IRRADIATION AND PROCESSING OF NAVY BEANS
(*Phaseolus vulgaris*)

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

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1969

ABSTRACT

IRRADIATION AND PROCESSING OF NAVY BEANS (Phaseolus vulgaris)

By

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Navy beans may require a 10 to 30 percent increase in process time, over that required for sterilization, to tenderize adequately the canned product. Beans, irradiated at 170 Krad with gamma radiation, soaked for 16 hours in cold water, and processed were more tender, as measured with an Instron Universal Testing Instrument, than were unirradiated beans. A sensory panel found a flavor difference between beans irradiated at 0 and 340 Krad, but could not distinguish any tenderness difference among bean samples treated at 0, 42, and 170 Krad.

Chemical analyses showed no losses of protein or starch from cold-water soaking. The drained weights of the canned beans decreased as irradiation dose increased. Fill volume, moisture content, and appearance showed little change. Radiation doses less than and greater than 170 Krad resulted in lesser tenderization. Above 340 Krad, the beans became tougher than the unirradiated samples.

Hot-water soaking for one hour, followed by processing resulted in an increased toughening as the irradiation dose increased. However, the hot-water soaked beans were more tender than those given the cold-water soak, even at 170 Krad.

IRRADIATION AND PROCESSING OF NAVY BEANS (*Phaseolus vulgaris*)

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Food Science

1969

ACKNOWLEDGEMENTS

The author is sincerely appreciative of the helpful guidance and assistance given by Dr. R. C. Nicholas, as advisor, in preparation of this study.

Other members of the Food Science Department helped make this research possible through their interest and support. Dr. C. L. Bedford and Dr. P. Markakis were very helpful in offering advise and information concerning the processing and irradiation of navy beans. Dr. E. J. Benne, Department of Biochemistry, gave valuable assistance in the protein determinations made in this study.

The author is also grateful to the above for their contribution in serving as members of the Examining Committee.

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INTRODUCTION

In the United States, beans have been and remain a popular food item. About 7-1/2 pounds of beans are consumed per person yearly (Doughty, undated). However, the form in which these beans are sold to the consumer has changed somewhat during the last 50 years. Today, the 100-lb sacks of dry beans are no longer popular, and even 1-lb sacks are less popular than the canned beans, especially for summertime eating. According to the Cooperative Extension Service (1968), "eighty-five to ninety per cent of the beans for domestic consumption are canned--the remainder are packaged and sold as dry beans."

The dry bean family consists of over 180 varieties. Michigan produces several of these including navy, light and dark red kidney, cranberry, yelloweye, pinto, red, and many minor varieties. Beans rate as Michigan's second largest cash crop with a value of about $50 million (Cooperative Extension Service, 1968). "Navy pea beans are preferred by processors; they are uniform, flavorful and hold their shape in the can" (Doughty, undated). Of all the navy beans produced in the United States, Michigan grows more than 98% of them; and three-fourths of these come from Michigan's Thumb and Saginaw Valley areas. There are several uses for these navy beans, but the most important product is canned pork and beans (Cooperative Extension Service, 1968).

"Canned pork and beans or beans with pork is a non-seasonal specialty item prepared from one of several varieties of beans, with the addition of a formulated tomato sauce or sweetened sauce and pieces of pork" (Continental Can Company, undated a). As background information concerning the canning of pork and beans, the overall operation is discussed in brief detail as given by the Canning Memorandum "The Canning of Pork and Beans" (Continental Can Company, undated a). The flow diagram of this process is given in Appendix A.

The raw materials used in canning pork and beans include dried beans of any one of the three varieties generally used. Although the Michigan pea bean or navy bean is preferred, California pea beans or Great Northern beans can be used. The pork to be added should be small pieces of well-cured sweet salt jowl, or fat side. The tomato sauce or plain sauce varies with each pork and bean processor, but the formulas in Appendix B are typical.

As part of the preparation of the beans for canning, they are first inspected, and moldy, off colored, or otherwise defective beans are removed. Soaking, either by a long cold-water soak or a short hot-water soak, is the next preparation step.

In the canning operation, the cans are first spray-washed with 180°F water. At the time of filling, the pieces of pork are put into the cans first, then the soaked beans, and, finally, the sauce is added at a temperature near the boiling point. The proper fill-in weight of beans depends strongly on the quantity of water absorbed prior to filling, because additional water is taken up during and after processing. The cans are closed at atmospheric pressure, and washed in a warm water spray.

The closed cans are sent without delay to the heat processing operation to sterilize the product. The sterilization process depends primarily on the tomato pulp and starch content of the sauce (Continental Can Company, undated a). The National Canners Association (undated) recommends the heat processes listed in Appendix C for sterilizing beans in sauce. However, it is noted by Continental Can Company (undated a) that a much longer heat process is often required to tenderize adequately Michigan and California pea beans. In addition, Continental Can Company (undated a) mentioned that a 10 to 30% increase in the process time, over that required for sterilization, has been required depending on various conditions, principally water hardness. As soon as possible after completion of the heating process, the cans are cooled by water until the contents reach 100°F.

Although the present process yields an acceptable product, prolonging the cook just to tenderize the beans is a disadvantage. Testing the possibility of using gamma radiation to tenderize the beans was the basis purpose of this study. In addition, the effects on pack characteristics, water absorption, possible loss of proteins and starch, and flavor changes of the beans were examined.

REVIEW OF THE LITERATURE

Initially, it was thought that gamma ray irradiation of dry navy beans (Phaseolus vulgaris) would be of great value in decreasing the heat processing time required for their tenderization. Schroeder (1962) was granted a patent for a process which tenderized and shortens the cooking time of dehydrated vegetables by exposure to ionizing radiation such as gamma rays or electron beams. Afterwards, they could be rehydrated to an edible and desirable texture in a much shorter time than was previously required without irradiation, for instance 3 minutes instead of 10 or more. The radiation dose required to effect a given decrease in rehydration and cooking time varied with different vegetables. However, it was found that, in general, the greater the radiation dose the greater the reduction in rehydration and cooking time. The range of irradiation dosage found to be satisfactory was about 1 to 11 million rep.[1]

Schroeder (1962) also found that irradiation of dehydrated vegetables reduced or eliminated undesirable

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[1]Evans (1947) defines rep (roentgen equivalent, physical) as the energy lost by ionizations, produced by a primary source other than photons, in tissue, equal to the same energy loss for one roentgen in air.

side effects, such as poor flavor and/or texture loss, that occur when irradiating vegetables in the fresh state. Dennison (1967) mentioned that dehydrated vegetables will rehydrate more quickly if irradiated than they will if not irradiated. He claimed that vegetables irradiated in the dehydrated state may have great promise for manufactured food products like dried soup.

Irradiation studies made on beans by Bakker-Arkema, Bedford, Hedrick, and Hall (1966) showed no consistent results in their flavor evaluations of bean powders made from irradiated beans (1 Mev electrons). The beans had been subjected to doses from 0 to 1600 Krad.[1] Beans given more than 200 Krad did, however, show some indication of flavor detriment. Bakker-Arkema *et al.* (1966) claimed that the rate of rehydration of beans soaking for 40 minutes in 210°F water showed little or no change due to radiation of the beans. Both the irradiated and the non-irradiated bean samples had weight increases between 56 and 60% after soaking. Cooking for 90 minutes at 250°F produced no further increase in weight.

Markakis, Nicholas, and Schweigert (1965) found that dry navy beans exposed to gamma radiation showed a steady decrease in firmness as the irradiation dose increased up to 1600 Krad (Figure 1). These beans were

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[1]Rad = 100 erg/g, energy absorbed/unit mass of material (energy imparted by ionizing radiation, either direct or indirect). U. S. Department of Commerce (1962).

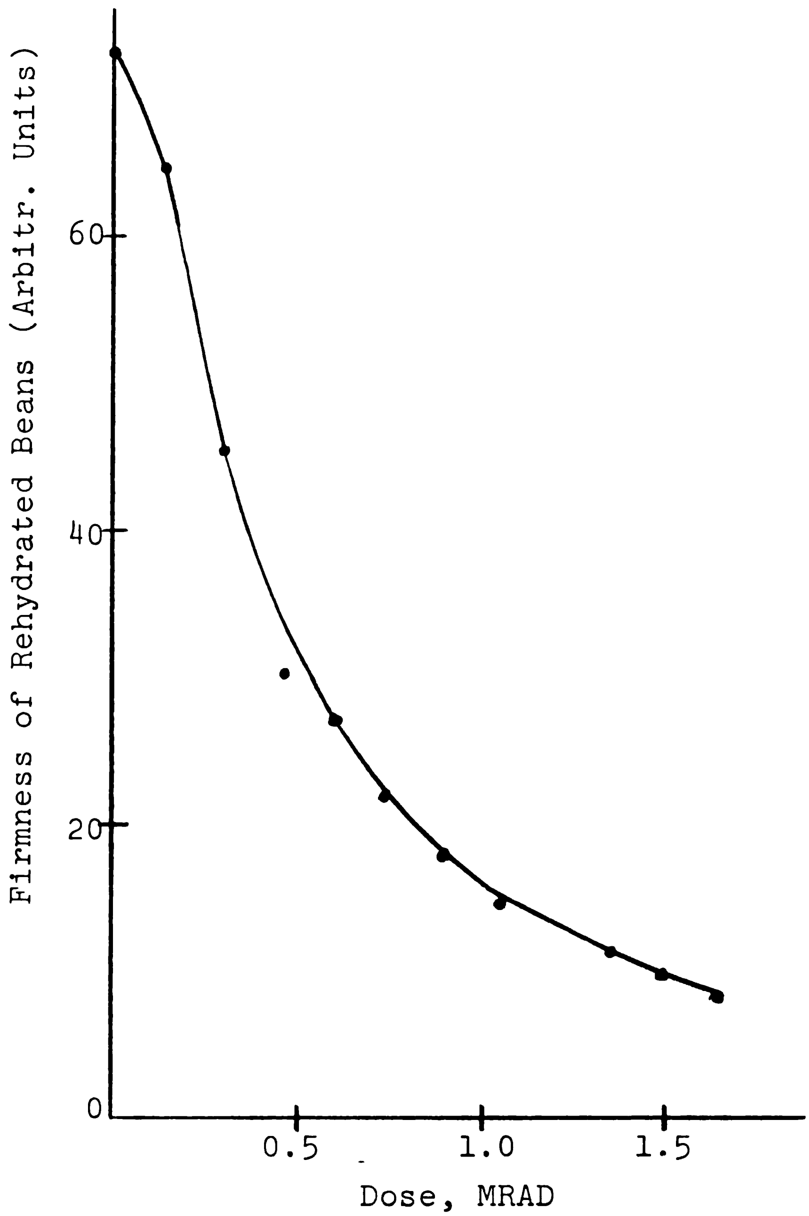

Figure 1. Effect of gamma irradiation on the texture of navy beans (Markakis _et al_. 1965).

not cooked, however, only rehydrated in four times their weight of distilled water for 24 hours. In addition to this decrease in bean firmness, the soak water showed an increase in soluble solids from 1.5% for the unirradiated bean samples to 7.0% for the bean samples given a 1.6 Krad dose (Figure 2). The weight gain of the beans after rehydration was 90% for the unirradiated samples and 101% for the samples exposed to 450 Krad. The moisture content for the above two samples was 54% and 56% respectively.

The percent weight increase of irradiated and unirradiated navy beans soaked for 16 hours in distilled water, and samples that were soaked and then cooked at atmospheric pressure was studied by Markakis et al. (1965). Dry bean samples had been irradiated at the following doses: 0, 10, 400, 600, 800, and 1,000 Krad of gamma radiation. The cooking times used were 0, 0.5, 1.0, and 2.0 hours at atmospheric pressure. The results, as shown in Table 1, show that the samples exposed to 400 Krad generally had the highest percent weight increase.

Markakis et al. (1965) also attempted to reduce the processing time, on the basis of tenderness, by use of gamma radiation. Dry Great Northern beans were irradiated at 0, 300, and 600 Krad, soaked 16 hours, steam-blanched 3 minutes, and retorted at 240°F for various lengths of time from 15 to 75 minutes. After 2 days storage, the canned bean samples were examined and it was reported

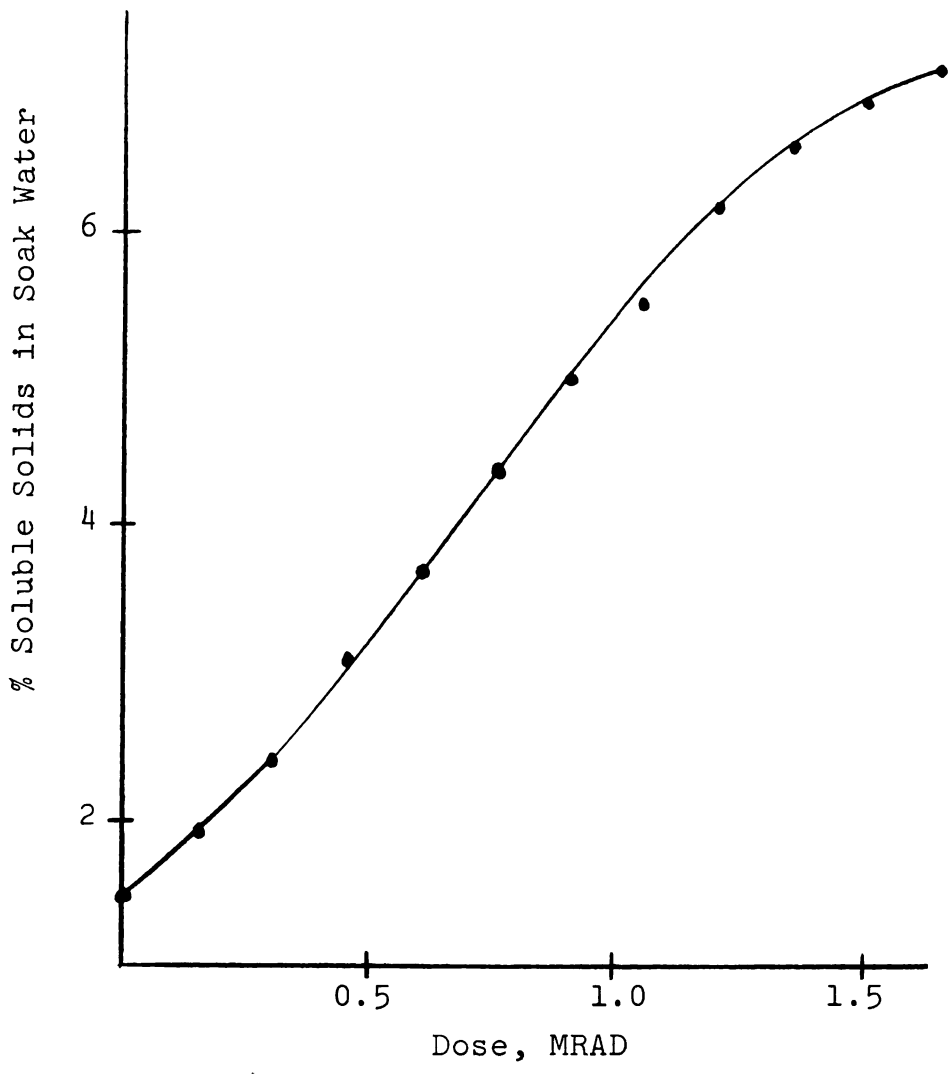

Figure 2. Effect of gamma irradiation on soluble solids of navy beans (Markakis _et al_. 1965).

TABLE 1. Effect of gamma irradiation on the water uptakes of dry beans after soaking (16 hrs) and cooking. Figures indicate % of weight increase.[1]

Dose (Krad)	0	200	400	600	800	1,000
Soaking only	92.0	96.0	100.0	102.1	84.4	104.1
Soaking + 1/2 hr cooking	97.3	124.0	125.1	118.8	116.7	114.5
Soaking + 1 hr cooking	127.1	139.6	140.7	134.4	125.1	126.1
Soaking + 2 hr cooking	144.8	144.6	164.5	141.7	135.5	133.3

[1]Markakis *et al*. (1965), p. 49.

that "the irradiated samples were the softest when short periods of retorting were used, but this tendency reversed as retort time increased."

Markakis _et al_. (1966) irradiated dry navy beans at 400 and 800 Krad, and tested them for hardness after being cooked at various times without prior soaking. The beans were cooked in demineralized water at atmospheric pressure, and at 0.5, 1.0, 2.0, and 3.0 hour intervals during the cooking, samples were removed for hardness measurement in a shear press. Again, the irradiated samples initially were softer than the unirradiated beans, but after 2 hours of cooking, the hardness measurements were about the same for all samples. The beans had to be cooked for 3 hours in order to be considered properly soft. In addition, no difference in taste was noticed between the irradiated and unirradiated bean samples.

