Physical, chemical, and sensory characteristics of irradiated, prepackaged frankfurters with natural and synthetic antioxidants

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Physical, chemical, and sensory characteristics of irradiated, pre-packaged frankfurters with natural and synthetic antioxidants

by

William Joseph Fields

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
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This is to certify that the Master’s thesis of
William Joseph Fields
has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
# TABLE OF CONTENTS

## CHAPTER 1. GENERAL INTRODUCTION
Thesis Organization

## CHAPTER 2. REVIEW OF THE LITERATURE
I. Introduction
II. General Irradiation
III. Fresh Meat Irradiation
   A. Effects of Irradiation on Color
   B. Sensory Changes due to Irradiation
   C. Lipid Oxidation due to Irradiation
   D. Microbial Load and Shelf Life Effects
IV. Processed Meat Irradiation
   A. Color Changes due to Irradiation
   B. Sensory Changes due to Irradiation
   C. Lipid Oxidation in Processed Products
   D. Microbial Load and Shelf Life Effects
V. *Listeria monocytogenes*
VI. Antioxidants
   A. Synthetic Antioxidants
   B. Natural Antioxidants
VII. Summary
VIII. References

## CHAPTER 3. PHYSICAL, CHEMICAL, AND SENSORY CHARACTERISTICS OF IRRADIATED, PRE-PACKAGED FRANKFURTERS WITH NATURAL AND SYNTHETIC ANTIOXIDANTS
I. Abstract
II. Introduction
III. Materials and Methods
   A. Raw Materials
   B. Frankfurter Preparation
   C. Irradiation
   D. pH Analysis
   E. Chemical Analysis
   F. Texture Analysis
   G. Purge Loss
   H. Color Analysis
   I. Sensory Analysis
   J. Statistical Analysis
IV. Results and Discussion
V. Conclusions
VI. References 71

CHAPTER 4. GENERAL CONCLUSION 75

ACKNOWLEDGEMENTS 77
CHAPTER 1. GENERAL INTRODUCTION

In the past, problems with foodborne illnesses have often been associated with undercooked raw products. Irradiation has been shown to reduce pathogenic microorganisms and improve food safety in raw products. The destruction of pathogenic microorganisms can be achieved with low or medium dose irradiation. These levels of irradiation may cause changes in a product’s quality, depending upon the processing conditions. Research has been conducted to examine the effects of irradiation on the quality aspects of raw products.

Recently, problems have arisen with ready-to-eat, thermally processed products contaminated with *Listeria monocytogenes*. This is especially dangerous due to the consumption of these processed products without reheating or further cooking. Proper thermal processing will eliminate *L. monocytogenes*, but recontamination during packaging is a problem. *L. monocytogenes* has been shown to be susceptible to low and medium dose irradiation. The irradiation of processed products after packaging may be used to ensure a safer product once handling is completed. There are still many questions dealing with the quality aspects of irradiated processed meat products, such as product color, texture, and flavor.

Presently, the Food and Drug Administration does not allow the irradiation of processed meat products. This research investigates the effects of irradiation on the quality aspects of processed frankfurters. The quality aspects investigated included the physical, chemical and sensory characteristics of irradiated frankfurters. Therefore, the objective of this study was to determine the extent to which irradiation influences the quality of frankfurters. The second objective was to evaluate the efficiency of antioxidants in
minimizing irradiation's effects on the quality of frankfurters. If irradiation-induced changes (if present) can be reduced, then this technology can be realized to ensure a safer product.

**Thesis Organization**

This thesis is organized into four chapters. The first chapter is a general introduction to the irradiation of processed meat products. The second chapter is a general literature review of relevant topics pertaining to this research. The third chapter is a manuscript to be submitted to the *Journal of Meat Science*. The manuscript contains an abstract, introduction, materials and methods, results and discussion, conclusion and references. The fourth chapter is a general summary of this research.
CHAPTER 2. REVIEW OF THE LITERATURE

I. Introduction

One of the main questions facing the food industry today is food safety. The public has become more concerned with the safety of the food supply. McNutt et al. (1986) reported that food safety concerns of consumers averaged 9.6 (10 being very important). Consumer concerns with food safety has further increased due to the recent problems with foodborne illness and product recalls. Concerns for food safety are followed closely by concerns for technology used to increase food safety. Brewer et al. (1994) surveyed consumers' attitude towards food safety and the food industry. Univariate tests showed that as general levels of concern with food safety increased, so did concern for chemicals (food additives, preservatives, etc.), health issues (fat, cholesterol, etc.), and spoilage issues (shelf stability, microbial contamination, etc.). Irradiation can increase shelf life of a product, and decrease consumer concern with food safety.

