (Table 2) exhibit trends similar to those of Phase I. As in Phase I, there is evidence that some irradiated beef products were tougher than the unirradiated controls; namely, the −30°C and the −80°C samples have maximum shear stress values that are equal to

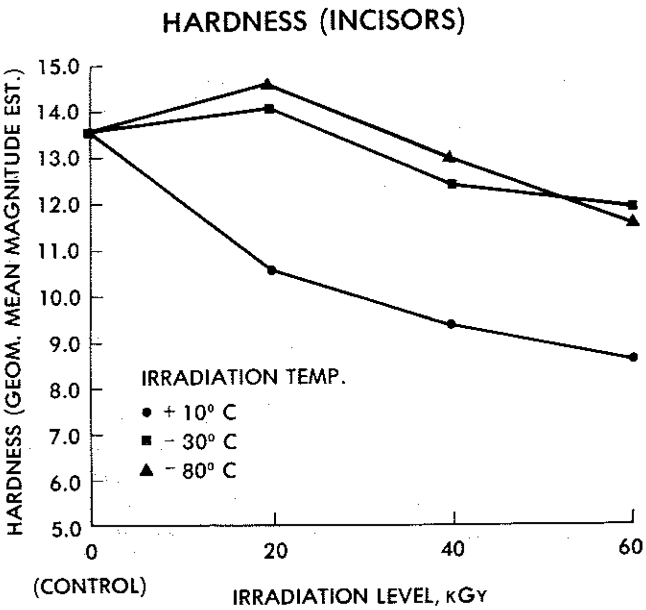

Fig. 1—Effect of irradiation temperature and dose level on the texture panel evaluation of hardness of beef rolls.

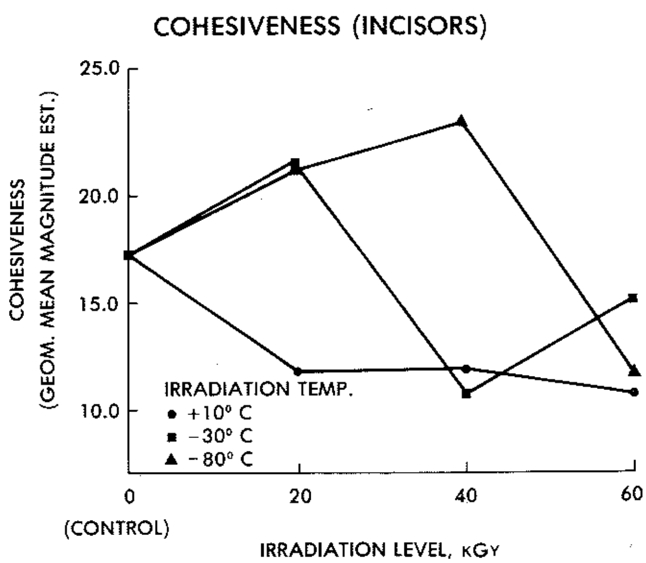

Fig. 2—Effect of irradiation temperature and dose level on the texture panel evaluation of cohesiveness of beef rolls.

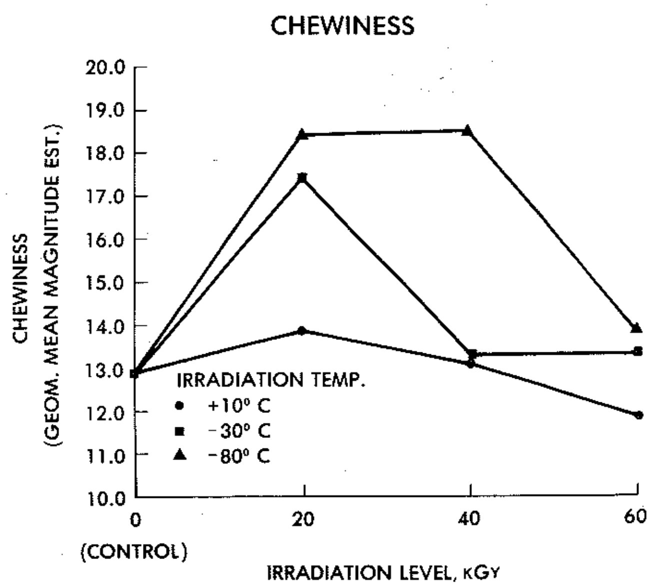

Fig. 3—Effect of irradiation temperature and dose level on the texture panel evaluation of chewiness of beef rolls.