Other methods besides radiation have been used to aid in tenderizing and shortening the heat process time for navy beans. The practice of soaking beans is the best known, and there are many variations of this widely used method. According to Bedford (1968) the amount of time required for soaking depends on the water temperature, water hardness, and the bean quality. The Continental Can Company (undated a) also agreed that the tenderness of canned beans is greatly influenced by the hardness of the soak water and the water used in preparing the sauce.

Water having 4 to 9 grains of hardness is considered the most desirable for canning beans. Soft water has disadvantages because it may cause the beans to split excessively, to become too soft, and to mat together in the can. However, too much hardness causes the canned beans to toughen which then requires a longer cook time for the desired tenderness (Continental Can Company, undated a).

Bigelow and Fitzgerald (1918) mentioned several factors concerning the soaking of beans. The length of time required for soaking varies according to the moisture content. For instance, beans containing 15 to 18% water require about 8 to 10 hours soaking, whereas drier beans may require 12 to 15 hours because they rehydrate less uniformly. It has been observed that no difference occurs whether the beans are soaked in shallow layers or in deep tanks. Some beans tend to rehydrate with more difficulty than others, possibly due to the outer bean coating being impervious in nature. A preliminary blanching may be used prior to the soaking procedure, but this isn't always advantageous. During the soaking and blanching procedures, the water extracts 2 to 4% of the solids from navy beans, depending on the temperature and length of time in the soak water.

According to Bedford (1968), the soak time varies among bean processors. Some use 16 to 20 hours at room temperature, or 7 to 8 hours at 90°F, or 20 to 60 minutes at 180-210°F. However, the high temperature--short time soaking method is the most popular because it lessens the potential for bacteriological problems and requires less equipment and floor space, among other advantages. In addition, the beans need not be blanched with the hot-water soak. In fact, the blanching operation is probably not needed even when using the cold-water soak. During the soaking operation, the beans should have absorbed enough water to approximately double their weight; their moisture content should then be between 53 and 57%. At this moisture level, the beans are usually considered ready for further processing.

The mechanisms that control the rehydration rate in beans and also affect the tenderness of canned beans are not clearly understood. Bedford (1968) states:

> "There is no doubt that moisture content, age, storage conditions, composition and factors related to production conditions influence water uptake. Various theories concerning the toughness or hardness factor in beans have implicated divalent metal ions, pectins, free fatty acids and changes in the proteins."

Gloyer (1928) used the term "hardshell" to describe beans that had a seed-coat that showed impermeability to water. He also inferred that hardshell was the same thing as toughness of the seed-coat. In 350 varieties of beans, the percentage of hardshell varied from 0 to about 80%. Hardshell in beans is rather difficult to detect by a visual examination alone. Gloyer (1928), in his investigation of beans, found no correlation between bean color and hardshell. The difficulty with hardshell seems to be influenced by the soaking temperature. For instance, it took 24 hours at 130°F, and 17 days at 100°F to swell all hard beans during soaking experiments. Beans can develop the condition of hardshell quickly if stored at a temperature of 72°F or above, and if the relative humidity is less than 65%. If the canner finds that his beans have 10 to 30% hardshell, he will need to steam them 5 to 10 seconds before soaking. Also, soaking the beans at 180°F for 10 minutes prior to the regular soaking procedure will overcome the hardshell condition (Gloyer, 1928).

Dawson, Lamb, Toepfer and Warren (1952) reported a satisfactory short soaking method. The beans were placed in boiling water for 2 minutes, then the heat was removed and the beans allowed to soak for 1 hour in the hot water. When the beans were later cooked in this soak water they were equal in palatability to beans soaked overnight. However, when the soak water was discarded after hot-water soaking, the cooked beans were less palatable and contained less thiamine and ash than when the soak water was retained.[1] Dawson _et al_. (1952) reported that the addition of sodium bicarbonate allowed as much

[1]In commercial practice, soak water is discarded.

as a 42% reduction in cooking time for beans without a loss of thiamine or ash, although the palatability scores were lower than for beans without sodium bicarbonate.

In comparing the cook times for beans at 250°F with that of cooking in boiling water, great reductions were noticed (Dawson <u>et al</u>., 1952). Beans stored at 40°F were fully cooked in 5 minutes instead of 90, and beans stored at 75°F cooked in 10 minutes compared to 120. The cook times listed above for 250°F were exclusive of the 25 minutes required to bring the temperature up to 250°F and to lower it again to 212°F.

Hoff and Nelson (1965) found that the rate of water absorption in dry pea beans was increased by steam pressure, vacuum, and sonic energy. This result occurred because the absorbed or trapped gases were released from the bean surfaces. The fastest rate of water absorption occurred in layers measuring less than three bean diameters thick. By restricting the bean layers to this thickness, the beans could be ready for cooking after only 20 minutes soaking at 176°F. According to Hoff and Nelson (1965), the rate of water absorption by beans could be increased by the addition of polyphosphates to the soak water. Certain combinations of both polyphosphates and sodium chloride increased the rate of water absorption even more, giving higher yields and beans that were more tender than those conventionally processed. On the other hand, sodium chloride by itself in the soak water had very little effect.

Snyder (1936) found that the cooking time of beans could be reduced 40% by scarification prior to soaking; however, it produced beans of poor appearance. Other methods reported by Snyder (1936) to soften the bean seed coats include the use of sodium bicarbonate, which he proposed was due to solvent action with the pectic acid. The bean seed coats can also be softened by the action of ammonium salts of oxalic, citric, and tartaric acids, but oxalic acid was claimed to be the most efficient.

In processing pork and beans, Bigelow and Fitzgerald (1918) reported that 240°F was the optimum temperature. They did not favor using a lower temperature than this, and also cautioned that a temperature materially higher than 240°F yields an undesirable brown color. Rockland (1965) reported that beans generally require a 12-hour or longer rehydration time prior to cooking. The hot-water methods of accelerating dry bean rehydration produce unfavorable texture and flavor changes when boiling water is used. Rockland (1965) experimented with other methods to increase the rehydration rate and soften the beans. These included vacuum hydration with salt solutions prepared by using the alkali metal salts of tripolyphosphate, pyrophosphate, and ethylenediamine-tetra-acetate.

The cookability of dry beans could also be improved by the proper storage of dry beans after harvest. Burr, Kon, and Morris (1968) reported that beans stored at high temperature and high moisture content had to be cooked longer. They indicated an optimum moisture content of 10% for maintaining quality of dry beans during storage. At this moisture content, the quality is maintained for several years regardless of storage temperature. Muneta (1964) agreed with the above conclusion, and also found a high correlation between moisture content and cooking time. However, the moisture content was still not considered by Muneta (1964) to be the primary factor affecting cooking time. Instead, he assumed that the moisture content is probably correlated with another factor or factors requiring longer cook time. Since dry beans contain highly unsaturated lipids, he concluded that the possibility of their oxidation and polymerization may result in changes in the water permeability and cooking time.

Kon (1968) studied the effect of high moisture and high storage temperature on the cooking rate of dry beans. His purpose though, was to determine if the poorer cooking quality was due to changes in the quantity of pectic substances. He concluded that no significant difference occurs between the total pectic substances from either high or low moisture beans. Even though it appears that there is no relation between the decreased cooking quality of beans and the pectic substances, the pectic content does have other affects. Hamad and Powers (1965) found that the pectic content of dry beans was "conversely" related to the rate of water absorption for both cold-water (room temperature) and hot-water (190-200^{o}F) soaking. They also found that the pectic content of the dry beans was directly related to drained weight after canning.

Another aspect concerning the processing of beans that needs some discussion here is the effect of processing on the nutritive value. Hackler, LaBelle, Steinkraus, and Hand (1965) mentioned that soaking beans overnight improves their nutritive value, probably because some of the antinutritional factors were removed. Kakade and Evans (1965) stated: "Rats fed the diet containing autoclaved beans gained weight and appeared to be normal. This improvement can be attributed to the destruction of heat labile trypsin inhibitors and hemagglutinins." Hackler et al. (1965) found that beans cooked for 40 minutes or longer at 250^{o}F had a decreased protein efficiency ratio.[1] A further decrease in protein nutritional quality results when carbohydrate is added to the beans after cooking. A greater decrease results from dextrose, however, than from sucrose. Powrie and Lamberts (1964) found that by processing navy beans for 70 minutes

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[1]Protein efficiency ratio, or PER, as described by Kakade and Evans (1965) is a measure of protein quality equal to the weight increase in grams per gram of protein consumed.

at $250^{\circ}F$ instead of 20 minutes, the apparent digestibility decreased 6%, in addition to decreases in experimental rat weight gain, protein efficiency ratio, and biological value. The protein nutritive value decreases slightly when only sucrose is added to the liquid of the canned beans. The addition of glucose, however, greatly decreases the protein digestibility and biological value.

The above information concerning handling and processing effects on navy beans is summarized in Table 2.

The cooking rates of dry beans can be estimated by measuring their tenderness, according to Binder and Rockland (1964). By using a L.E.E.-Kramer shear press equipped with an automatic recorder, they measured the maximum shear pressures of cooked beans to determine their tenderness after various cooking times. Primarily, 100 g samples were employed, using a multibladed shear head descending at a constant rate of 5.71 cm/min with the shear pressures being recorded on the strip chart traveling at a speed of 4.57 cm/min. The curves showed 2 peaks for lima beans. Their explanation was that the first peak results from the shear of the cotyledons, while the second was from the seed coats, which had detached and were stratified as the cotyledonous material was extruded.

Irradiation of dry beans may serve another purpose: to destroy insects that infest beans in storage. According to Larson and Fisher (1938) the bean weevil

TABLE 2. Summary of Handling and Processing Effects on Navy Beans.

Treatment	Effect
Irradiation	
over 200 Krad	Flavor detriment
up to 1600 Krad	Increased tenderness after rehydration in cold water, increased soluble solids in soak water, and increased rehydration rate.
Storage	
Temp. 72°F or greater	Development of hardshell, and increased cooking time.
Relative Humidity less than 65%	Development of hardshell.
Moisture content of beans over 10%	Increased cooking time, and possibly correlated with oxidation and polymerization of lipids causing changes in water permeability.
Soaking	
Soft water	Excessive splitting, softening, and matting.
Hard water	Toughening.
Overnight soaking	Removes some antinutritional factors.
Hot water	Increased rehydration rate.
Hot water discarded after soaking	Lower palatability, less thiamine and ash.
Boiling water	Production of unfavorable texture and flavor changes.
$NaHCO_3$ added	Reduction in cooking time, lower palatability, softing of bean seed coats.
Polyphosphates added	Increased rehydration rate.
NaCl added	Either negative or slight positive effect of rehydration rate.
Polyphosphates + NaCl	Increased rehydration rate, greater yields of processed beans, and increased tenderization rate during processing.
Ammonium salts of oxalic, citric, and tartaric acids	Softens bean seed coats.
Pectic content of beans	Conversely related to rehydration rate, and directly related to drained weight after canning.
Forced gas release	
Steam pressure	
Sonic energy	
Vacuum	Increased rehydration rate during soaking.
Vacuum Hydration with salt solutions (alkali metal salts of tripolyphosphate, pyrophosphate, and EDTA	Increased rehydration rate and tenderization.
Scarification	Reduces cooking time, and poorer appearance.
Cooking	Improves nutritive value by destruction of trypsin inhibitors and hemagglutinins.
250°F	Reduces cooking time over that of an atmospheric cook.
over 40 min at 250°F	Decreases protein efficiency ratio.
Carbohydrate added after cooking	Decrease in protein nutritional quality.

(Acanthoscelides obtectus, Say) and the southern cowpea weevil (Callosobruchus maculatus, F) can inflict injuries to the beans leading to huge losses. These insects grow and develop easily under the same climatic conditions that favor the growth of beans, which conditions may often prevail even after the beans are harvested and stored. Larson and Fisher (1938) described these weevils as follows: "The adults are small active beetles that oviposit in or on maturing pods in the field, and on or among dry seeds in storage. They live from a few days to a month or more depending on the temperature and food supply." To control bean weevils, Baker, Taboada, and Wiant (1954) irradiated infested navy beans at a dose of 10,000 rep of accelerated electrons, which was lethal to 100% of the weevils after 1 week.

METHODS AND MATERIALS

Preparation

Beans

Navy beans (*Phaseolus vulgaris*) from either of the 3 100-lb lots described below were used:

Lot 1. 1967--crop, "Casserole brand Michigan Navy Beans." The beans were purchased in the fall of 1967 from the Michigan Elevator Exchange, Lansing, Michigan. On October 29, 1968, the moisture (w.b.) was determined to be 13.68%. These beans are referred to as: "old 1967--crop beans."

Lot 2. 1967--crop, "Jack Rabbit brand Michigan CHP Navy Beans, Packed by Michigan Bean Co., Saginaw, Michigan." The beans were purchased in September, 1968, from the Michigan Elevator Exchange, Lansing, Michigan. On December 6, 1968, the moisture (w.b.) was determined to be 15.20%. These beans are referred to as: "new 1967--crop beans."

Lot 3. 1968--crop, "Jack Rabbit brand Michigan CHP Navy Beans, Packed by Michigan Bean Co., Saginaw, Michigan." The beans were purchased in November, 1968, from the Michigan State University Food Stores. The moisture (w.b.) was determined to be 13.81% on December 6, 1968, and 14.15% on April 30, 1969. These beans are referred to as: "1968--crop beans."

All the above beans were stored at 36°F. Prior to irradiation and processing, the beans were sorted by hand to eliminate discolored, broken, and cracked beans.

Radiation

Irradiation of the bean samples was accomplished by using the Cobalt-60 Research Irradiation Facility located in the Food Science Building at Michigan State University, East Lansing, Michigan. At the time of installation of the Research Irradiator source, June 1967, the strength was 50,500 curies. The source consists of 24 source strips arranged vertically in about a 1-foot diameter cylindrical configuration. All irradiations were conducted in air. When the source is not in use, it is lowered into a 15-foot deep water pool, to provide shielding while placing samples in the irradiator cell.

The irradiation dose is dependent on the distance from the source center, as well as the time of exposure. The field of radiation for the MSU Research Irradiator source has been mapped using ferrous-cupric and Fricke chemical dosimetry. The field intensity is expressed as Krad/hour at various distances from the source, all referred to a reference date of August 1, 1967. The intensity on any other date is calculated by applying the decay correction factor for Co-60 given in U.S.P.H.S. (1960). The average dose received by a sample is based on the approximation that the sample thickness can be expressed as water equivalent, and that the extinction coefficient for gamma rays in a sample of density different from water is the same as that for an equivalent thickness of water.

The bean samples to be irradiated were weighed into polyethylene bags (see Figure 3), sealed by a heat sealer, and placed upright on the floor of the irradiator cell; the center of the bag was about 2.6 cm from the floor. The bulk density of these bagged bean samples was determined to be 0.82 g/cm^3, with an estimated thickness measured parallel to the radiation of 6.5 cm. The equivalent thickness in terms of water of 1 g/cm^3 density equaled 6.5 cm X 0.82 = 5.3 cm. The samples were turned 180° midway during the exposure to reduce the difference between the maximum and the minimum dose received. For a sample of equivalent thickness of 5.3 cm, a theoretical calculation shows the maximum dose received to be 87% of that falling on the face closest to the source, the minimum is 84.5%, and the average is 85.5%. The theoretical calculation was verified with chemical dosimetry. An example showing the calculation of the actual dose received by the sample is given in Table 3.

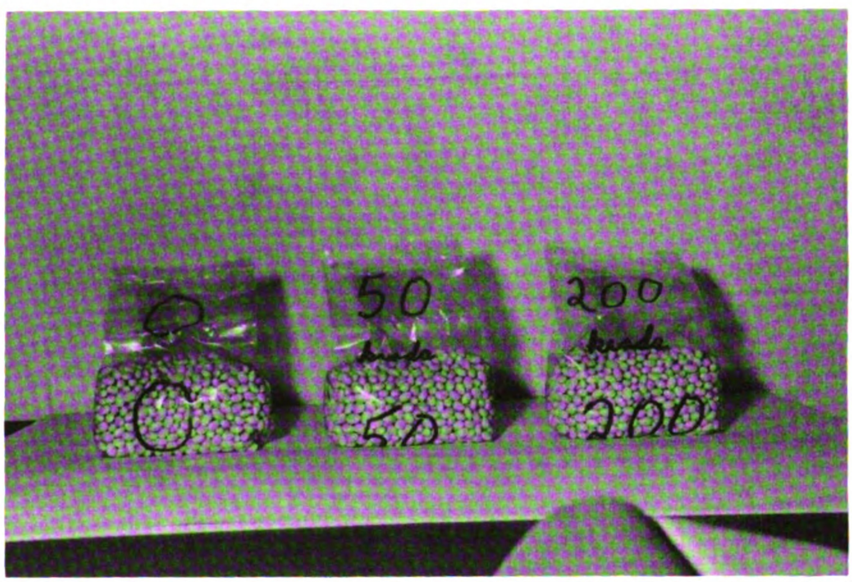

Figure 3. Dry navy beans, 300 g/polyethylene bag, ready for exposure to gamma radiation.