Radiation is a physical phenomenon in which energy travels through space or matter (Radomyski et al., 1994). Irradiation, as used in food science, is the application of this energy to a specific material, such as a food product. The purpose of irradiation of food products is increasing storage stability through the reduction of microorganisms, elimination of parasites or insects and the blockage of enzyme activity (Andrews et al., 1998). For food irradiation, controlled amounts of ionizing energy are used to produce ions. The time of product exposure to the ionizing energy and the strength of the source determines the irradiation dose the product receives, which is measured in kiloGrays (kGy) (Institute of Food Science and Technology, 1998). The term gray (Gy) was developed by the
International System of Units and is described as the quantity of radiation energy absorbed by a material such as food (Andrews et al., 1998). One thousand gray equals one kiloGray (kGy). An older unit of measure still encountered in some literature is the rad. One Gray equals 100 rad and thus, 1 million rads equals 10,000 Gray, or 10 kiloGray (Olson, 1995).

Ionizing energy can have a variety of effects on microorganisms. The primary target of irradiation is the cellular DNA of an organism. Irradiation destroys microorganisms by breaking bonds on the DNA molecule, thereby rendering the cells unable to replicate (Murano, 1995). More specifically, DNA base damage, single-strand and double-strand DNA breaks, and cross-linking between bases are the main effects of irradiation (Olson, 1998). There are three sources of ionizing radiation, which include, gamma rays produced from $^{60}$Co or $^{137}$Cs, machine generated electron beams, and X-rays.

There are many distinct advantages to using irradiation in the food industry. The reduction of pathogenic microorganisms and destruction of spoilage organisms are two large benefits of irradiation. Irradiation pasteurization with low dose gamma rays, X-rays, and electrons will effectively control foodborne pathogens on beef, pork, lamb, and fish (Council for Agricultural Science and Technology, 1996). Research has shown that irradiation can be effective in reducing the levels of such microorganisms as *Campylobacter jejuni*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, various *Salmonella* sp. and *Staphylococcus aureus* (Thayer et al., 1992, Radomyski et al., 1994, Rocelle et al., 1994; Thayer, 1995).

Meat irradiation is by no means the only area in which irradiation is being used or researched. Doses up to 10 kGy are recommended for dried herbs and spices to reduce levels of contaminating microorganisms and to reduce viable food poisoning bacteria (IFST, 1998). Doses of 1-3 kGy have been recommended to improve the microbiological safety of
imported seafood, to reduce the number of spoilage micro-organisms in fruits and vegetables and to kill insects, as a quarantine measure, in cereals, grains and certain fruits (IFST, 1998). The IFST (1998) also recommends high-dose irradiation (doses of 45kGy) to produce sterile foods such as ready meals. It is advised that only frozen products receive sterilization doses to reduce the adverse effects, but frozen storage is not recommended.

Food irradiation cannot, nor is it intended to replace proper food sanitation, packaging, storage and preparation (Thayer, 1990). Although irradiation can effectively reduce or eliminate pathogens and spoilage organisms, it is not a replacement for good manufacturing practices (GMP’s). Irradiation cannot reverse spoiling processes. It can delay microbiological spoilage, but at doses applied in food irradiation will have almost no influence on the enzymatic processes (Leemhorst, 1990). When a product is substandard (where GMP’s are not applied), irradiation cannot be used to improve the quality aspects of a product (Leemhorst, 1990). While irradiation is not a “cure-all” for the food industry, it is commended as a safe and effective process to reduce the risk of foodborne illness and improve the shelf life of some food products.

II. General Irradiation

Irradiation is not a new technology, but has received attention in the last few years. Due to the recent problems with foodborne illnesses, irradiation has gained strength as a food safety tool. The first attempts at applying ionizing radiation to food processing were made at the end of the 19th century (Mörsel, 1998). Irradiation of food products did not see commercial applications until later in the 20th century. In the 1950’s, researchers began applying ionizing radiation to food applications. This processing technology was ready to be commercialized by the late 1950’s (Olson, 1998). Today, the Food and Drug Administration
(FDA) has approved irradiation for many types of food products. Irradiation is used to eliminate insects from wheat, potatoes, flour, spices, tea, fruits and vegetables. Irradiation can also be used to control sprouting and ripening of vegetables (Redlinger and Nelson, 1997). In 1985 and 1990, approval was given for the irradiation of pork, to control trichinosis, and for poultry, to control harmful bacteria, respectively. Furthermore, in 1997, the FDA approved the use of irradiation to control pathogens, such as \textit{E. coli} and \textit{Salmonella}, in fresh and frozen red meats (Redlinger and Nelson, 1997).