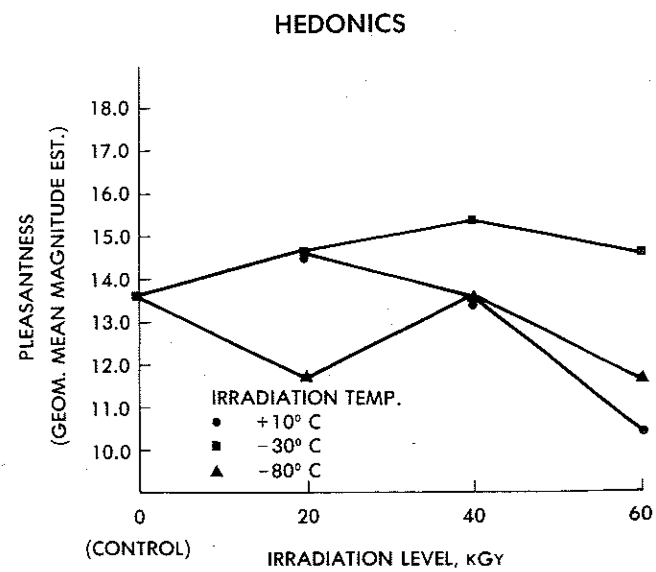

Fig. 4—Effect of irradiation temperature and dose level on the texture panel evaluation of overall acceptability (pleasantness) of the texture of beef rolls.

or greater than the controls at all dose levels, with the 40 kGy dose producing increases significant at the 95% level or higher. Some crossing of the constant temperature curves occurs, but in general, the -30°C data fall between the two extremes. The $+10^\circ$C data showed no significant tenderization at irradiation doses of 20 or 40 kGy while in Phase I tenderization was seen at 40 kGy, but not at 20 kGy.

To summarize, the Instron data show (1) that toughening occurs with irradiation of frozen samples and (2) the onset of tenderization occurs at slightly higher dose levels in Phase II than in Phase I.

Sensory data. Since the method of magnitude estimation does not restrain panelists in the number than they choose to assign to the first sample, the data were first analyzed by normalizing the magnitude estimates (Stevens, 1971) so as to bring each panelist's scale of intensity judgments to a common modulus. Then, since magnitude estimates are known to be log-normally distributed (Marks, 1974), the geometric mean of the magnitude estimates were calculated for each sample and each attribute. These means were plotted as a function of irradiation level and temperature of irradiation and can be seen in Figures 1–4.

Subjective evaluations of hardness (Fig. 1) reveal a decrease in hardness with increasing irradiation level at all irradiation temperatures. In addition, samples irradiated in the frozen state (-30°C and -80°C) were perceived to be harder than samples irradiated in the nonfrozen state ($+10^\circ$C). There appears to be no difference between the -30°C and -80°C samples. In addition, while most test samples were found to be less hard than the control sample, the two samples irradiated at 20 kGy/-30°C and 20kGy/-80°C were actually harder than the control.

Since the above data, as well as other data to be presented below, are suggestive of a possible main effect of freezing vs nonfreezing on the texture of these products, rather than a specific temperature effect, a three-way repeated measures ANOVA was used to analyze the data, with *frozen* vs *nonfrozen* being one factor and temperature within *frozen* as another factor. In this way it was possible to assess whether effects were due simply to freezing vs nonfreezing, or whether the specific temperature of freezing also had an effect. Results of this analysis demonstrated a significant main effect of frozen vs nonfrozen ($F = 5.71$; $df = 1,9$; $p < 0.05$), but no effect of temperature within frozen. Surprisingly, no main effect of irradiation level was found, in spite of the monotonicity of the hardness judgments as a function of irradiation level (Fig. 1).