TABLE 3. An example of the calculated dose for a 300 g sample of dry navy beans placed 50 cm from the source and irradiated for 2.33 hrs on 3/6/69.

Dose Rate 8/1/69	Decay Correction for 3/6/69	Time of Irradiation	Absorption Correction for Ave. Dose	Calculated Ave. Dose
216 Krad/hr	0.81	2.33 hrs	0.85	347 Krad

Soaking

The beans were soaked prior to retorting to help rehydrate, clean, and tenderize the beans. Since Continental Can Company (undated b) considered water with 4 to 9 grains hardness optimum for soaking beans, an approximate average of 6 grains hardness was used. In a few preliminary experiments, however, beans were soaked in distilled water. These beans, after retorting at least 7 days storage in cants, showed more splitting and matting than beans soaked in the artificially prepared hard water of 6 grains hardness. Continental Can Company (undated b) stated: "It has been shown that extremely soft water used for soaking and blanching will contribute to the splitting and matting of the beans in the can."

The 6 grains hardness used is measured as $CaCO_3$, thus only 40.04% of the hardness is due to calcium. All calculations for preparing the hard water were based on the above fact. In addition, a correction was made for the $CaCO_3$ in the distilled water used, which contained approximately 2 ppm. Initially, $CaCl_2$ was used to prepare the artificial hard water of 6 grains hardness. This was later changed, however, to $CaSO_4 \cdot 2H_2O$, then $CaSO_4$ when it became available. According to Dawson et al. (1952), calcium and sulfate ions ". . . represent the type of permanent hardness found in most hard waters of this country."

The containers used for soaking the beans included an aluminum screen basket containing the bean sample, which was in turn placed into a glass beaker with 4 times the bean sample weight of the artifically prepared hard water. (see Figure 4). Only two soaking methods were used:

1. Cold-water soak of 16 hours at 36°F.
2. Hot-water soak of 1 hour at approximately 180°F.

The temperature of the long, cold-water soak was purposely kept low, to slow down bacterial growth.

Processing

After soaking, the beans were canned as quickly as possible in 211 x 400 cans. Each can contained 167 g of beans plus 167 g of sweetened sauce. Production and Marketing Administration (1947) defines a sweetened sauce used in canning dried beans as ". . . sweetening ingredients in the packing medium with or without any one or more of the following: salt, thickening ingredients, coloring agents, spices or other flavorings, and molasses." For this research, an unthickened sauce was desired just to give flavoring to the canned navy beans, but hopefully not to mask any radiation off-flavor. The sweetened sauce formula used was one described by Continental Can Co. (undated b): 20 pounds of NaCl and 30 pounds of sucrose per 100 gallons of sauce. In preparing this sweetened sauce, approximately 2.4% NaCl and 3.6% sucrose was made

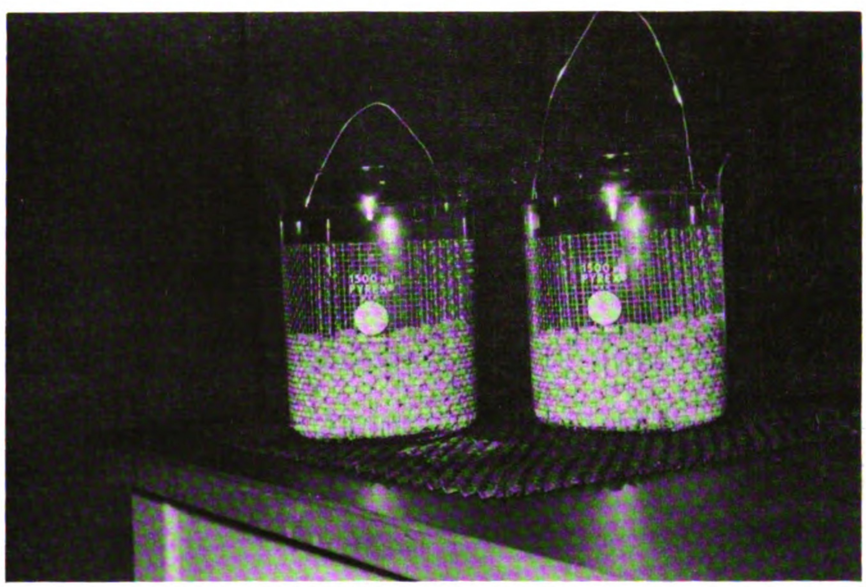

Figure 4. Navy beans, 300 g/dry sample, in aluminum screen bags, soaking in 1200 ml of artificially prepared hard water.

up to 1 gallon with the artificially prepared hard water of 6 grains hardness, as described previously under the soaking method.

Bedford (1968) suggested that the approximate fill of soaked beans should be 50% by weight of the total fill. The weight of water filling a 211 x 400 can is 334 grams. Thus, for the majority of the experiments, each can contained 167 g of soaked beans plus 167 g of the sweetened sauce at the time of canning. A few of the early experiments, however, had only 105 g fill weight of soaked beans. The sauce was added at a temperature of about 200°F to give an initial temperature of the can contents at the time of retorting of about 110-120°F for the beans given a cold-water soak, and about 130-140°F for the beans given a hot-water soak. The time between filling and retorting varied between 15 and 30 minutes and temperature measurements of the can contents at 15 and 30 minutes after filling gave the temperatures mentioned above.

The heat process used is one suggested by the National Canners Association (1966) for beans in a light sauce packed in number 2-1/2 and smaller cans: 245°F for 30 minutes. The initial temperature of the can contents at the time of retorting is recommended to be in the range of 100-140°F, which is in agreement with actual initial temperatures mentioned above. At the end of the heat process time, the cans were cooled by a cold-water spray.

Storage

After processing, the canned beans were stored at approximately 72°F for a time long enough for the beans and the liquid to equalize. To determine the length of time necessary for equalization, 6 cans of beans each containing 105 g of soaked beans at the time of canning, were processed and stored for various lengths of time at approximately 72°F. After 6 days, 1 can was opened, 2 cans were opened after 12 days; and, 3 cans were opened after 22 days. In each can, the beans had increased in volume to occupy two-thirds of the can. Bedford (1968) suggested that 7 days should be sufficient time for the beans to equalize with the liquid inside the can. Thus, based on the above information, the canned beans for these experiments were stored for at least 7 days at approximately 72°F prior to examination.

Examination

Moisture

The method of determining moisture content of the dry beans is the vacuum oven method described by Makower, Chastain, and Nielson (1946), but with some modification. The Makower et al. (1946) method was also used by Morris and Wood (1955) in determining the moisture content of dry beans.

Essentially, the Makower et al. (1946) method included the following:

1. 100 g sample, systematically sampled.
2. The sample was coarsely ground in a Wiley mill equipped with a U.S. 10-mesh sieve, which has 2.00 mm sieve openings.
3. A quartering funnel used to separate out a 25 g portion, which was reground to pass through a U.S. 40-mesh sieve, having 0.42 mm sieve openings.
4. Two to 4 g samples were placed in small glass-stoppered weighing bottles, 20 mm in diameter and 25 mm high for drying.
5. Two empty bottles were included with each set of samples to check on reproducibility of weighing.
6. Determinations were made in duplicate or triplicate.
7. Drying was accomplished in a vacuum oven kept at a pressure of 5 mm of mercury or less, and at 70°C for 40 hours.
8. At the end of the drying time, air dried by passage through a calcium chloride tube was slowly admitted into the oven for 20 to 30 minutes to bring it up to atmospheric pressure.
9. Samples were allowed to cool in dessicators containing calcium chloride, prior to reweighing.

The modifications to the above method included:

1. 100 g sample of dry beans taken equally from the top layers of 2 separate sacks of beans. This procedure was followed because all the beans experimented with came from the top layers.
2. The sample was ground in a Micro mill to pass through a sieve having 1.00 mm sieve openings.
3. 25 g of the coarsely ground sample was randomly taken and reground to pass through a sieve having 0.50 mm sieve openings.
4. Approximately 2 g samples were weighed into predried, aluminum moisture pans with lids. The pans were 4.5 cm deep, 6.3 cm in diameter, and having a cover that fitted over the pan with a 0.5 cm overhang. The pans were predried for 4 hours in the vacuum oven at 100°C and a vacuum of about 29 inches of Hg. All weighings were made to the fourth decimal place.
5. $CaSO_4$ was used in the dessicator and to dry the air going into the vacuum oven.

A model 524 vacuum oven was used in conjunction with a model 25 vacuum pump, both made by Precision Scientific.

In calculating the percent moisture, the loss in weight of the ground sample during drying was taken as a measure of the moisture content. All the moisture determinations were calculated on a wet basis.

The moisture content of soaked, and processed beans was based on drained weight determinations, and the weight of the dry matter in the dry beans. All drained weights were determined after a 2 minute drain. Soaked beans were drained in the aluminum screen bag that they were originally soaked in, but the processed beans were drained in a No. 7 sieve having 2.83 mm openings. A No. 7 sieve was used for convenience, instead of the more common No. 8.

Appearance

The visual examination consisted of estimating the fill volume of beans in the can, as an indication of slack fill, and noting the general appearance of the can contents according to prevalence of cracked beans, matting, bean color, and consistency of the sauce. This examination gave in impression of the overall acceptability of the canned beans.

Tenderness

The word "tender" was used to describe the ease with which cooked beans could be broken down, cut, or chewed. The words "texture," "hardness" or "softness" had been considered also, but they seemed to connote other meanings that are not entirely appropriate here. For instance, texture indicates structure; hardness means a degree of unyielding firmness, and softness means giving away easily under pressure. Although these other terms could possibly be used, they do not convey the exact meaning desired. Binder and Rockland (1964) used the term "tenderization rate" to describe the work required to shear lima beans.

An Instron Universal Testing Instrument, Type TTBM, was used to measure the tenderness of the beans. Bourne et al. (1966) gave a good description of this instrument and its use in measuring food properties. Basically the Instron has 2 main parts, the crosshead and the load-sensing device, which is connected to an automatic recorder. The crosshead is driven vertically by twin lead screws, and can be set at selected rates of travel ranging from 0.05 to 50 cm/min. The system of load sensing and recording is made up of electric bonded-wire strain gauges whose output is recorded on a strip-chart. The full scale load range of this Instron model is 2 g to 500 Kg, and a compression load cell is used to obtain this range. The rate of travel of the recording strip-chart can be set by changing the drive gears. Chart speed can equal that of the crosshead or be a simple multiple of it, because the same power supply drives both systems. The working parts have a total space of about 28 x 20 cm between the twin drive screws, and an 80 cm stroke length.

Fitted onto the crosshead of the Instron, was a stainless steel L.E.E.-Kramer shear press cell (see Figures 5, 6, and 7). In measuring the tenderness of the beans, the sample was put into the sample cell box, and the blades were driven down through the sample and 0.5 cm

Figure 5. Processed navy beans, after storage, being tested for tenderness on the Instron, fitted with a L.E.E.-Kramer shear press cell on the crosshead.

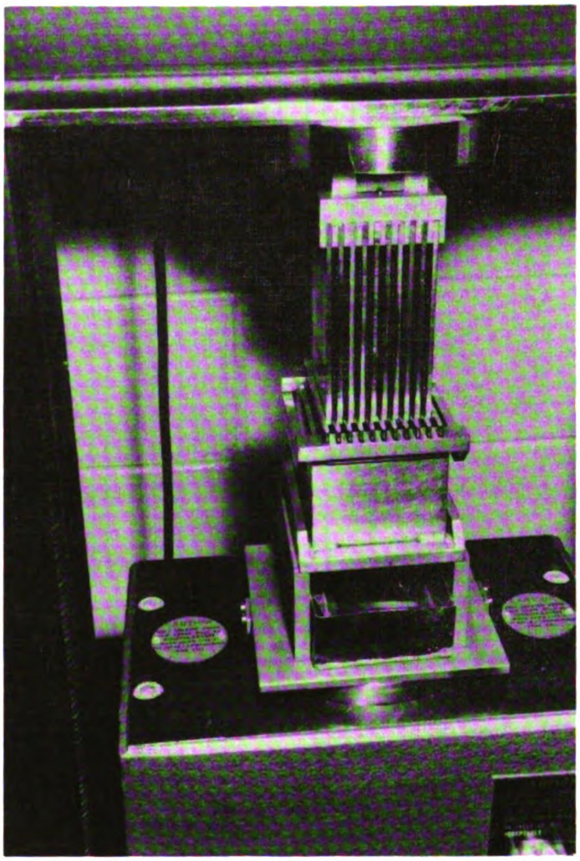

Figure 6. L.E.E.-Kramer shear press cell fitted onto the crosshead of the Instron.

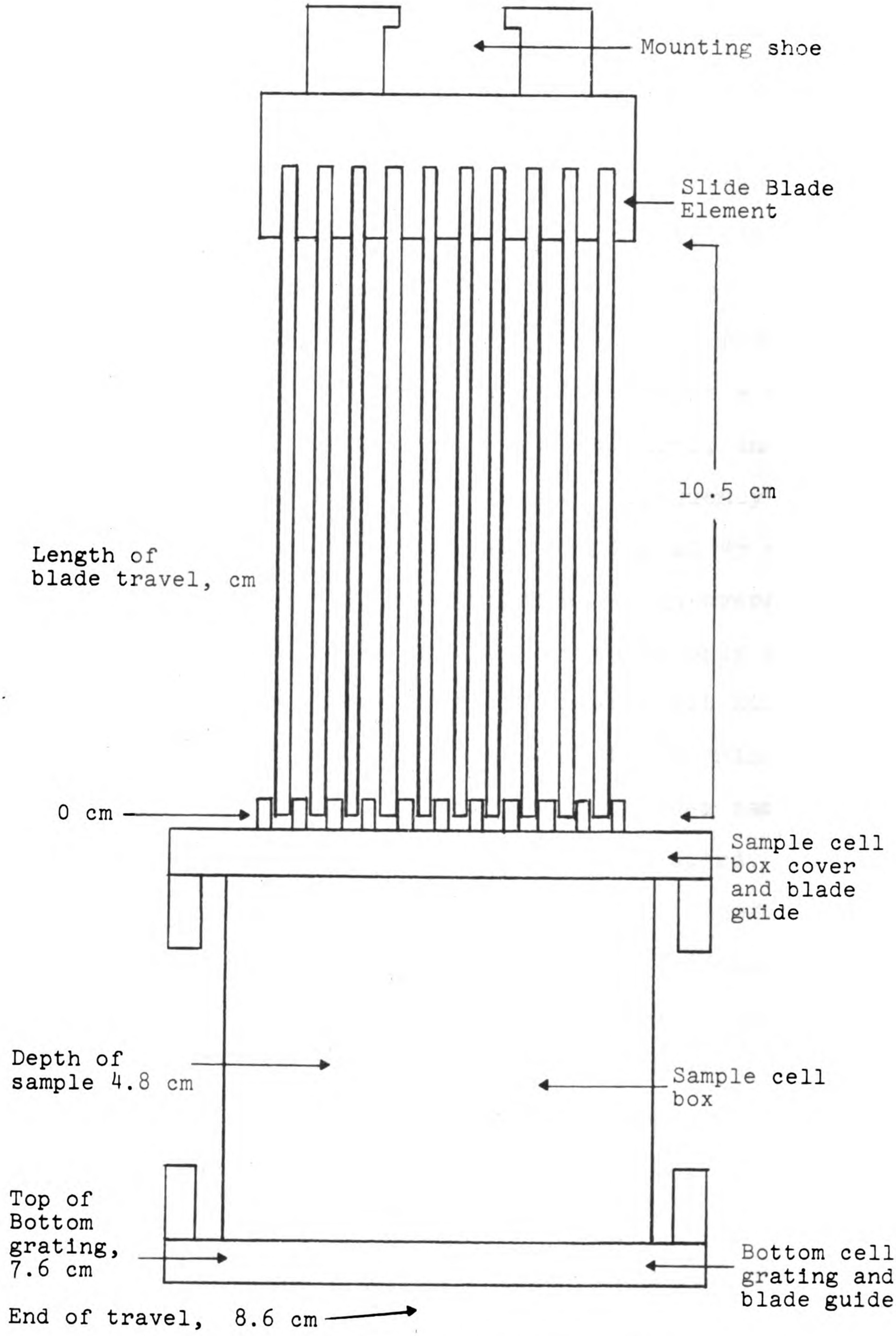

Figure 7. L.E.E.-Kramer shear press cell.

past the bottom cell grating. The size of the sample used was 100 g, which was the preferred quantity of sample used by Binder and Rockland (1964). The descent rate of the crosshead and shearing blades was set at the maximum for this instrument--50 cm/min to attempt to simulate the descent rate of human teeth in actual chewing. The recording-chart speed was also set at 50 cm/min. Proctor, Davidson, Malecki, and Welch (1955) worked on a strain-gage tenderometer fitted with human dentures, an instrument mechanically arranged to simulate frequency of chewing. Their denture tenderometer, cycling at 45 cycles/min with a stroke of 2.1 cm, traveled at an average speed of 189 cm/min. Thus, the Instron speed is only about a third the chewing rate, but gives the closest simulation presently available. A descent rate of 5 cm/min was also tested, and the tenderness values for 6 100-g samples of beans were lower than at the 50 cm/min speed. In other words, the average force recorded at 5 cm/min was approximately 20% greater than that at 50 cm/min.