The FDA regulates all aspects of irradiation: product usage, dose levels, and product labeling (Redlinger and Nelson, 1997). In 1984, the World Health Organization (WHO) recommended general rules for the safe application of food irradiation:

- Food (raw material, as well as final products) should only be irradiated up to a maximum dose of 10 kGy
- Maximum radiant energy should be 10 MeV for electron beams and 15 kGy for isotope sources
- Multiple irradiation should not be permitted

In many countries, these recommendations became laws. In the United States, the FDA and the United States Department of Agriculture (USDA) have set the regulations differently for various products. For example, herbs and spices can be irradiated with a maximum dose of 30 kGy to control microorganisms. Refrigerated and frozen poultry is approved at doses between 1.5 kGy and 3.0 kGy to control pathogenic bacteria (Olson, 1998). Refrigerated and frozen red meats (beef, pork, and lamb) have been approved at maximum doses of 4.5 kGy and 7.0 kGy, respectively. Since the 1970’s, NASA has used irradiation to sterilize frozen
meat products for astronauts. The minimum dosage for sterilization of meat products is 44 kGy.

The FDA requires that irradiated products must carry the “radura” symbol. The “radura” symbol is an internationally recognized irradiation symbol that resembles a stylized flower. Irradiated foods sold at the wholesale level are required to bear either the phrase “Treated by irradiation, do not irradiate again” or “Treated with irradiation, do not irradiate again” (Olson, 1998).

Recent research has classified irradiation doses into three basic categories. High doses (>10 kGy) essentially sterilize foods; medium doses (1-10 kGy) exert pasteurization effect, extending shelf life; and low doses (<1 kGy) are effective in controlling parasites in fresh meat, delaying senescence in fresh fruits or sprouting in vegetables and destroying insects and pests in grains and fruits (Radomyski et al., 1994). Radomyski et al. (1994) also reported that medium dose levels are effective at either reducing microbial numbers or completely destroying them.

Andrews et al. (1998) classified irradiation doses into radurization, radicidation or radappertization. Radurization refer to treatment of foods with ionizing radiation sufficient to lengthen shelf life by reducing the initial number of spoilage organisms before or immediately after packaging. The radurization doses are usually considered low dose, being <2 kGy. Urbain (1986) reported a 6.0 x 10^7 reduction in the total plate count (per gram) of vacuum packaged beefsteaks, at 21 days when radurization product was stored at refrigerated temperatures. Radicidation is the irradiation treatment required to sufficiently reduce the level of non-spore-forming pathogens, including parasites, to an undetectable level. Thus, radicidation reduces the risk of foodborne illness to near zero. Radicidation levels are
considered part of the medium dose range and are between 2-5 kGy, which are often used in food products. Radappertization is the highest level of irradiation processing required to achieve sterility in food products. Sterility of food products allow for shelf stability at ambient temperatures and are generally considered high dose, being >10 kGy. It is generally accepted that as doses increase, more molecules are affected, and in this manner, a dose limit for an acceptable amount of change in a food may be reached (Urbain, 1986).

The dose that is absorbed during irradiation is not easily measured from irradiated products. For that reasons a radiation sensitive material called a dosimeter is irradiated along with the product. A dosimeter is then measured to determine what level of irradiation the product received. Hence, control of the irradiation process and compliance with dose regulations depends on having an accurate and reliable dosimeter system (Olson, 1995). There are two main types of dosimeters, radiochromic films or plates and alanine pellets. The radiochromic films or plates change color when irritated and the color change represents the dose absorbed (Olson, 1995). The color change is read using a spectrophotometer. The alanine pellets form free radicals when exposed to irradiation. The free radicals can then be read by using an electron spin resonance spectrometry, which indicates the amount of retained free radicals.