The data for cohesiveness (Fig. 2) are more complicated. The samples irradiated at $+10^\circ$C were perceived to be less cohesive than the other samples, with the exception of the sample irradiated at 40 kGy and -30°C. The data for the latter sample appear to be anomalous. Samples irradiated at frozen temperatures (-30°C and -80°C) are more cohesive than the control at low irradiation levels, but less cohesive than the control at high irradiation levels. Analysis of variance for these data revealed a significant main effect of frozen vs nonfrozen ($F = 11.48$; $df = 1,9$; ($p < .01$), but no effect of temperature within frozen. A significant effect of irradiation was also found ($F = 8.30$; $df = 2,20$; $p < 0.005$), as was an interaction effect of irradiation by frozen vs. non-frozen ($F = 8.63$; $df = 2,18$; $p < 0.005$). Thus, there are significant main effects of freezing and irradiation on the cohesiveness of meat rolls, but the effects of each are dependent on the treatment level of the other.

The data for chewiness (Fig. 3) are similar to those for cohesiveness, although all of the frozen treatment samples are chewier than the control, as are the nonfrozen samples at low irradiation levels. Results of the ANOVA again showed a significant main effect for frozen vs nonfrozen, but no effect of temperature within frozen. Also, as with the data for hardness judgments, no significant effect of irradiation was observed.

The hedonic data are shown in Figure 4 with the only

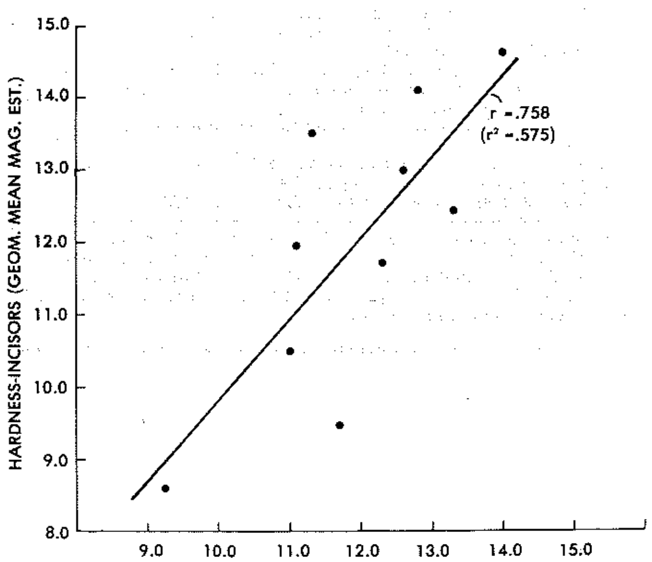

Fig. 5—Regression line of texture panel evaluation of hardness vs instrumental measurement of punch shear stress at yield.

Table 2—Instron punch and die shear stress at failure for cooked beef: Data from Phase II

Treatment	γ_m (N/cm^2)
Control	11.3 ± 2.5
20 kGy, +10°C	11.1 ± 4.4
20 kGy, –30°C	12.7 ± 2.9
20 kGy, –80°C	14.0 ± 3.7
40 kGy, +10°C	11.7 ± 2.8
40 kGy, –30°C	13.3 ± 3.0
40 kGy, –80°C	12.6 ± 3.4
60 kGy, +10°C	9.23 ± 2.23
60 kGy, –30°C	11.1 ± 2.6
60 kGy, –80°C	12.3 ± 3.5

Table 3—Pearson product-moment correlation coefficients for the relationship between yield shear stress (N/cm^2) and each of the sensory attributes tested

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Yield Shear Stress vs *Hardness*	0.758*
Yield Shear Stress vs *Chewiness*	0.693
Yield Shear Stress vs *Cohesiveness*	0.496

*Significant at 0.05 level

Table 4—Instron punch and die shear stress at failure for cooked ham and beef: Effect of sub-freezing temperatures

	γ_m (N/cm^2)	
Treatment	Beef	Ham
2 hr at +10°C	22.5 ± 6.7	11.2 ± 3.2
2 hr at –30°C	19.5 ± 7.9	10.1 ± 3.3
2 hr at –80°C	23.3 ± 8.0	11.6 ± 2.9
4 hr at +10°C	19.1 ± 3.3	10.4 ± 3.5
4 hr at –30°C	17.6 ± 3.7	11.9 ± 5.1
4 hr at –80°C	19.7 ± 4.9	10.5 ± 2.5

important aspect of these data being the fact that the −30°C samples were perceived as more acceptable than both the +10°C and −80°C samples at every irradiation level, although the effect is not statistically significant.