The curve obtained on the recording strip-chart showed 2 peaks for every sample run (see Figure 8). Binder and Rockland (1964) also reported that double peaks appeared on recorder tracings while shearing intact lima beans using a L.E.E.-Kramer shear press. They concluded that the first peak resulted from the response of shearing both the seedcoat and cotyledons of the beans, but primarily the cotyledons. The second peak was thought

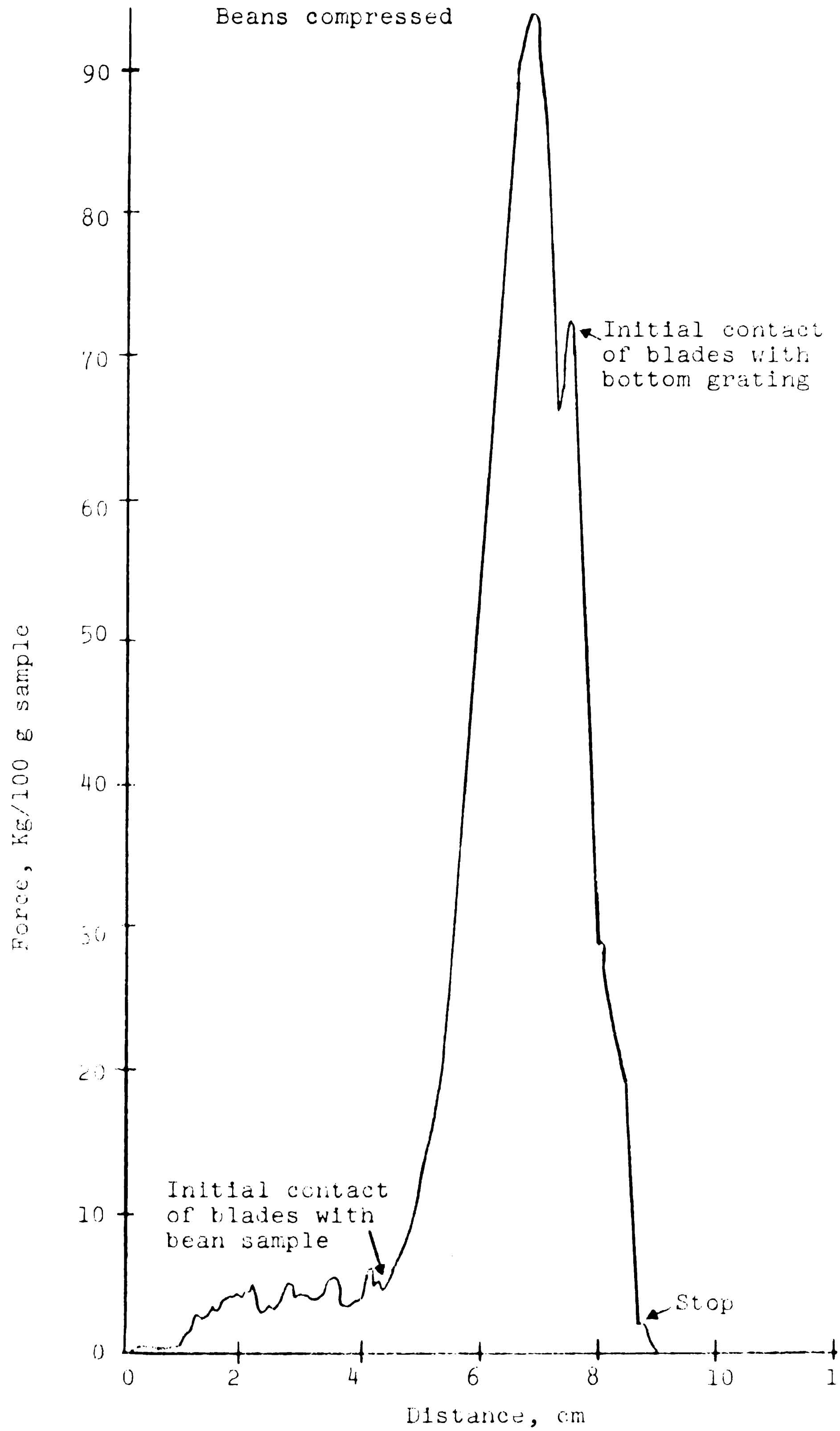

Figure 8. Compression curve for a 100 g sample of processed whole navy beans, after storage. (L.E.E.-Kramer shear press cell fitted onto an Instron, blade descent rate and recording chart speed 50 cm/min).

to be due to the independent shear of the seedcoats that became detached and stratified as cotyledonous material was extruded. In attempting to determine the cause of the double peaks while shearing navy beans, a 100 g sample of intact processed beans was subjected to the shear blades on the Instron, and examined at the positions showing the 2 peaks. At the starting position of 0 cm (Figures 7 and 8), the shear blades were about 4.7 cm above the sample and 7.5 cm above the top of the bottom grating. The first peak occurred at 7.0 cm distance, which is about 80% through the original sample, which was just beginning to extrude through the bottom grating. The second peak occurred at 7.5 cm, where the blades are just beginning to mesh with the bottom grating. At this position, the blades have forced some of the bean sample through the bottom grating and the rest of the sample into the spaces between the blades. The extruded beans at both peaks appeared to have equal proportions of seedcoats and cotyledons. Thus, from the above observations, it is concluded that the first peak results primarily from the compression of the bean as a whole, and there is no special separation of seedcoats from cotyledons. The second peak results from the force required to extrude the beans through the bottom grating along with the initial meshing of the blades with the grating. Based on these conclusions, it was decided that only the first peak gives an uninterrupted measure of the tenderness of the beans, thus only the results from the first peak are reported.

To obtain some knowledge of what is the generally accepted measure of tenderness for processed beans, 7 commercial brands of canned beans were examined for tenderness by using the Instron. In addition to tenderness, the amount of can fill and appearance were noted. Table 4 shows the results from 2 sample cans from each of the 7 commercial brands. Each can contained enough beans for 2 100-g samples. All the samples of commercial beans in Table 4 contained cracked beans, with only the Meadowdale samples having some of the beans completely broken. The fill of beans in the cans ranged from approximately 80 to 100% of the total volume.

Since the other tenderness measurements, in the literature, on processed beans were determined with a shear press instead of the Instron, a comparison of the tenderness measurements from these 2 instruments was made. Samples of 1968-crop beans were given a cold-water soak, processed, and stored for 7 days prior to examination. Each can provided 2 100-g samples, as was the case in most of the other experiments on tenderness described later. An exception was made in this comparison for the blade descent and chart speed from the 50 cm/min speed described earlier; instead, 20 cm/min was used, because this was the maximum blade descent speed with the Allo-Kramer Shear

TABLE 4. Tenderness, kg/100 g product, of commercial brands of canned beans.[1]

	American Beauty Navy Beans	Meadowdale Navy Beans	Kroger Navy Beans	Stokely Van Camp's Pork & Beans	Campbell's Pork & Beans	Spartan Red Beans	Spartan Great Northern Beans
	85.0	51.0	53.0	46.0	33.5	76.0	58.5
	82.0	48.0	45.5	42.0	32.5	72.5	58.5
	85.0	54.5	55.0	46.5	35.5	76.5	60.5
Mean	84.5	48.5	54.0	45.5	32.0	72.5	55.5
	84.1	50.5	51.8	45.0	33.4	74.4	58.1

[1]Two sample cans/brand, and 2 100 g samples/can.

Press values to be 7.3 kilograms or 12% higher per sample than from the Instron (Table 5).

TABLE 5. Tenderness, kg/100 g product, comparisons of processed navy beans measured by an Instron and a Allo-Kramer Shear Press.[1]

	Instron	Shear Press[2]
	62.5	65.0
	58.0	68.2
	56.0	61.8
	53.5	58.6
	54.5	61.4
	54.5	67.7
Mean	56.5	63.8

[1]Blade descent and recording chart speed 20 cm/min, 3 cans tested on each instrument, 2 100-g samples/can.

[2]3000-lb ring.

Sensory Panel Evaluation

Two factors were investigated by sensory panel. These included flavor and tenderness differences, which were possibly due to gamma irradiation. A triangle test was used for determining differences in flavor, and a 3-sample ranking test was used for tenderness differences. Both tests were run in duplicate.

The irradiated samples used in the triangle test had been exposed to 340 Krad gamma irradiation, because at this dose the tenderness is about the same as it is for unirradiated beans. For the ranking test, the 3 samples were given the following doses of irradiation: 0, 42, and 170 Krad. Prior to the sensory tests, the bean samples had been given a cold-water soak, processed, and stored for 8 days.

Chemical Analysis

Crude protein and free soluble starch were the only constituents analyzed. The measurement of crude protein was made by using the Kjeldahl method for determination of total nitrogen. All the bean samples to be tested for protein were first dried to complete dryness by using the method mentioned previously for moisture determination. Details of the Kjeldahl nitrogen determination as recommended by Benne (1969), are as follows:

1. 1 g samples of the dried, ground beans were used.
2. 0.1-0.5 g $CuSO_4$ and 8-12 g K_2SO_4 added to increase the boiling point of the solution for better digestion of the sample.
3. 25 ml conc H_2SO_4 added for digestion of the sample.
4. Samples were heated to boiling for approximately 2.5 hours.
5. After cooling the Kjeldahl flasks, the following was added in approximate amounts: 3 or 4 drops mineral oil, 200 ml distilled H_2O, 1

granule of mossy zinc, and 80 ml of 50% NaOH solution.

6. The Kjeldahl flasks were heated to boiling, and the ammonia distilled off into Erlenmeyer flasks containing 1 drop methyl red indicator solution and 15 ml 0.2N H_2SO_4.
7. If the methyl red indicator changed to a yellow color, indicating an alkaline solution in the Erlenmeyer flask, 5 ml additional 0.2N H_2SO_4 was added.
8. 2 additional drops of methyl red indicator solution was added to the contents of the Erlenmeyer flasks, then titrated with 0.1N NaOH.

From the amount of 0.1N NaOH required to titrate the remaining unneutralized 0.2N H_2SO_4, the percent of nitrogen in the original bean sample was calculated. The percent of protein was in turn calculated by multiplying the percent nitrogen by a factor of 6.25.

The blue value index was used as an indication of the free soluble starch content of the soak water after cold-water soaking of navy beans. The procedure followed is the same as that described by Palnitkar (1967), except that extraction was accomplished on whole beans soaked in 4 times their weight of artificially prepared hard water, described previously, for 16 hours at 36°F. A measured volume of 5 ml of the soak water was combined with 2 ml of 0.02N iodine-potassium iodate solution and 93 ml of distilled water. This solution was allowed to stand for 10-15 minutes. The absorbancy of the solution at 660 mu was then measured on a Bausch & Lomb Spectronic 20 colorimeter, with red filter and photocells recommended for use at this wavelength. The colorimeter was standardized with 2 ml of the 0.02N iodine-potassium iodate solution diluted to 100 ml with distilled water.

Statistical Analysis

The tenderness and drained weight measurements were analyzed statistically by using analysis of variance. When significant differences were found within the sources of variance having a series of 3 or more means, Duncan's Multiple Range Test was used to test all the possible differences. The triangle tests for flavor were tested for significant differences using Kramer's tables listed by Amerine, Pangborn, and Roessler (1965). These tables listed the totals required for significance for a normal distribution. The totals for both triangle tests for flavor were also evaluated by the chi-square distribution. This test was used to find out if the observed frequency distribution, f_o, differs significantly from the theoretical or expected frequency, f_e. Since the triangle test involves only 1 degree of freedom, the chi-square formula was adjusted as follows:

$$\chi^2 = \Sigma \frac{(/f_o - f_e/ - \frac{1}{2})^2}{f_e}$$

In testing for significant agreement between rankings for tenderness, the total ranking results were compared with Kramer's rank totals for significance. These tables are also listed by Amerine et al. (1965). The ranking results were also analyzed using the statistic W, the coefficient of concordance (Amerine et al., 1965).

EXPERIMENTAL AND RESULTS

Tenderness and Pack Characteristics

Based on the previous research concerning the tenderization effects of gamma radiation on dehydrated vegetables and dry navy beans, experiments were conducted to explore this effect further. Only dry navy beans were used in these experiments, but they were subjected to various gamma radiation doses and various processing conditions, including different soaking methods and heat processing times.

a. Cold-water soak for 16 hours, and a 30-minute processing time at 245°F.

Table 6 shows the tenderness measurements of canned beans previously soaked in artificially hardened water ($CaCl_2$) for 16 hours at 36°F, and heat processed 30 minutes at 245°F. The average tenderness values, Table 6, tended to show increased tenderness as the irradiation dose increased from 0 to 340 Krad, however, these differences were not significant. The 2700 Krad samples showed no tenderization effect at all; in fact, the beans appeared tougher than even the unirradiated samples. The average values for these 2700 Krad samples were significantly higher than all the other samples. In addition, there was a significant interaction between the doses and the cans.

TABLE 6. Tenderness[1], kg/100 g product, of irradiated processed navy beans (cold-water soak), measured after 7 days storage.

	Dose, Krad			
	0	42	340	2700
	66.5	57.0	64.5	113.5
	69.0	58.5	65.0	
	60.5	58.0	58.5	102.5
	62.5	60.5	58.5	
	61.0	55.0	48.0	99.0
	61.0	60.0	48.0	
Mean	63.4	58.2	57.1	105.0

[1]Three cans at each dose, 2 100-g samples/can, except at 2700 Krad (see text).

The drained weight of the contents from each can, the percent fill, moisture after soaking, and moisture after processing and storage of the beans are listed in Table 7. In comparing the average drained weights from each group of samples given different irradiation doses, it was noted that the drained weights decreased as the dose increased beyond 42 Krad. This decrease was significant at the 5% level of statistical significance, and for the 2700 Krad samples, it was significant at the 1% level.

TABLE 7. Pack characteristics of irradiated, processed navy beans. (cold-water soak, 211x400 cans, measured after 7 days storage).

Characteristic	Dose, Krad 0	42	340	2700
Drained weight, g/can	238.0	246.0	225.0	202.5
	249.0	242.0	228.0	207.0
	245.0	247.0	245.0	209.0
Mean	244.0	245.0	232.7	206.2
Fill volume, %[1]	90	90	85	80
Moisture, % after soaking	55	55	56	57
after storage[1]	69	69	68	64

[1]Average of 3 cans.

The moisture of the beans after soaking and prior to canning tended to increase slightly as the radiation dose increased. However, the moisture after processing and storage decreased as the radiation dose increased; this effect also showed up in the decreasing percent fill of beans in the cans. The percent fill was so low for the 2700 Krad samples that 2 100-g samples of beans for the tenderness measurements were not available. Although the 2700 Krad samples had drained weights over 200 g after 2 minutes draining, part of this weight was attributed to the sweetened sauce clinging to the beans. After the drained weights were taken and prior to weighing out the second 100 g sample for tenderness measurement, enough sauce had dripped off the beans resting in the No. 7 sieve to account for the lack of sufficient sample.

The general appearance of the canned beans was also noted. Beans previously exposed to 0 and 42 Krad showed slight cracking of the seedcoats and cotyledons, plus a very slight amount of matting. The 340 and 2700 Krad beans showed even fewer cracked beans, but at the 2700 Krad dose the beans showed some brown off-color and small pieces of white material in the sauce.