Many food processes attempt to eliminate or reduce the microbial load of a particular food product. A good measure of a process’s ability and efficiency to eliminate or reduce the microbial load is a D-value. In thermal processing, the D-value is the time required at a specific temperature to reduce the designated microbial population by 90%, or one log (Andrews et al., 1998). In irradiation, the D-value is used to estimate the dose required to destroy 90% of the microbial population, in a given medium. The D-value also provides a
convenient, quantitative measure of comparing different bacteria and provides an index of the radiation sensitivity of a bacterium (Urbain, 1986). Andrews et al. (1998) explained the D-value as the calculated linear portion of the bacterial semilog survival plots. By using linear regression analysis, the D-value = 1/slope of the regression curve.

D-values differ for microorganisms depending on the sensitivity levels and the organism’s ability to repair and recover from the effects of ionizing radiation. It is generally accepted that the simpler the life form, the more resistant to irradiation and the higher the D-value. Viruses are usually more resistant than spores of bacteria, which are more resistant than vegetative cells of bacteria, which are more resistant than yeast and molds (Murano, 1995). In fact, irradiation doses of between 0.2-0.5 kGy have been used to control insect infestation in wheat and wheat flour (Thayer, 1990).

The cellular response to irradiation is measured by the number of viable cells remaining after low or medium dose irradiation and complete destruction of all cells using high dose irradiation. The low dose irradiation or radurization can be referred to as sublethal due to the lack of total viable cell destruction. Sublethal doses can be due to the bacteria's ability to block or bind harmful free radicals. This ability is dependent upon the bacterium's general metabolism and may be related to its general vitality and pathogenicity (Andrews et al., 1998). It has been suggested that through enzymatic activity some bacteria are able to repair damage inflicted by low dose irradiation, thus surviving the irradiation process.

Andrews et al. (1998) reviewed the ability of bacterial cells to quickly rejoin breaks in DNA caused by gamma irradiation. The authors believed there were many more molecular processes that allow bacteria to use enzyme systems actively for repair and recovery in a toxic environment, such as that produced by irradiation.
Another important factor having an effect on the D-value of microorganisms is the environment during radiation exposure. One of the main factors affecting the products environment during irradiation is packaging. The atmosphere around the product during irradiation is directly dependent on the packaging and environment created during irradiation. Research has shown that in most cases, the presence of oxygen during irradiation will increase the sensitivity of microorganisms, such as *Salmonella* (Lee *et al.*, 1996; Zhao *et al.*, 1996; Andrews *et al.*, 1998). Zhao *et al.* (1996) packaged fresh pork chops in air, vacuum, 25% CO₂, 50% CO₂, or 75% CO₂ balanced with N₂, and irradiated at 1.0 kGy. The pork chops were inoculated with *salmonella* and in general, the *salmonella* were more irradiation resistant when irradiated in anaerobic conditions. However, the sensory scores of the aerobically packaged samples were significantly lower as the length of storage time increased. The air-permeable-packed samples also had the highest TBA values. This supports the theory that autoxidation is increased in the presence of O₂ during irradiation (Urbain, 1986). Vacuum conditions had a greater effect on lipid oxidation of irradiated fresh pork than CO₂ atmospheres packaging. However, the researchers concluded that this might be due to the degree of vacuum achieved.

Lee *et al.* (1996) concluded that the effects of irradiation on shelf life, safety and sensory qualities of fresh meat and poultry products varied with the species and type of packaging used. The researcher suggested that beef products required a lower dose rate (1.5 kGy vs. 1.0 kGy) to extend the shelf life and improve safety. In pork and poultry products, the conclusion was that the dose rate varied little in aerobically and anaerobically packaged products.
Lambert et al. (1992) irradiated fresh pork loins with oxygen and without oxygen in a modified atmosphere of N₂. The researchers concluded that a substantial extension in sensory shelf life was achieved using modified atmosphere packaging in conjunction with low-dose irradiation. It was determined that irradiation in the presence of oxygen had a detrimental effect on physical, chemical and sensory characteristics, resulting in a rejection of the product as storage time increased.

Patterson (1988) irradiated seven different bacterial species inoculated on sterile poultry products and under various atmospheres (air, CO₂, vacuum and nitrogen). The sensitivity of *Streptococcus faecalis* and *Staphylococcus aureus* was unaffected by atmosphere. The other microorganisms, (*Pseudomonas putida, Salmonella typhimurium, Escherichia coli, Moraxella phenylpyruvica* and a *Lactobacillus* sp.), were found to be more sensitive (lower D-values) when irradiated in atmospheres other than air. In general, a vacuum or CO₂ atmosphere during irradiation had the most lethal effect.