In addition to the above analyses, the subjective data were correlated with the objective yield shear stress data. Table 3 shows for each of the three sensory attributes, the Pearson product-moment correlation coefficients for the relationship between the objective and subjective measures. Only the correlation coefficient for the relationship between yield shear stress and perceived hardness is significant at the 0.05 level. The plot of hardness as a function of yield shear stress is shown in Figure 5.

The above data lead to a number of conclusions: (1) Freezing vs nonfreezing of the samples during irradiation has a significant effect on the hardness, cohesiveness, and chewiness of the meat. Frozen samples are harder, more cohesive, and chewier. (2) The temperature of freezing has no effect on any of the above sensory attributes. The effect is one of freezing vs nonfreezing, not one of temperature. (3) The effect of irradiation is only significant for the attribute of cohesiveness, although there is an interaction of irradiation level with freezing vs nonfreezing for this attribute. In the cases of hardness and chewiness, both seem to decrease with increasing irradiation level, but the effects are not statistically significant. (4) Frozen samples irradiated at low levels are often harder, more cohesive, and chewier than control samples. (5) Objective measures of the texture of meat rolls using a punch and die test are significantly correlated with magnitude estimates of perceived hardness.

It may be concluded from the above that freezing of meat rolls during time of irradiation has a "toughening" effect (increases hardness, cohesiveness, and chewiness) on this product. Furthermore, this toughening effect can counteract the softening of irradiation at low levels so that a sample irradiated at low dosage can still be "tougher" than a control, if it is irradiated while in the frozen state. However, it is not evident from these data whether the effect of freezing occurs independently of irradiation sterilization, or whether the "toughening" occurs through a process of physical interaction of freezing and irradiation.

Phase III

Instron data. This third experiment was designed to test whether or not the toughening of the frozen samples could be explained by the effect of freezing alone. Results for beef and ham (Table 4) exhibited no distinct trends when freezer temperature was the independent variable. Beef samples held at a given temperature for 4 hr were always more tender than those held for only 2 hr, but the observed difference was small. This trend was not always true for ham. The instrumental data show that freezing by itself has very little effect on the texture of beef or ham and thus the textural changes observed in Phase I and II must occur from temperature-irradiation interactions.

Sensory data. No main or interaction effects were found for freezing vs nonfreezing, temperature within freezing, or length of time of exposure, for either beef or ham. Plots of geometric mean magnitude estimates of hardness, cohesiveness, and chewiness showed no systematic variation as a function of temperature or time of exposure.

It is clear from the above data that the effects of freezing vs nonfreezing found in Phase II may only be explained if there is a physical process of interaction between freezing and irradiation. When meat rolls are exposed to subfreezing temperatures without simultaneous irradiation, no sensory or objective toughening of the meat results. However, when meat rolls are exposed to these temperatures during low-level irradiation, such toughening does occur. At higher irradiation levels, the tenderizing effect of irradiation offsets this factor.

CONCLUSIONS

IRRADIATION STERILIZATION has a tenderizing effect when applied to unfrozen meats (+10°F). This is shown both by lowered ratings of sensory hardness and cohesiveness for beef and by lowered Instron shear values for beef and other meat products.

Exposing meats to sub-freezing temperatures before and during the irradiation treatment counteracts the tenderizing effect of irradiation, and at lower dose levels results in meat that has a firmer texture than the nonirradiated control.

The retention of textural quality produced by irradiation at subfreezing temperatures appears to be a freezing vs nonfreezing phenomenon rather than an effect of temperature. Varying the temperature within the sub-freezing range had little effect on texture except for pork where the lowest temperature produced the firmest product.

The effect of freezing vs nonfreezing appears to be due to an interactive effect of freezing and irradiation.

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