Based on these results, it was concluded that 2700 Krad was too extreme a dose for producing canned beans of acceptable quality. To narrow down the radiation doses, 2 experiments were conducted, one in the dose range of 0 to 680 Krad and the other 680 to 1400 Krad. Tables 8 and 9 show the results from these experiments, and Figure 9 shows the tenderness results graphically. The bean samples, after exposure to the different irradiation doses, were processed the same way as those of the previous experiment. The only exception was that the beans were soaked in water artificially hardened with $CaSO_4 \cdot 2H_2O$ instead of $CaCl_2$ for 16 hours at 36°F prior to the heat processing.

The tenderness values in Table 8 show that tenderness increased as the irradiation dose increased to 170

TABLE 8. Tenderness[1], kg/100 g product, of irradiated, processed navy beans (Cold-water soak), measured after 7 days storage.

	Dose, Krad							
	0	85	170	340	680	680	1000	1400
	65.0	58.0	57.0	62.5	68.0	66.5	80.5	81.5
	67.0	62.0	54.5	62.5	68.0	67.0		
	60.0	55.5	52.5	58.5	61.0	59.0	69.0	72.0
	60.0	56.5	56.5	61.0	60.0	61.0	67.0	
	55.0	53.5	56.0	58.0	62.5	58.5	64.0	71.5
	57.5	57.0	56.5	57.5	62.0	61.0	65.0	70.5
Mean	60.7	57.1	55.5	60.0	63.5	62.2	69.1	73.9

[1]Three cans at each dose, 2 100 g samples/can, except at 1000 and 1400 Krads.

TABLE 9. Pack characteristics of irradiated, processed navy beans. (Cold-water soak, 211 x 400 cans, measured after 7 days storage).

	Dose, Krad							
Characteristic	0	85	170	340	680	680	1000	1400
Drained weight, g/can	236.0	237.0	234.5	223.5	217.5	215.0	208.5	205.0
	243.5	238.0	234.0	225.5	226.0	223.0	214.0	208.5
	241.0	234.5	235.0	228.0	219.5	220.0	217.5	212.0
Mean	240.2	236.5	234.5	225.7	221.0	219.3	213.3	208.5
Fill volume, %[1]	90	90	90	90	85	83	80	75
Moisture, %								
after soaking	55.4	55.2	55.7	56.1	56.5	56.8	57.0	57.3
after storage[1]	69.0	68.3	68.4	67.5	67.1	67.1	66.3	65.8

[1]Average of 3 cans.

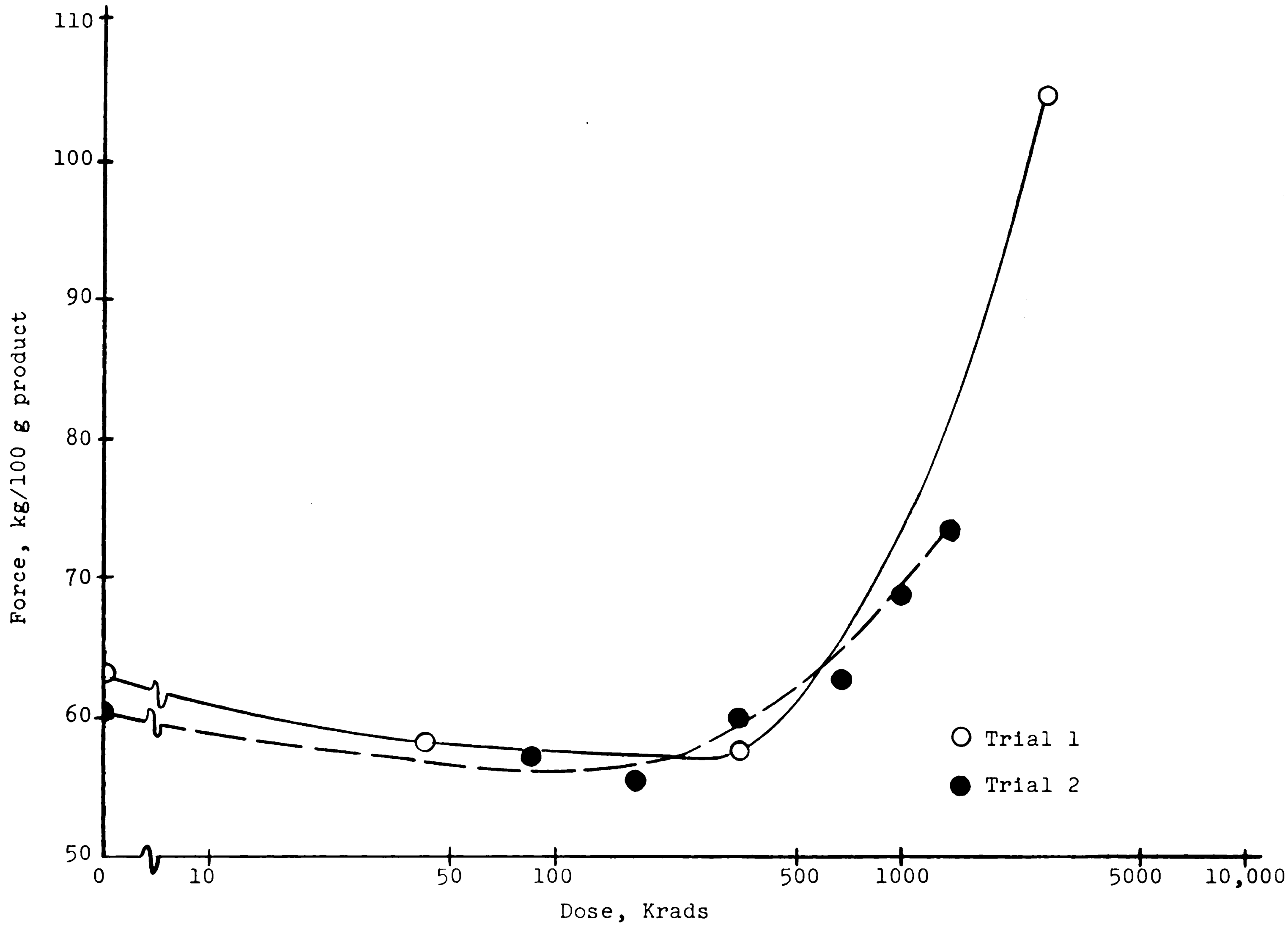

Figure 9. Tenderness of irradiated dry navy beans as a function of dose. (Two trials, cold-water soak, processed at 245°F for 30 minutes, and stored 7 days).

Krad, but from 340 Krad and up, the beans became tougher. It should also be noted that the bean samples given the 340 Krad dose were similar to the unirradiated samples in tenderness. The statistical analysis showed significant differences among the doses, and cans, plus a significant interaction between these 2 sources of variation. With so many irradiation doses being discussed here, it is less confusing just to give the value for the shortest significant range between adjacent means for tenderness among the doses. This value was 5.4 Kg. Between cans of beans, the significant difference was between can 1 and the other 2 cans, at the 5% level of significance only.

In Table 9, the drained weights of the canned beans again show results similar to the last experiment. The drained weights decreased as the radiation dose increased. A significant difference was noted between the doses and the cans. The shortest significant range between adjacent means for drained weights, among the doses, was 4.5 g. The only can significantly different from the others was can 1. The percent moisture of the beans after soaking and prior to processing showed slight increases as the irradiation dose increased. However, after processing and storage, the percent moisture decreased as the radiation dose increased. This last statement also helps explain why the percent fill of beans exposed to 680 Krad and higher decreased. The general appearance of the canned beans shows the 0 to 170 Krad samples to have slightly cracked beans, no matting, and good overall appearance. The samples exposed to higher doses of radiation than 170 Krad showed fewer cracked beans, but at 680 to 1400 Krad white particles were seen in the bean sauce.

Since the 170 Krad irradiation dose yielded the tenderest beans with very little detrimental effect, further investigation of this was made. Table 10 shows the tenderness results from duplicate experiments of beans irradiated at 0, 42, 170, and 250 Krad. These particular doses were used to more closely point out where maximum tenderization of the beans occurs. Again the maximum tenderization occurred at 170 Krad. At 250 Krad, the tenderization effect appeared to be decreasing again and causing the beans to toughen compared to the 170 Krad samples. Statistically, the effect of doses was significant. When the means from each dose were compared, the 0 and 42 Krad samples were significantly different at the 5% level from the samples irradiated at 170 and 250 Krad; at the 1% level of significance the 0 Krad samples were significantly different from all the other irradiated samples.

As with the last experiment, the cans were again significantly different. Based on a comparison of means, the beans from the can 1 samples were significantly less tender than the can 2 and can 3 samples. Along with this, the difference between the 2 experiments was significant.

TABLE 10. Tenderness[1], kg/100 g product, of irradiated, processed navy beans (cold-water soak), measured after 7 days storage, 2 experiments designated here as a and b respectively.

	Dose, Krad							
	0		42		170		250	
	Experiments							
	a	b	a	b	a	b	a	b
	63.5	64.0	58.5	59.5	57.5	57.0	56.0	61.0
	61.0	63.5	59.0	60.0	57.5	60.0	55.5	60.0
	57.0	58.0	52.0	56.0	51.0	54.5	54.5	56.0
	56.5	59.0	51.5	56.5	55.0	55.5	53.5	53.0
	54.0	58.0	53.0	55.5	50.0	52.0	51.0	53.5
	54.5	58.0	55.0	55.0	51.0	52.0	52.0	53.5
Mean	57.7	59.3	54.8	57.1	53.7	55.2	53.7	56.2
Overall Mean	58.5		55.9		54.4		54.9	

[1]Three cans at each dose, 2 100-g samples/can.

The 2 experiments were not significantly different, however, when only the drained weights were considered (Table 11).

The pack characteristics are given in Table 11. Again, the drained weights tended to decrease as the radiation dose increased. The difference between doses was significant, and the means of the 0 and 42 Krad samples were significantly different from the 170 and 250 Krad samples. The mean drained weight of can 1 was significantly different from that of cans 2 and 3, which agrees with the last experiment described. The fill volume of beans in the cans decreased as the irradiation dose was increased to 170 and 250 Krad. This same effect was noticed in the amount of liquid absorbed by the beans after processing, as measured by the percent moisture after the storage period. The opposite effect was observed with increasing irradiation dose, when the percent moisture after soaking was measured. However, these differences in percent moisture were small. The general appearance of the beans did not change between the samples given different irradiation doses. All the bean samples showed cracked beans but no matting.

Since tenderness and drained weight continued to show significant differences among cans, an explanation and remedy were sought. A possible cause of these variances may be attributed to the method used to fill the cans of beans with hot sauce prior to processing. The

TABLE 11. Pack characteristics of irradiated, processed navy beans. (Cold-water soak, 211 x 400 cans, measured after 7 days storage, 2 experiments designated here as a and b respectively).

	Dose, Krad							
	0		42		170		250	
	Experiments							
Characteristic	a	b	a	b	a	b	a	b
Drained weight, g/can	236.0 241.5 246.5	239.5 241.0 242.0	235.5 242.5 236.5	235.0 239.5 241.0	228.0 230.0 234.5	227.0 232.0 237.0	225.0 231.0 231.0	231.0 236.5 237.5
Mean	241.3	240.8	238.2	238.5	230.8	232.0	229.0	235.0
Fill volume, %[1]	90	90	90	90	87	87	83	87
Moisture, % after soaking	55.1	54.8	55.5	55.5	55.9	55.8	56.2	55.0
after storage[1]	68.9	68.7	68.8	68.8	68.1	68.2	68.1	68.0

[1]Average of 3 cans.

method used was to fill and seal each can separately, in succession, starting with can 1 of the lowest irradiation dose samples and then proceeding to can 2, can 3, and then going to the next higher dose samples, etcetera, to can 3 of the highest dose samples. By filling the cans in this manner, can 1 of 0 Krad samples was always in the hot sauce the longest time, and therefore was allowed to cool the greatest amount of time prior to heat processing. On the other hand, can 3 of the highest irradiation dose was just the opposite. To correct this, 2 more experiments like the ones just described were performed; the only procedure change was that all the cans of beans were filled with the hot, sweetened sauce at approximately the same time and at random. The time between filling the first can and filling the last was about 1 minute.

Table 12 shows the tenderness results of the beans that had been covered with the hot, sweetened sauce all at approximately the same time. The tenderness increased as the irradiation dose increase. These results were quite similar to the last experiments using these same doses, except that here the 250 Krad dose showed just a little more tenderness than the 170 Krad dose. Again, the doses were significantly different. The average tenderness values for doses showed the 0 Krad samples significantly different from all the irradiated samples at 5% level of significance, and different from the 170 and 250 Krad doses at the 1% level of significance.

TABLE 12. Tenderness,[1,2] kg/100 g product, of irradiated, processed navy beans[3] (cold-water soak), measured after 7 days storage, 2 experiments designated here as a and b respectively.

	Dose, Krad							
	0		42		170		250	
	Experiments							
	a	b	a	b	a	b	a	b
	68.0	67.8	64.0	60.3	50.0	55.9	58.0	51.9
	69.5	65.1	63.5	59.1	53.0	56.7	60.0	56.8
	63.0	58.6	57.0	50.5	56.5	55.4	57.0	52.0
	61.5	56.0	59.5	52.0	57.0	54.8	56.0	55.0
	62.0	55.9	58.0	55.9	58.0	52.0	52.5	54.0
	57.5	57.0	56.0	53.3	60.0	54.8	55.0	54.2
Mean	63.6	60.1	59.7	55.2	55.7	54.9	56.4	54.0
Overall Mean	61.8		57.4		55.3		55.2	

[1]Three cans at each dose, 2 100-g samples/can.
[2]See Appendix E for analysis of variance.
[3]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.

The difference between cans for the experimental results shown in Table 12 was only to the 5% level, instead of the 1% as with the Table 10 results. Thus, it appears that the method of filling the cans with hot sauce all at once may have reduced the variance between cans; however, the error variance was 7 to 8 times as large as before. Can 1 was again the significantly different one, which agrees with the results from Table 10. A difference again appeared between the 2 experiments shown in Table 12, but this time it was significant only to the 5% level.

Table 13 shows the results from drained weights taken from each of the cans of beans used in these last 2 experiments. The results for doses were significantly different, which agrees with the other experiments discussed previously. At the 5% level of significance, the 0 and 42 Krad samples were different from the 170 and 250 Krad samples. At 1% level of significance, the 0 Krad samples were significantly different only from the 170 Krad samples, and the 42 Krad samples different from 170 and 250 Krad samples. This revised technique, of filling the cans all at once with hot sauce, minimized the differences in drained weights between replicate cans. However, significant differences were obtained between duplicate experiments, which has not occurred before, (Table 11).

Table 13 also shows that the fill volume of beans in the cans did not vary consistently in one direction

TABLE 13. Pack characteristics of irradiated, processed navy beans.[1] (Cold-water soak, 211x400 cans, measured after 7 days storage, 2 experiments designated here as a and b respectively).

	Dose, Krad							
	0		42		170		250	
	Experiments							
Characteristic	a	b	a	b	a	b	a	b
Drained weight, g/can[2]	229.5	234.5	231.0	238.0	232.0	231.5	227.5	238.0
	238.0	241.5	235.0	242.5	227.5	231.5	227.0	240.0
	238.0	243.5	237.0	247.0	226.0	237.0	229.0	232.0
Mean	235.2	239.8	234.3	242.5	228.5	233.3	227.8	236.7
Fill volume, %[3]	89	87	90	88	90	87	89	87
Moisture, %								
after soaking	55.2	55.8	55.2	55.4	55.8	55.9	56.1	56.0
after storage[3]	68.2	69.2	68.1	69.3	67.7	68.5	67.9	68.9

[1]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.
[2]See Appendix E for analysis of variance.
[3]Average of 3 cans.

or the other. This was seen to be the case with the measurements of percent moisture after processing and storage too, which indicated that the water uptake of beans during storage was not greatly affected by the irradiation doses. The percent moisture of the beans after soaking increased only slightly with irradiation doses of 170 and 250 Krads. General appearance of the beans after processing and storage was similar to that of the last duplicate experiments at these same 4 irradiation doses. The beans were cracked but were not matted, except to a slight degree with the 0 and 42 Krad doses in the first of the 2 experiments.