In all cases it was concluded that vacuum and modified atmosphere packaging resulted in better sensory qualities for irradiated fresh meat and poultry products. In some cases, the sensitivity levels of microorganisms were increased in a modified atmosphere. Other research showed that a modified atmosphere (whether vacuum or gas flushed) needs only a 0.5 kGy increase to achieve the same lethal effect as an aerobic atmosphere, and still retain a high quality product (Lee et al., 1996; Zhao et al., 1996; Lambert et al., 1992).

Many factors have a bearing on D-values; examples are temperature when irradiated, water activity, dose rate, and food component. Irradiation seems to be more effective at reducing pathogenic microorganisms at refrigerated temperatures than frozen temperatures (Radomyski et al., 1994; Rocelle et al., 1994; Thayer and Boyd, 1993; Thayer, 1995).
Research has proven that the temperature at the time of irradiation and the product’s storage temperatures are critical to microbiological survival and recovery. Rocelle et al. (1994) irradiated inoculated ground beef at temperature ranges of -15 to -17°C and +3 to +5°C. The authors found D-values of *E. coli* and *C. jejuni* were significantly higher at frozen temperatures than those at refrigerated temperatures. Thayer and Boyd (1993) irradiated ground beef and mechanically deboned chicken at fresh and frozen temperature between -20°C to +20°C. The D-value at -5°C was 0.44 kGy, versus 0.28 kGy at +5°C, representing a 57% increase in resistance. The increased resistance to irradiation in frozen products was contributed to the lack of water activity in these products. However, regardless of temperature during inactivation, most pathogens were highly sensitive to irradiation.

The lower the water activity of the product, the more resistant the microorganisms are to irradiation (Andrews et al., 1998). When water activity is low, as in dry foods, frozen foods or foods with high salt and sugar content, the indirect effects of radiolytic products are minimal and the irradiation resistance of bacteria is increased (Andrews et al., 1998). However, a lower water activity reduces the ability of cells to recover during storage (Radomyski et al., 1994). Low water content and temperature of the product at the time of irradiation have the same effect on free radicals. When water is not available (decreased temperature, especially below freezing), fewer radicals are formed and thus a higher dose is required to destroy cells (Murano, 1995).

The food component that is being irradiated will also affect the irradiation response of bacteria. The irradiation dose required is dependent on the type and the number of the spoilage organisms present, as well as on the type of food material to be irradiated (Proctor et al., 1952). The food component may be regarded as competing with the bacteria for
interaction with the active radiolytic products of water (Urbain, 1986). The degree of complexity of any food matrix is variable and the application of D-values for an irradiation process must be established for each combination of food product and bacterium of interest (Andrews et al., 1998). Research has shown that different food products require different dose rates (CAST, 1996; Lee et al., 1996; Andrews et al., 1998).

The dose rate is more likely to have an effect on bacterial sensitivity in low dose ranges than at higher doses (Andrews et al., 1998). The sensitivity of bacteria to irradiation dose decreases with lower dose rates and the specific bacterial repair ability (Andrews et al., 1998). This is due to the bacteria’s ability to repair some of the biomolecules that are damaged by the low dose irradiation. In complex food systems, dose rate is not likely to have a significant effect on the irradiation sensitivity of bacteria (Urbain, 1986). It is further explained that this is due to the radical interaction with food components that will predominate over a wide range of doses rates.

Other factors play important roles in the percentage of bacterial cells that will be killed by irradiation. The growth stage of the cells, the cell concentration prior to irradiation, and the pH of the product all need to be taken into account when preparing product for irradiation.

Irradiation has been proposed, and used for many different products and purposes. A few things irradiation has been proposed or used for are (1) insect disinfestation of grain; dried spices, vegetables, or fruits; and fresh fruits; (2) inhibition of sprouting in tubers and bulbs; (3) alteration of postharvest ripening and senescence of fruits; (4) inactivation of protozoa or helminthes in meats and fishes; (5) elimination of spoilage micro-organisms form fresh fruits and vegetables; (7) extension of shelf-life of meats, poultry, fish or shellfish; (8)
elimination of bacterial pathogens from meats, poultry, fish, or shellfish; and (9) sterilization
of foods and feeds (Thayer, 1990). The pharmaceutical industry has applied high dose
irradiation (10 to 60 kGy) to medical equipment to produce sterile pharmaceuticals (Bögl,
1985). Bögl (1985) reported that in over 90% of the solid substances irradiated, there was
either no decomposition or decomposition of only 2%.

Fruits and vegetables are being irradiated to eliminate insects and spoilage organisms,
to prevent over-ripening, and in the case of tubers and bulbs; to prevent sprouting (CAST,
1996). Since insects are a more complex organism and sensitive to irradiation, low dose
irradiation is sufficient for controlling infestation. The use of irradiation at a minimum dose
of 0.3 kGy and a maximum dose not exceeding 1 kGy has been approved by the FDA for
growth and maturation inhibition of fresh foods and for disinfestations of arthropod pests in
food (CAST, 1996).

Shelf-life extension is another benefit of irradiating fruits and vegetables. Irradiated
strawberries will last two to three weeks in refrigerated storage as compared to only a few
days for untreated berries (Redlinger, 1997). While it is agreed the shelf life of strawberries
can be extended, there has been quality problems associated with the irradiation of berries.
Irradiated strawberries were less firm than non-irradiated strawberries (Yu et al., 1995). The
researchers found that irradiated strawberries ranked lower on a sensory firmness test and
Instron results at days 0, 1, 2, and 4, than did non-irradiated berries. It appears there are two
limiting factors to the usefulness of irradiation in fruits and vegetable crops: quality
degradation and treatment cost (Andrews et al., 1998).

Irradiation has been approved for herbs, spices and dry vegetable seasonings, and is
used with regularity in the United States today. The FDA has approved irradiation doses not
to exceed 30 kGy for microbial decontamination and insect disinfestation in these products (CAST, 1996). Food irradiation can replace the use of ethylene oxide and methyl bromide as a sterilization technique in spices. Irradiation is less harmful to the spices, is more effective against bacteria than ethylene oxide and does not leave chemical residue on products (CAST, 1996).

III. Fresh Meat Irradiation

The irradiation of red meat and poultry products is of interest, due to the relatively short shelf life of fresh meat and the microbial contamination that may occur if improperly handled. Bacteria and microorganisms can be found at any location on and within an animal (i.e. skin, hair, digestive tract, etc.). Animal carcasses usually contain 1-3 log of bacterial cells per square inch of outside surface (Andrews et al., 1998). Furthermore, the bacterial loads on whole muscle cuts are similar to that of the carcasses, but ground product will be slightly higher at 4-5 log (Andrews et al., 1998). One microorganism that has been of recent concern is E. coli O157:H7, which has been associated with numerous food-borne illnesses and food recalls. E. coli O157:H7 is a problem in ground beef and chicken. Relatively low doses (<1.5 kGy) of irradiation can be used to achieve at least a 6 log reduction of E. coli O157:H7 (Thayer and Boyd, 1993; Rocelle et al., 1994; Olson, 1998). The D-values of E. coli O157:H7 ranged from .24 kGy to .42 kGy, depending on the study and the processing conditions during irradiation.

The use of irradiation to extend the shelf life of red meat and poultry and to increase food safety has been researched for years. Irradiation has been proven to be an effective tool in eliminating or reducing pathogenic microbial loads and producing a safer product. It is clear that irradiation offers a number of opportunities for improving the preservation and
safety of red meat and poultry, but must not have a negative effect on meat quality.

Precautions need to be taken during irradiation to control sensory changes to meat. Sensory characteristics include texture, color, firmness, softness, juiciness, chewiness, taste and odor, which are also closely related to possible changes in nutrient value (Thayer et al., 1993). Thayer et al. (1993) reported that these sensory changes cannot be too severe or the treated meat will have no economic value. The improvement of food safety is still very important, but insignificant if consumers dislike the product being produced.

A. Effects of Irradiation on Color

The perception of color plays a major role in consumers’ evaluation of meat quality. Often the consumer will use color as an indicator of flavor, juiciness, tenderness and freshness of the retail cut (Naumann et al., 1957; Calkins et al., 1986). It is important that any process the product is subjected to do not affect these qualities in a detrimental fashion. The principal pigment responsible for meat color is myoglobin, which can exist in several forms. The reduced form of myoglobin (deoxymyoglobin) is purplish in color, the oxygenated form (oxymyoglobin) is bright red in color, and the oxidized form (metmyoglobin) is brown in color. The relative proportion of these three forms of the pigment near the surface of the meat determines the overall color of the meat (Govindarajan and Hultin, 1977). Oxidation of myoglobin, causing meat to change to the brownish color, can be extremely detrimental to the consumer appeal of the product. Consumers prefer bright-red fresh meats, brown or gray-colored cooked meats and pink cured meats (Cornforth, 1994).