To investigate further the effects of covering the canned beans with hot, sweetened sauce at different times, the following experiment was performed in duplicate. The beans in 2 cans were covered with sweetened sauce at 200°F, but at about 35 minutes apart. This length of time was approximately how long the first can of beans, in the previously discussed experiments described in Tables 6 through 11, stood until the last can of each experiment was filled. They are designated here as cans 1 and 3. The beans in can 2 were covered with sweetened sauce at 36°F to find out what the contrasting effect on the beans was when unheated sauce was used. Table 14 shows the results of this experiment after the canned beans were processed and stored 7 days. In comparing the results between the beans in cans 1 and 3, it can be seen that can 3 was slightly more tender, had a higher drained weight, fill volume, and moisture content after processing and storage. These results for tenderness and drained weights agree with the other cans 1 and 3 mentioned in the previous experiments. This tends to add further evidence that filling the cans of beans with hot sweetened sauce at different times may add to the variability among cans.

TABLE 14. Tenderness[1], kg/100 g product, and pack characteristics of unirradiated, processed navy beans.[2] (Cold-water soak, 211x400 cans, measured after 7 days storage, duplicate experiments).

	Experiments 1			Experiments 2		
	Cans 1	2	3	1	2	3
Tenderness	64.5 61.0	54.5 58.0	60.0 61.5	66.0 64.7	53.7 53.3	55.2 ----[3]
Characteristic						
Drained weight, g/can	234.0	249.0	237.0	231.0	257.0	247.0
Fill volume, %	83	87	90	87	90	90
Moisture, % after soaking	55.2	55.2	55.2	55.6	55.6	55.6
after storage	68.0	69.9	68.4	67.9	71.1	70.0

[1]Two 100-g samples/can.

[2]The beans in cans 1 and 3 were covered with sweetened sauce at 200°F, with can 1 being covered first and can 3 covered about 35 minutes later. Can 2 was covered with sweetened sauce at 36°F at the same time as can 1.

[3]Loss of duplicate sample.

The results from Table 14 also show that can 2 is the most tender, has the highest drained weight and percent moisture after processing and storage. In addition, the percent fill of beans in can 2 is similar to can 3. These results point out that the hot sauce covering the beans may cause toughening and decreased liquid absorption of the canned, processed beans, despite the fact that these beans received a somewhat more severe heat process.

b. Hot-water soak for 1 hour, and a 30-minute processing time at 245°F.

Table 15 shows the tenderness measurements of canned navy beans previously soaked in hot, artificially hardened water ($CaSO_4$) for 1 hour, and heat processed 30 minutes at 245°F. The tenderness of the beans decreased or became tougher as the irradiation dose increased. This is just the opposite effect to that shown by the previously discussed cold-water soaked beans. Although the beans became less tender as the irradiation dose increased, they were still approximately 10 to 25% more tender than the cold-water soaked beans. When the mean tenderness values were statistically analyzed, it was found that the values for 0 and 42 Krad were significantly different at the 5% level from the 170 and 250 Krad values. At 1% level of significance, only the 0 Krad value was significantly different from the 170 and 250 Krad values, and the 42 Krad value was only significantly different from the 250

TABLE 15. Tenderness,[1,2] kg/100 g product, of irradiated, processed navy beans[3] (hot-water soak), measured after 7 days storage, 2 experiments designated here as a and b respectively.

	Dose, Krad							
	0		42		170		250	
	Experiments							
	a	b	a	b	a	b	a	b
	43.5	44.3	48.5	46.0	47.0	48.0	48.0	50.4
	47.5	42.3	46.5	45.1	47.0	48.0	50.0	50.0
	45.5	44.5	50.0	45.9	51.5	48.5	47.5	50.1
	47.5	45.0	48.0	43.9	48.5	50.0	46.5	47.0
	42.5	44.1	47.5	45.1	46.0	47.0	50.0	49.0
	46.5	44.3	44.0	43.0	46.0	48.0	50.0	49.3
Mean	45.5	44.1	47.4	44.8	47.7	48.2	48.7	49.3
Overall Mean	44.8		46.1		47.9		49.0	

[1]Three cans at each dose, 2 100-g samples/can.
[2]See Appendix F for analysis of variance.
[3]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.

Krad value. Another contrasting result different from most of the cold-water soaked beans was that neither the cans nor the 2 experiments were significantly different.

Table 16 shows the drained weight results from the hot-water soaked beans. As the irradiation dose increased, the drained weight values from canned beans decreased. This trend was similar to that from the cold-water soaked beans, but the individual drained weight values were approximately 10 to 18% higher than those from the cold-water soaked beans with the same irradiation doses. Statistical analysis of the differences between the mean values for each dose, showed that the drained weights from 0 to 42 Krad doses were significantly higher than those from 170 and 250 Krad doses at the 1% level of significance. There was also a significant difference between the duplicate hot-water soaking experiments. In contrast with the tenderness results of this experiment, and with the cold-water experiment, there was a significant difference between the drained weights for cans. The mean values for can 1 was significantly different from those of cans 2 and 3.

Table 16 also shows that the percent fill remained constant, and approximately 10% greater than those values from the cold-water soaked beans. The percent moisture after soaking was approximately 5% less than the values from the cold-water soaked beans. This means that these hot-water soaked beans had more solids per can than those

TABLE 16. Pack characteristics of irradiated, processed navy beans.[1] (Hot-water soak, 211x400 cans, measured after 7 days storage, 2 experiments designated here as a and b respectively).

	Dose, Krad							
	0		42		170		250	
	Experiments							
Characteristic	a	b	a	b	a	b	a	b
Drained weight, g/can[2]	288.5	285.0	282.0	282.0	271.0	267.0	262.0	261.0
	291.0	277.0	286.0	283.0	281.0	271.0	277.0	266.0
	293.0	288.5	289.0	284.5	283.0	273.0	271.0	270.0
Mean	290.8	283.5	285.7	283.2	278.3	270.3	270.0	265.7
Fill volume, %[3]	100	100	100	100	100	100	100	100
Moisture, % after soaking	49.7	49.3	48.8	49.8	50.2	50.2	50.4	50.6
after storage[3]	71.1	70.1	70.7	70.4	70.1	69.2	69.3	68.9

[1]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.

[2]See Appendix F for analysis of variance.

[3]Average of 3 cans.

cans with cold-water soaked beans. For all the experiments compared, each can initially contained 167 g of soaked beans prior to processing. This greater quantity of solids in the hot-water soaked beans may have contributed to the increased drained weights, and percent fill of beans in the cans compared to the cold-water soaked beans. The percent moisture after processing and storage was very similar to the cold-water soaked beans. This explanation, however, can only be part of the answer for the increased drained weights and fill volume for the hot-water soaked beans. This 5% less moisture after soaking, or increase in solids, was only half to one-third the drained weight increase of the hot-water over the cold-water soaked beans.

The general appearance of these hot-water soaked beans after processing and storage was similar to the cold-water soaked samples. The beans were cracked but not matted. However, the 0 and 42 Krad samples had tight packs, and no noticeable head-space in the can.

c. Temperature of canned beans at 15 minute intervals after being covered initially with 200°F sweetened sauce.

The following experiment was performed to determine the differences in temperature of the canned beans, after sitting for various periods of time in hot sweetened sauce. Two soaking methods were used, the hot-water soak and the cold-water soak as described in the methods and materials section. After soaking the navy beans, 3 167-g samples from each soaking method were placed into 211 x 400 size cans, with 200°F sweetened sauce covering them and filling the cans. The cans were sealed at atmospheric pressure, and a thermometer, inserted through a small hole in the center of the top of each can, located in the center of the can. The temperature was recorded for each can at 3 15-minute intervals, as shown in Table 17.

TABLE 17. Temperature, °F, of unirradiated navy beans, at 15 minute intervals after being covered with 200°F sweetened sauce,[1] (beans were previously soaked).

	Soaking Method							
	Cold water				Hot water			
Time minutes	0	15	30	45	0	15	30	45
	130	118	112	108	156	140	130	123
	132	121	115	110	151	136	126	119
	130	119	112	108	154	140	130	124
Mean	131	119	113	109	154	139	129	122

[1]Three 211x400 cans/soaking method.

The time interval of 0 to 30 minutes was used here, because it represents the maximum range of time between successively filling the first can and the last can of beans with the hot, sweetened sauce. By the time the cans were actually beginning the processing in the retort, 45 minutes had passed since filling can 1. This method of filling the cans of beans with hot, sweetened sauce was used in the experiments, the results of which are given in Tables 5 through 11. As seen from Table 17, after 45 minutes the hot-water soaked beans are only 13°F higher than the cold-water soaked ones. After 15 minutes, however, the difference in temperature between the 2 differently soaked bean samples was 20°F. Thus, the hot-water soaked beans went into the retort for processing at a higher temperature and received an effectively longer cook time than did the cold-water soaked beans. This may possibly account for the reason why the hot-water soaked beans are more tender than the cold-water soaked beans after processing and storage.

d. Hot-water soak for 1 hour, and variable processing times at 245°F.

Table 18 shows the tenderness measurements of unirradiated, navy beans that were given a hot-water soak for 1 hour, processed at various times at 245°F, and stored 14 days at about 72°F. As the process (cook) time increased, so did the tnederness (see Figure 10). The mean tenderness values were all significantly different from each other at the 1% level of significance, except for the 30 and 35 minute cooks. No significant difference was found among cans.

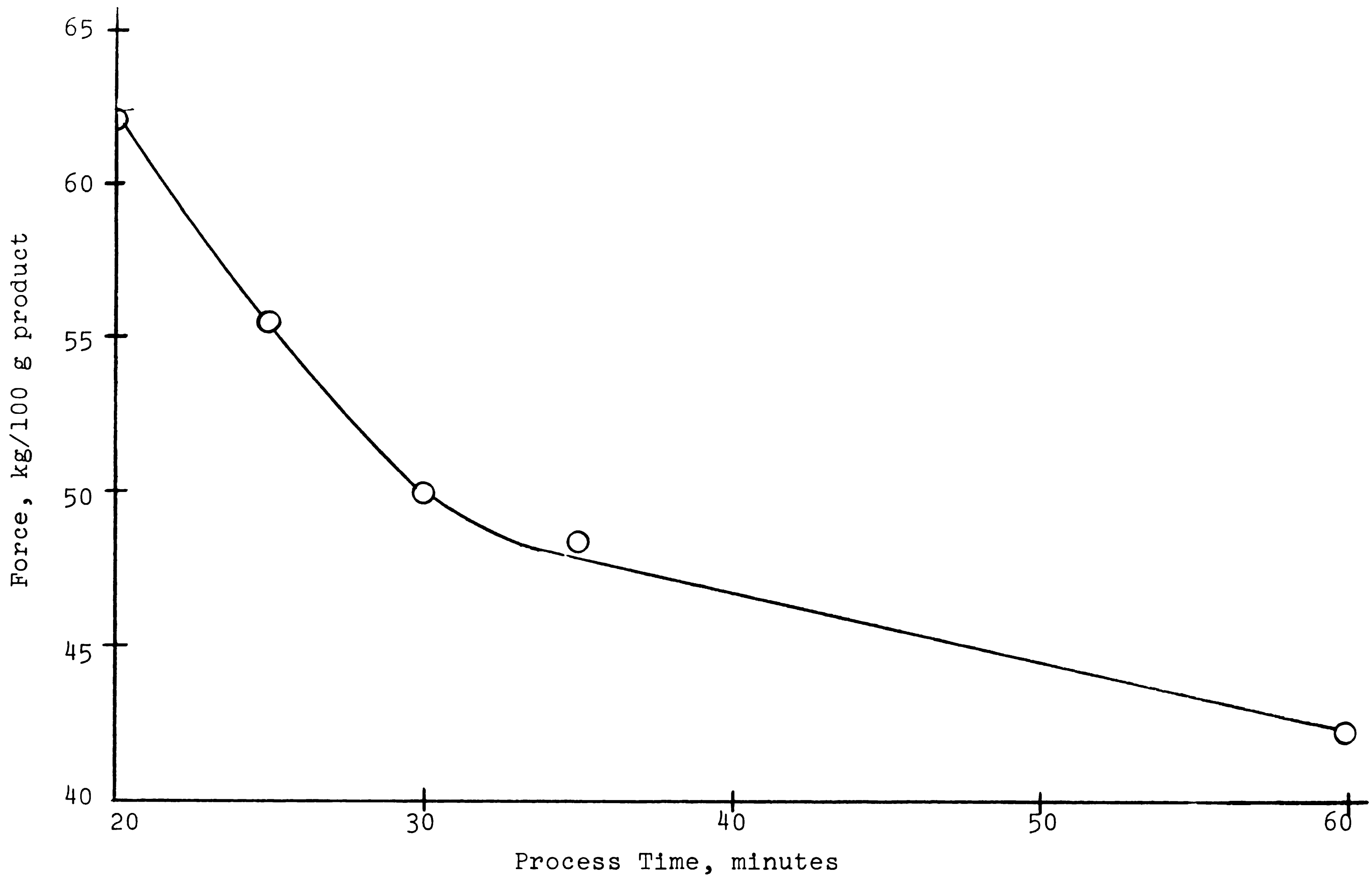

Figure 10. Tenderness of unirradiated dry navy beans as a function of process time at 245°F. (Hot-water soak, and stored 14 days).

TABLE 18. Tenderness[1], kg/100 g product, of unirradiated navy beans, (hot-water soak), processed at different times at 245°F[2], measured after 14 days storage.

	Process Times, Minutes				
	20	25	30	35	60
	63.0	56.0	53.0	48.0	40.5
	65.0	56.0	48.5	47.5	43.0
	58.5	58.0	48.5	49.0	42.5
	62.5	53.0	50.0	49.5	43.0
Mean	62.2	55.7	50.0	48.5	42.2

[1]Two cans at each process time, 2 100-g samples/can.
[2]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.

Table 19 shows the drained weight values of the cans of beans for each of the 5 different process times The drained weights increased as the process (cook) time increased from 20 to 35 minutes, but then dropped at the 60 minute process time. This trend was also seen in the present moisture after processing and storage. Although a difference appeared between the drained weight values for each process time, this difference was not significant. However, the drained weight values for the 60 minute process time were suspiciously different. Table 19 also shows that the percent fill did not reach 100% until the 30 minute process time. The percent moisture after soaking was about equal for all the samples, which was expected here since this represents the amount of moisture uptake prior to the different process times. Since the drained weight results were not significantly different, it was somewhat difficult to make conclusions about the optimum process time to recommend. However, it appears from the data in Tables 18 and 19 that the 30 minute process time, recommended by the National Canners Association (1966), would be the minimum.

TABLE 19. Pack characteristics of unirradiated, navy beans. (Hot-water soak, 211x400 cans, processed at different times at 245°F[1], measured after 14 days storage.)

Characteristic	Process Times, Minutes 20	25	30	35	60
Drained weight, g/can	254.0	268.0	269.0	273.0	292.0
	262.0	265.0	273.0	275.0	189.0
Mean	258.0	266.5	271.0	274.0	240.5
Fill volume, %[2]	90	90	100	100	100
Moisture, % after soaking	49.8	49.9	50.0	50.0	49.6
after storage[2]	68.8	69.9	70.5	70.8	66.5

[1]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.
[2]Average of 2 cans.

The tenderness values from Table 20 agree with the other hot-water soaked bean values mentioned previously, and with the 25 and 30 minute processed samples of Table 18. The unirradiated, and 30-minute processed samples were more tender than the irradiated, and 25-minute processed samples. These differences in tenderness were significant at the 1% level of significance. In addition, the differences in tenderness values between cans were not significant.

TABLE 20. Tenderness[1], kg/100 g product, of irradiated navy beans, (hot-water soak), processed at different times at 245°F[2], measured after 7 days storage.

	Process Times, Minutes			
	25		30	
Dose, Krad	0	170	0	170
	54.2	59.4	53.0	62.7
	57.7	57.6	50.6	53.5
	52.7	59.9	50.2	54.0
	50.2	59.0	47.3	57.6
	57.1	60.0	50.9	57.8
	55.3	63.8	53.3	55.4
Mean	54.5	59.9	50.9	56.9

[1]Three cans at each dose, for each of the 2 process times, 2 100-g samples/can.
[2]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.

The values in Table 21 show trends similar to the results found in Tables 16 and 19. For example, the values for drained weights and percent moistures after processing and storage were the lowest for the irradiated samples, and for the shortest processing time samples. Also, the values for percent moisture after soaking, but prior to processing and storage, were slightly higher for the irradiated samples. Statistical analysis of the drained weight values showed the unirradiated samples to be significantly higher than the irradiated samples; the can 3 mean value was significantly higher than that for can 1; and there was no significant difference between the values for the 2 process times.

TABLE 21. Pack characteristics of irradiated, navy beans. (Hot-water soak, 211x400 cans, processed at different times at 245°F[1], measured after 7 days storage).