The objective measurement of color in meat products can be accomplished with different types of equipment, as long as the L* (lightness), a* (redness) and b* (yellowness)
values of the product is measured. Sensory panels can also be used to determine a subjective measurement of color in red meat and poultry products. Zhao *et al.* (1996) irradiated fresh pork loin chops in various packaging atmospheres to determine bacteriological, physicochemical, and sensory quality changes. The treatments were irradiated at a dose of 1.0 kGy and were monitored for 4 weeks. The researchers concluded that irradiated pork loins generally had higher (P<0.05) L* values than unirradiated pork. Furthermore, as the storage period increased, the L* values of irradiated samples remained more constant, whereas unirradiated samples decreased in lightness (L* values). Irradiation of pork packaged in air-permeable packages resulted in significantly (P<0.05) lower a* values, but irradiation of pork chops packed in vacuum or CO₂ (25%, 50%, and 75% CO₂) atmospheres showed no significant change (P<0.05). Also, the a* values of irradiated pork did not change during storage. As for the b* values, the researchers found a significant increase (P<0.05) in yellowness occurred with the irradiated pork in all atmospheres. The b* values were initially lower for irradiated samples, but increased during the first 2 weeks of storage and were higher than unirradiated pork. The sensory scores were somewhat contradictory of the color readings. In general, irradiated pork chops had significantly less (P<0.05) desirable color than unirradiated samples throughout storage time. The researchers concluded that the presence of O₂ during irradiation was a negative factor in this study.

Color was determined for boneless pork chops irradiated at 0, 1.5 and 2.5 kGy (Luchsinger *et al.*, 1996). The researchers found that there was no significant difference (P<0.05) in L* values due to irradiation. The difference in lightness was contributed to the packaging atmosphere. Vacuum packaged pork chops appeared redder (P<0.05), with greater a* values, as dose increased from 1.5 to 2.5 kGy at day 0 and from 0 to 2.5 kGy at
days 3, 7, and 14. No differences (P<0.05) were observed across display days for all vacuum-packaged pork chops. Irradiated chops had greater (P<0.05) $b^*$ values than controls at all display days, regardless of package type. The researchers concluded that irradiation of vacuum packaged boneless pork chops produced a redder, more color-stable product.

Lambert et al. (1992) irradiated fresh pork loins to determine the effects on physical, chemical, and sensory changes. Irradiation doses of 0, 0.5, and 1.0 kGy were used, along with different packaging, to determine changes in product quality. The results were similar to previous work with irradiation, in the presence of oxygen, increasing L* values, lowering $a^*$ value, and increasing $b^*$ values compared to all other treatments. The researcher concluded that irradiation of pork in the presence of O$_2$, while initially improving redness, was a detrimental effect on not only color, but also chemical and sensory characteristics.

Nanke et al. (1999) irradiated whole muscle pork, beef and turkey at dose rates of 1.5, 3.0, 4.5, 7.5 and 10.5 kGy to examine the effects on color characteristics. Also, a sensory panel was used to determine visual color measurements. The L* values for pork and turkey were unaffected by increasing irradiation, while increasing irradiation levels significantly (P<0.05), but inconsistently affected beef. Irradiated pork and beef became less red (lower $a^*$ values) as a result of increased irradiation and display time. While turkey redness values increased after irradiation, they decreased during display time. The yellowness ($b^*$ values) of the irradiated samples of all species increased as a result of irradiation and display. The redness visual scores for pork and beef decreased (P<0.001) as irradiation dose levels increased from 0 to 3.0 kGy, meaning the both samples were more brown than the unirradiated controls or samples irradiated at doses >4.5 kGy. Turkey redness scores decreased (P<0.05) from 0 to 3.0 kGy, increased (P<0.05) from 1.5 to 7.5 kGy and then
decreased \((P<0.05)\) again at 10.5 kGy. Overall, the increased brownness in beef and pork at lower doses were the most noticeable change.

**B. Sensory Changes due to Irradiation**

Sensory panels are used to obtain subjective measures of quality that reflect the consumers' perception of product differences (Taub \textit{et al.}, 1979). These measurements can cover a wide range of product characteristics such as odor, flavor, texture, etc. As for red meat and poultry products that have been irradiated, sensory panels are used to determine differences, whether positive, negative or nonexistent. Two of the main characteristics sensory panelists are used to determine are visual color and odor differences between irradiated and nonirradiated products. Other characteristics might include juiciness, texture and overall acceptance.