	Process Times, Minutes			
	25		30	
Characteristic	Dose, Krad 0	170	Dose, Krad 0	170
Drained weight, g/can	279.5	260.5	283.0	262.0
	280.0	269.0	284.0	271.0
	285.0	273.5	285.0	275.0
Mean	281.5	267.7	284.0	269.3
Fill volume, %[2]	100	100	100	100
Moisture, % after soaking	50.1	50.6	50.0	50.5
after storage[2]	70.4	69.2	70.6	69.3

[1]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.
[2]Average of 3 cans.

e. Cold-water soak for 1 hour, and a 30 minute processing time at 245°F.

To determine whether or not irradiation could be used to shorten the cold-water soak time required to help tenderize navy beans, the following experiment was performed. Two 300-g samples of 1968-crop dry navy beans were irradiated at 0 and 170 Krad. The 170 Krad dose was used because the results from Table 12 showed this to yield the tenderest beans. The 2 bean samples were then soaked in artificially hardened water ($CaSO_4$) for 1 hour, instead of 16. After soaking, the beans were canned, processed 30 minutes at 245°F and stored for 30 days at approximately 72°F. Table 22 shows the tenderness results for these beans. Although the irradiated samples were a little more tender than the unirradiated samples, the difference was not significant. When comparing the mean values with those from Table 12, the 0 and 170 Krad samples are 15 and 20% less tender than the 16-hour cold-water soaked samples. Statistical analysis also showed that the values for cans were not significantly different either, in contrast with the corresponding results from 16-hour cold-water soaking.

TABLE 22. Tenderness[1], kg/100 g product, of irradiated and unirradiated navy beans, cold-water soaked 1 hour (processed 30 min at 245°F)[2], measured after 30 days storage.

	Dose, Krad	
	0	170
	77.2	70.6
	73.9	72.1
	69.0	63.0
	73.1	65.7
	74.4	75.1
	71.2	66.2
Mean	73.1	68.8

[1]Three cans at each dose, 2 100-g samples/can.
[2]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.

Table 23 shows the rest of the results from this experiment on 1 hour cold-water soaking. The drained weights were less for the irradiated samples, but the difference was not significant. The statistical analysis also showed that the drained weight values between cans were not significantly different. Table 23 shows the percent fill and percent moisture after processing and storage to also be less for the irradiated samples. However, the percent moisture after soaking was greater for the irradiated samples. The trends for these above-mentioned factors were similar to those of the 16-hour cold-water soaked beans, but the individual values were less.

The general appearance of these beans soaked for 1 hour, showed them to be cracked with no matting, but the sauce was watery. It appears that the 1-hour cold-water soak method does not produce canned, navy beans with characteristics as desirable as with the 16-hour cold-water soak.

TABLE 23. Pack characteristics of irradiated and unirradiated navy beans. (Cold-water soaked 1 hr, 211x400 cans, processed 30 min at 245°F[1], measured after 30 days storage.)

Characteristic	Dose, Krad 0	Dose, Krad 170
Drained weight, g/can	220.0	214.0
	228.0	229.0
	238.0	226.0
Mean	228.7	223.2
Fill volume, %[2]	85	80
Moisture, % after soaking	46.6	47.1
after storage[2]	67.3	66.8

[1]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.
[2]Average of 3 cans.

f. Cold-water soak for 16 hours of "Hard Beans," and a 30 minute processing time at 245°F.

Table 24 shows the results of an experiment to soften "hard" navy beans by use of irradiation, 16-hours, cold-water soaking, and processing for 30 minutes at 245°F. The "hard" bean samples were received in cans from the Waters Trading Company, N Richmond, Victoria, Australia with a letter dated December 22, 1966. The beans were originally Michigan navy beans. A moisture determination was made on these beans just prior to processing which showed them to contain 12.00% moisture. After processing, the canned beans were stored at approximately 72°F for 7 days prior to examination. The beans irradiated at 170 Krad were slightly more tender than the unirradiated product, however, this difference was not significant. When these tenderness values were compared with others in which 1968-crop navy beans were irradiated and processed, they showed a considerable difference. The "hard" beans were twice as tough as the 1968-crop beans and apparently irradiation had little softening effect. The only tenderness values that were significantly different for these "hard" beans were the ones between cans. Can 1 was significantly less tender, at the 1% level of significance, than cans 2 and 3.

Table 25 includes the drained weight results of the canned "hard" beans. The irradiated samples had a lower drained weight than the unirradiated samples. However, these differences were not significant. Also, there was no significant difference between the drained weight values for cans. The "hard" bean values for drained weight, fill volume, moisture content after soaking, and after processing

TABLE 24. Tenderness[1], kg/100 g product, of irradiated and unirradiated, "hard" navy beans, cold-water soaked 16 hrs (processed 30 min at 245°F),[2] measured after 7 days storage.

	Dose, Krad	
	0	170
	136.0	123.5
	125.0	125.5
	115.0	102.5
	100.5	108.0
	103.0	104.5
	103.5	101.0
Mean	113.8	110.8

[1]Three cans at each dose, 2 100-g samples/can.
[2]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.

TABLE 25. Pack characteristics of irradiated and unirradiated, "hard" navy beans. (Cold-water soaked 16 hrs, 211x400 cans, processed 30 min at 245°F[1], measured after 7 days storage.)

	Dose, Krad	
Characteristic	0	170
Drained weight, g/can	213.5	211.5
	225.0	215.0
	222.0	218.0
Mean	220.2	214.8
Fill volume, %[2]	83	83
Moisture, %		
after soaking	52.8	52.6
after storage[2]	64.2	63.1

[1]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.
[2]Average of 3 cans.

and storage were all lower than those values for the 1968-crop beans (Table 13).

Sensory Evaluation

a. Flavor difference between irradiated and unirradiated, processed navy beans, as evaluated by a sensory panel.

An untrained sensory panel, 15 members of the Food Science Department of Michigan State University, was used to determine if navy beans irradiated at 340 Krad had a different flavor from the unirradiated navy beans. The dose of 340 Krad was used because at this dose level the beans had the same tenderness value as unirradiated beans (Table 8). The purpose here was to eliminate the effect of tenderness differences which might influence evaluation of flavor differences. After irradiating the dry bean samples, both the irradiated and unirradiated samples were given the 16-hour cold-water soak, canned, processed at 245^{o}F for 30 minutes, then stored 10 days at about 72^{o}F. Just prior to serving the beans to the sensory panel, the beans were heated. A triangle difference test was used and was given twice in succession to the same sensory panel.

The results from the first triangle test showed that 9 out of the 15 panel members correctly identified the different sample, while in the second test, only 8 members correctly identified the different sample. Kramer's tables, listed by Amerine, Pangborn, and Roessler (1965), was used to determine the totals required for significance for triangle tests for a normal distribution.

According to the Kramer tables, 9 out of 15 judgments must be correct for significance at the 5% level. For 30 judgments, 17 need to be correct for significant differentiation at the 1% level. Thus, in the first test the sensory panel could significantly differentiate samples irradiated at 340 Krad, but could not for the second test. When considering both tests together, the results show that the sensory panel could differentiate between different samples to the 1% level of significance. When the total results were statistically evaluated by the chi-square distribution, the results also showed that the panel members could significantly differentiate the irradiated bean samples by flavor. These statistical analyses point out the fact that this sensory panel could differentiate the bean samples irradiated at 340 Krad, except for the second test when evaluated by itself. It also seemed that some of the people on the panel were more sensitive than others in detecting the differences, because 7 members correctly selected the different sample on both tests, while 5 members missed the correct sample on both tests. It appeared that 340 Krad may be near the threshold level for detection of irradiation differences in canned navy beans.

b. Tenderness differences between irradiated and unirradiated, processed navy beans, as evaluated by a sensory panel.

An untrained sensory panel of 16 members of the Food Science Department of Michigan State University was used to determine if irradiated navy beans were more tender than unirradiated navy beans. Doses of 42 and 170 Krad were used because the previous experiments showed them to give the tenderest processed beans. In addition, it is well below the 340 Krad dose that gave a different flavor to the beans, as determined in the previous flavor evaluation experiment. After irradiation, both the irradiated and unirradiated samples were given the 16-hour cold-water soak, canned, processed 30 minutes at 245°F, and stored 10 days at approximately 72°F. Just prior to serving the beans to the sensory panel, the beans were heated. Two ranking tests were given in succession to the same sensory panel, and the members were asked to rank the 3 samples according to tenderness only with the most tender sample given a rank of 1.

Table 26 gives the ranking totals for both tests. These results were first statistically analyzed by using the Kramer Ranking Tables listed by Amerine <u>et al</u>. (1965). For 16 replicates and 3 samples, the Kramer Table values for 5% level of significance are as follows:

25 = lowest insignificant rank sum, any treatment.

39 - highest insignificant rank sum, any treatment. Only in the second test did the 170 Krad samples exceed 39, thus indicating that the sensory panel judged this as the tenderest sample. Amerine et al. (1965) mentioned, however, that Kramer's method is not as accurate as the method where W, the coefficient of concordance is calculated. Thus, the ranking results for the 2 tests were reanalyzed using the coefficient of concordance. The data were arranged in an analysis of variance pattern, and the statistic W calculated. The W value was then tested for significance by use of the F-distribution. Results of this statistical analysis on the ranking totals for both tests show that the judges do not exhibit a noticeable degree of agreement in their ranking. Thus, it appears that this sensory panel does not significantly think the 170 Krad samples to be the tenderest.

TABLE 26. Ranking totals for tenderness of irradiated and unirradiated navy beans[1], for duplicate ranking tests by a 16-member sensory panel, (Tenderest = 1).

	Dose, Krad		
	0	42	170
Ranking Test 1	34	30	32
Ranking Test 2	26	30	40

[1]All samples were given the 16-hr cold-water soak, canned, processed for 30 min at 245°F, and stored 10 days prior to testing.

Table 27 gives the tenderness values, as measured on the Instron, of samples of the navy beans used in the ranking tests. These results show that the 42 and 170 Krad samples were significantly more tender than the unirradiated bean samples.

TABLE 27. Tenderness[1], kg/100 g product, of irradiated and unirradiated, navy beans, (cold-water soak, processed 30 min at 245°F, stored 10 days).[2,3]

	Dose, Krad		
	0	42	170
	68.1	60.6	64.9
	73.3	64.4	61.1
	60.8	60.0	57.2
	60.0	61.1	55.9
Mean	65.5	61.5	59.8

[1]Two cans at each dose, 2 100-g samples/can.
[2]All bean samples were covered with the hot, sweetened sauce at approximately the same time prior to processing.
[3]Samples are from the same batch as those used for the sensory panel, ranking tests for tenderness.

Chemical Analysis

a. Determination of protein loss from cold-water soaked navy beans.

Preliminary tests on the soak water, in which navy beans had been given a 16-hour cold-water soak, showed increases in the refractive index for the bean samples irradiated at 340 to 2700 Krad. Soak water from samples irradiated at 0, 42, 85, and 170 Krad showed no increases in refractive index. The refractive index was measured by an Abbw-56 Refractometer. Because of these results, a more sensitive measure of possible leaching losses during the soaking of beans irradiated at 170 Krad was deemed necessary. Since navy beans contain a high percentage of protein, (see Appendix D), a test for protein loss was made.

Six samples each of the following were taken: dry beans, beans given a 16-hour cold-water soak; and beans given an irradiation dose of 170 Krad plus a 16-hour cold-water soak. The 170 Krad dose and the 16-hour cold-water soak was used, because the previous experiments showed that navy beans treated in this manner yielded the tenderest beans with irradiation. All bean samples were dried to approximately 0% moisture by the method used for moisture determinations. Afterwards, a Kjeldahl nitrogen determination for crude protein was made on the dried, powdered bean samples. Table 28 lists the results of this protein determination. It can be seen from the above table that no significant quantity of protein was lost because of the cold-water soaking, not even after the bean samples were irradiated at 170 Krad.

TABLE 28. Protein, %/g product, of navy beans given different treatments (6 samples/treatment), determined by Kjeldahl nitrogen determination for crude protein.

	Treatments		
	Untreated	16-hr cold-water soak	Irradiated at 170 Krads, 16-hr cold-water soak
	25.75	26.00	25.56
	25.75	26.00	26.00
	25.75	25.56	25.56
	25.75	25.56	25.56
	26.19	25.94	26.19
	26.13	25.69	26.13
Mean	25.89	25.79	25.83

b. Determination of starch loss from cold-water soaked navy beans.

An analysis for the presence of starch in the soak-water, after giving navy beans the cold-water soak for 16 hours, was also made. Navy beans contain a large percentage of carbohydrate, in addition to protein, so it seems probable that starch may also be leached out into the soak water. To detect the presence of soluble starch in the soak water, the Blue Value Index method was used, as described by Palnitkar (1967), and Cording, Sullivan, and Eskew (1959).

Again, samples of navy beans were irradiated at 170 Krad to be tested. The 300-g bean samples were soaked in artificially hardened water ($CaSO_4$), for 16 hours at approximately 36^{o}F. Two irradiated samples and 2 unirradiated bean samples were soaked separately in 4 times their weight of the water. After the soaking period, the beans were disposed of, and the soak water tested. In addition to this, 3 prepared starch solutions were also tested. These solutions were prepared with soluble potato starch to the following approximate concentrations: 0.1, 0.2, and 0.5% by weight. The artificially prepared starch solutions were used to test the effectiveness of the iodine solution. Table 29 lists the absorbance readings recorded from the test solutions. As seen from the table, no soluble starch was detected in the soak water from either the 170 Krad irradiated or unirradiated navy beans.

TABLE 29. Absorbance readings from a Spectronic 20 Colorimeter of prepared starch solutions, and of soak water used to soak irradiated and unirradiated navy beans 16 hrs at 36°F (2 samples tested per solution).

Prepared starch solutions			Soak water from irradiated beans (Krads)			
0.1%	0.2%	0.5%	0	0	170	170
.0132	.0132	.0555	0	0	0	0
.0155	.0132	.0655	0	0	0	0

SUMMARY AND CONCLUSIONS

The overall objective of this research was to determine whether irradiation of raw, dry navy beans, prior to soaking and processing, would aid in producing a more tender product. Different radiation doses and soaking methods were examined in searching for the best procedure for radiation tenderization.

Using a 16-hour, cold-water (36°F) soak, irradiation doses up to 250 Krad increased the tenderness of the processed product about 10% over the unirradiated beans, with the maximum occurring in the range of 170 to 250 Krad. At doses from 340 to 2700 Krad the beans were less tender.

With a 1-hour, hot-water (180°F) soak, increasing the irradiation doses resulted in decreasing tenderness compared to unirradiated beans, and at 170 Krad the tenderness was reduced about 7%.

Hot-water soaked beans, whether irradiated or not, were more tender than cold-water soaked beans, averaging approximately 27% more tender (Figure 11).

Certain processing details seemed to be the source of variation, especially in the tenderness of the finished product, and particularly when the beans were given the

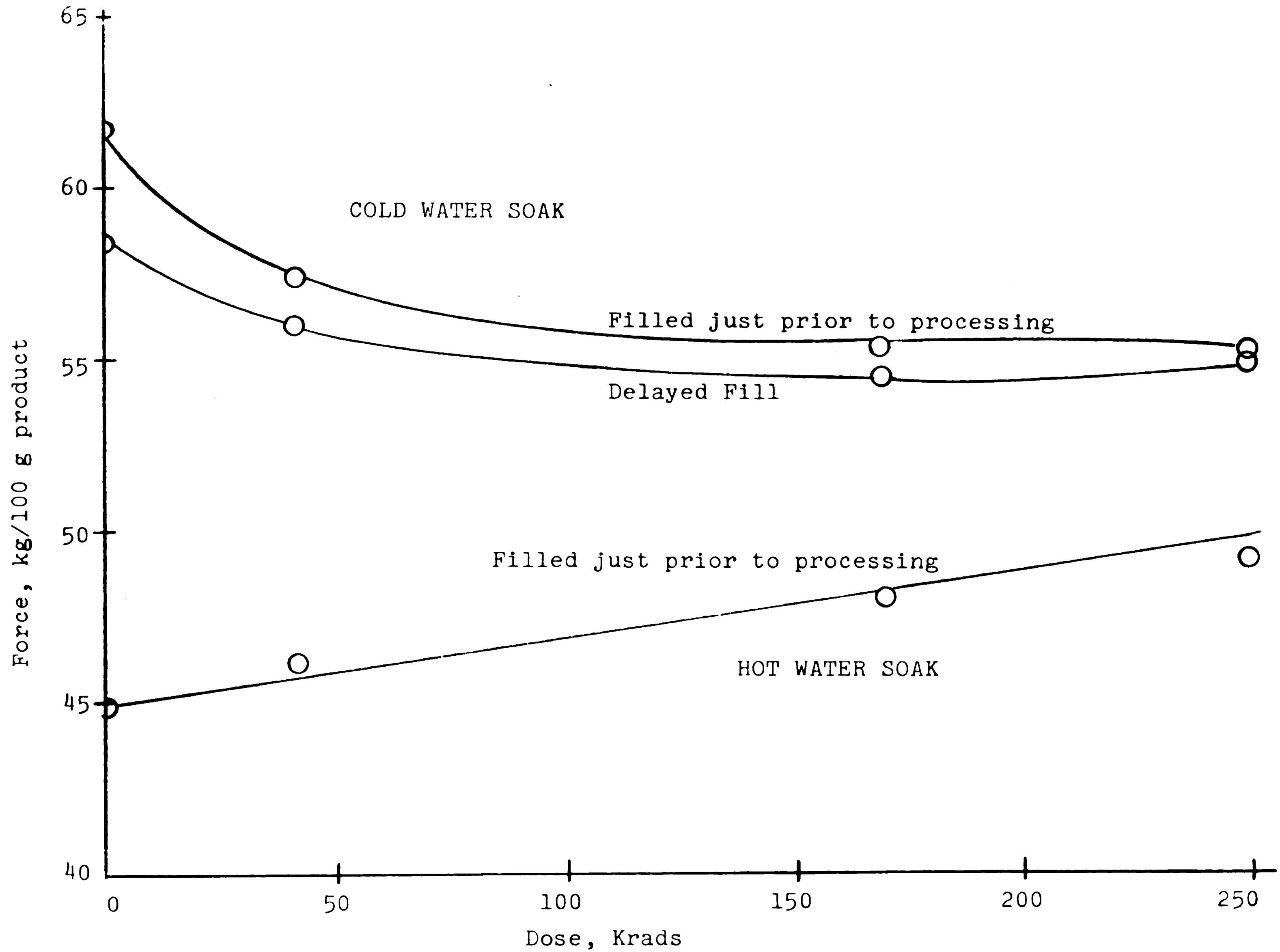

Figure 11. Tenderness of irradiated dry navy beans as a function of dose. (Cold-water soak or hot-water soak, processed at 245°F for 30 minutes, and stored 7 days).

cold-water soak. The most pronounced variation found in these experiments was that among the different cans of beans presumably treated alike. Actually, the term "cans of beans" is an incomplete description. In each of the experiments, the bean cans were filled with beans directly from the soaking containers. That is, the beans placed into can 1 always came from the top layer of the soaking container; can 2 was filled from the middle layer of beans; and can 3 was always filled from the bottom layer of beans in the soaking container. Thus, instead of the term "cans of beans," this perhaps should also be described as "layers of beans." Statistical analysis of the tenderness results of processed navy beans, previously given the cold-water soak, showed the "cans" (or "layers") to be significantly different; this result contradicts that of Bigelow and Fitzgerald (1918). However, there was no layer effect if the beans had previously been given the hot-water soak. The beans given the cold-water soak generally had the most tender samples from can 3 (the bottom soak layer); this tenderness decreased with cans 2 and 1 (the middle and top soak layers). A possible explanation for this phenomenon might be that the beans in the bottom soaking layers may be compressed so much that in trying to expand in size while absorbing water, some tissue breakdown may occur. Thus, these beans should be more tender than those from the top soaking layer, which is under very little compression.

Another possible cause of the variations found in the canned beans may be due to the length of time they sat covered with hot, sweetened sauce, or to the temperature of the canned beans just prior to processing. It was found that statistically, the differences among cans of beans (layers) similarly treated were larger when covered with the hot sauce and each can sealed in succession, than when all were covered at approximately the same time and the cans not sealed until all were filled. The time difference (successively filling and sealing) between the first can and the last can, in each experiment, was approximately 30 to 35 minutes. The temperature difference between these cans of beans (first to last) was 18°F on the average. The tenderness results between the beans from these cans varied from 2 to 6 kg per 100 g product. These differences between cans (layers) of beans also appeared in the drained weights. No significant differences among layers were found when the cold-water soaked beans were covered with hot sauce all at approximately the same time.

Canned navy beans were also changed by radiation and soaking method in other characteristics than those mentioned above. At the higher doses of irradiation (680-2700 Krad) the canned beans became less cracked in appearance, but had white particles of material in the sauce and adhering to the beans. After soaking, the beans previously exposed to higher doses of radiation had higher moisture content. Just the opposite effect occurred after processing and storage, and the fill volume in the cans also decreased with increasing irradiation dose. Thus, with these high doses, slack fills in the cans would be one of the several processing problems introduced.

The hot-water soaking method used also caused differences compared to the 16-hour cold-water soak. No significant difference was found for the tenderness values for cans or layers, or between experiments using the hot-water soak. This result could possibly be explained by the fact that the beans soaked only 1 hour instead of 16 hours in cold water. The lower layers of beans would be compressed for a much shorter time with hot-water soaking. However, hot-water soaking has a detrimental effect; the moisture content after soaking was about 11% less than the cold-water soaked samples. Thus, if the same fill-in weight was used per can, more bean solids would be used, making it more expensive. However, after processing and storage, the hot-water soaked beans had approximately 3% more moisture, 20% higher drained weight, and 11% greater can-fill by volume. The general appearance of these beans was similar to the cold-water soaked beans.

Other investigations on the beans canned in these experiments uncovered the following information. When a sensory panel was used to detect flavor and tenderness differences in irradiated navy beans, after cold-water soaking, processing and storage, the following was noted:

1. The panel could detect a flavor difference between unirradiated beans and those irradiated at 340 Krad (α = 5%).
2. The panel could not detect a tenderness difference between unirradiated beans and those irradiated at 42 and 170 Krad (α = 5%).

Investigation of possible losses of protein and starch from beans irradiated at 170 Krad, while soaking in cold water for 16 hours, showed that no losses occurred. In comparing the range of tenderness values from these experiments with that from the commercial brands tested, a large difference was noted. Although the different bean samples from each individual brand had similar tenderness values, the mean values between brands varied from 33.4 to 84.1 kg/100 g product. This was an even greater range of values than that obtained from the different soaking and irradiation dose experiments.

The overall conclusion from all these results, point out that canned navy beans, that were unirradiated, and given a 1-hour hot-water soak prior to processing, yielded a more desirable product than if irradiation and/or cold-water soaking was used. Further research on the effects of cold-water soaking is recommended, however, since this is an economical method of rehydrating and tenderizing navy beans.

Irradiation of dry beans in storage has been suggested for insect disinfestation. Larson and Fisher (1938) discuss the effects of insects (*Acanthoscelides obtectus, (Say*) and *Callosobruchus maculatus, (F)* on beans in storage. Baker, Taboada, and Wiant (1954) found success in controlling insect infestation of dry beans by using irradiation from a Van de Graaff electron accelerator. A dose of 42 Krad of gamma irradiation could possibly be used for this purpose without causing undesirable effects in the canned product. Results from these experiments showed no significant differences between the unirradiated processed navy beans and those irradiated at 42 Krad.

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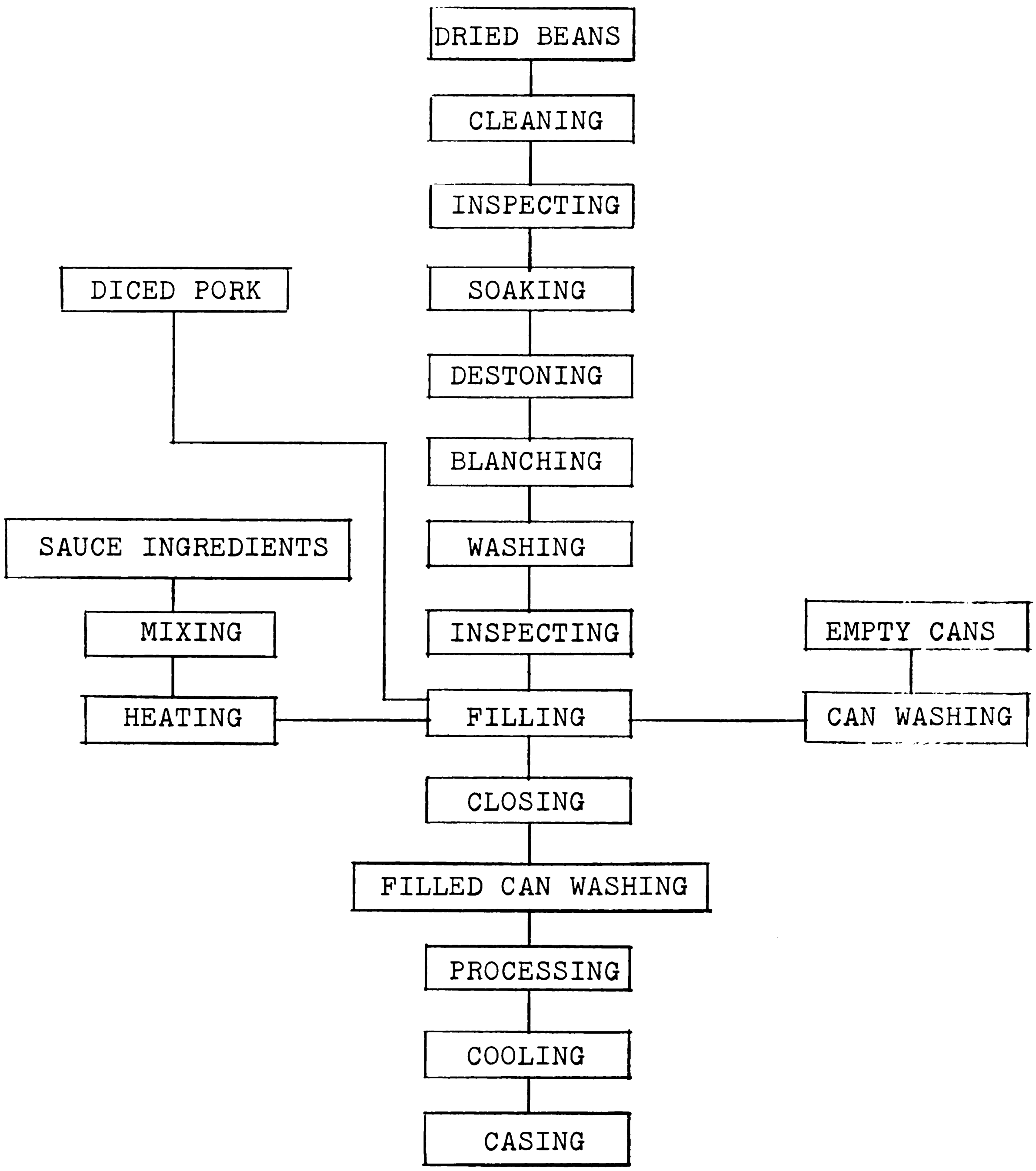
APPENDIX A

Flow diagram for the canning of pork and beans
(Continental Can Company, undated a, p. 14)



APPENDIX B

Suggested sauce formulas for canned pork and beans
(Continental Can Company, undated a, p. 3)

Tomato Sauce

Tomato Pulp (1.045 sp. g.)	12-15 gal.
Sugar, White	50 lbs.
Corn Syrup (Commercial)	20 lbs.
Salt	20 lbs.
Starch	7 lbs.
Onion Powder	4 ozs.
Garlic Powder	1 oz.
Pepper	3-1/2 oz.
Mustard	8 oz.
Paprica	1 lb.
Cinnamon	2/3 oz.
Cloves	2/3 oz.
Mace	1 oz.
Vinegar, 5%	2 qt.
Water, Quantity sufficient to make	100 gal.

Plain (Sweetened) Sauce

Sugar, White	30 lbs.
Sugar, Brown	25 lbs.
Corn Syrup (Commercial)	20 lbs.
Salt	20 lbs.
Starch	7 lbs.
Onion Powder	5 oz.
Garlic Powder	1 oz.
Pepper	3-1/2 oz.
Mustard	8 oz.
Water, Quantity sufficient to make	100 gal.

APPENDIX C

Processes suggested for dried beans in 3 ranges of sauce formulation
(National Canners Association, 1966)

Beans in Heavy Sauce, with or without pork, or baked beans

Can Name	Dimensions	Initial temperature*	Time at 240° F.	Time at 245° F.	Time at 250° F.
		Deg. F.	Min.	Min.	Min.
No. 1 (Picnic)	211 x 400	100	75	65	55
		140	70	60	50
		180	60	50	45
Kitchenette	307 x 214	100	80	70	65
		140	75	65	60
		180	65	55	50
No. 300	300 x 407	100	90	80	70
		140	80	70	65
		180	70	60	50
No. 303	303 x 406	100	95	85	75
		140	85	75	65
		180	75	65	55
No. 303 Cylinder	303 x 509)	100	100	90	80
No. 95	307 x [illegible])	140	90	80	70
	)	180	75	70	[illegible]
No. 2	307 x 409	100	105	95	[illegible]
		140	95	85	75
		180	80	70	[illegible]
Jumbo	307 x 510)	100	105	100	90
No. 2 Cylinder	307 x 5[illegible])	140	95	90	80
	)	180	80	75	65
No. $2\frac{1}{2}$	401 x 4[illegible]	100	130	115	[illegible]
		140	115	100	[illegible]
		180	95	85	[illegible]
No. 10	603 x 700	100	235	215	200
		140	210	190	175

Beans, with or without pork, in tomato sauce containing no added starch and 10 to 20 gallons of tomato pulp (1.045 sp. gr.) per 100 gallons sauce

Can Name	Dimensions	Initial temperature*	Time at 240° F.	Time at 245° F.	Time at 250° F.
No. $2\frac{1}{2}$ & smaller	401 x 411) & smaller)	100-140	65	45	35
No. 10	603 x 700	100-140	100	75	55

Beans, with or without pork, in tomato sauce containing no added starch and 10 gallons or less of tomato pulp (1.045 sp. gr.) per 100 gallons sauce

Can Name	Dimensions	Initial temperature*	Time at 240° F.	Time at 245° F.	Time at 250° F.
No. $2\frac{1}{2}$ & smaller	401 x 411) & smaller)	100-140	45	30	20
No. 10	603 x 700	100-140	70	55	40

*Initial temperature is the average temperature of can contents at the time the steam is turned on for the process.

APPENDIX D

Composition of raw, dry, white beans
(Watt and Merrill, 1963)

	1 pound	100 grams
Food energy, Cal	1542	340
Protein, g	101.2	22.3
Fat, g	7.3	1.6
Carbohydrate, g	278.1	61.3
Calcium, mg	653	144
Phosphorus, mg	1928	425
Iron, mg	35.4	7.8
Sodium, mg	86	19
Potassium, mg	5425	1196
Vitamin A, IU	0	0
Thiamine, mg	2.96	0.65
Riboflavin, mg	1.02	0.22
Niacin, mg	10.80	2.38
Ascorbic acid	---	---

APPENDIX E

Analysis of variance of tenderness values From Table 12.

Source	D.F.	Mean square	F[1]
Dose, D	3	114.6	6.5**
Experiments, E	1	94.9	5.4*
Cans, C	2	77.1	4.4*
Interactions:			
D X E	3	7.41	2.8
D X C	6	32.1	12.1**
E X C	2	6.78	2.6
D X E X C	6	11.5	4.3**
Error	24	2.65	---

[1]Interactions used to test main effects.

Analysis of variance of drained weight values from Table 13.

Source	D.F.	Mean square	F[1]
Dose, D	3	83.9	7.2**
Experiments, E	1	263.3	22.6**
Cans, C	2	25.8	2.2
Interactions:			
D X E	3	7.15	0.71
D X C	6	18.7	1.9
E X C	2	1.97	0.20
D X E X C (Error)	6	10.1	---

[1]Interactions used to test main effects.

APPENDIX F

Analysis of variance of tenderness values from Table 15.

Source	D.F.	Mean square	F[1]
Dose, D	3	42.0	11.1**
Experiments, E	1	5.81	1.5
Cans, C	2	4.86	1.3
Interactions:			
D X E	3	7.49	3.7*
D X C	6	5.06	2.5*
E X C	2	0.99	0.49
D X E X C	6	1.60	0.79
Error	24	2.02	---

[1]Interactions used to test main effects.

Analysis of variance of drained weight values from Table 16.

Source	D.F.	Mean square	F[1]
Dose, D	3 482.5	482.5	38.9**
Experiments, E	1	184.3	14.9**
Cans, C	2	91.3	7.4**
Interactions:			
D X E	3	9.98	2.1
D X C	6	16.1	3.3
E X C	2	27.6	5.7*
D X E X C (Error)	6	4.8	---

[1]Interactions used to test main effects.