Many researchers have reported minimal effects of irradiation on red meat and poultry (Hashim \textit{et al.}, 1995; Kanatt \textit{et al.}, 1997; Mattison \textit{et al.}, 1986; Ab-Tarboush \textit{et al.}, 1997). Ab-Tarboush \textit{et al.} (1997) irradiated raw and cooked chicken with doses from 2.5 to 10.0 kGy. A sensory panel was used to determine the acceptability (appearance, odor, texture and taste) of irradiated chicken from days 0 to 21. Tenderness and juiciness was only slightly affected, and irradiated chicken was not rejected at 21 days of storage at 4°C. Hansen \textit{et al.} (1987) also irradiated chicken with up to 1200 krad to determine any chemical and sensory changes (mainly odor) that could occur. The sensory panel concluded that the irradiated samples had acceptable odor, while the controls did not. Minor changes the researchers found in product were contributed to the \(O_2\) present at the time of irradiation. Kanatt \textit{et al.} (1997) irradiated chicken, lamb and buffalo meat at doses up to 2.5 kGy. The study concluded that there was not a negative effect on the sensory qualities (general
appearance and odor) of the meat for up to 4 weeks at 0-3°C. The unirradiated controls had a shelf life of 2 weeks under the same conditions. Hashim et al. (1995) irradiated dark and white whole muscle chicken meat at dose up to 2.68 kGy. The product was irradiated in the frozen and fresh state and either cooked or raw. Irradiation did not effect appearance of moistness and glossiness of raw chicken (white or dark). Raw irradiated chicken actually had a higher “fresh chicken,” bloody and sweet aromatic aroma than nonirradiated samples. Cooked, irradiated, frozen dark meat had more chicken flavor, and cooked, irradiated, refrigerated dark meat was more tender than controls. No other sensory attributes of cooked chicken were affected.

Other researchers found that irradiation had minimal, but detrimental, effects on sensory qualities (Luchsinger et al., 1996; Lefebvre et al., 1994; Zhao et al., 1996; Lambert et al., 1992). Lambert et al. (1992) reported the effect of irradiation on the sensory changes in fresh pork loin chops at doses between 0 and 1.0 kGy. Irradiation, in the absence of oxygen, extended the sensory shelf life of pork from 9 to 26 days at 5°C. After 21 days at 5°C, irradiated, N₂ packaged samples had a weaker off-odor (P< 0.01) compared to nonirradiated samples. However, irradiation (1.0 kGy) of aerobically packaged samples stored at 5°C was more discolored (P<0.01) than other treatments and had a stronger initial off-odor (P< 0.01). The researchers concluded that the sensory changes were due to the irradiation of product in the presence of O₂. Zhao et al. (1996) irradiated (0 to 1.0 kGy) fresh pork chops to determine the effects on sensory characteristics. The results of the Zhao et al. (1996) study agreed with the reports of Lambert et al. (1992), that aerobic packaging caused more discoloration of irradiated pork than did anaerobic treatments. The conclusion was that the presence of O₂ during irradiation favors the oxidation of myoglobin to brown
metmyoglobin. Using anaerobic packaging controlled organoleptic quality changes in irradiated pork chops.

Luchsinger et al. (1996) irradiated (0 to 3.85 kGy) fresh and frozen boneless pork chops. The sensory changes were less apparent in frozen than fresh pork. These results agreed with Lambert et al. (1992) and Zhao et al. (1996). Aerobic packaging combined with irradiation slightly increased undesirable characteristics of pork products. The conclusion was that frozen pork could receive a higher dose of irradiation without decreased sensory attributes. Also, the packaging condition had a great effect on sensory characteristics, especially in the presence of oxygen.

Lefebvre et al. (1994) determined that irradiation had detrimental effects on red meat. The researchers irradiated (1.0 to 5.0 kGy) ground beef to determine the effect on sensory quality through 16 days of storage at 4°C. Panelist indicated a noticeable effect of irradiation on the odor and color of the raw ground beef product. The odor and favor of irradiated ground beef was slightly disliked, while the color was considered more pleasant when compared to nonirradiated samples. The researchers concluded that cooking also diminished the negative effect of irradiation on the odor of the treated samples. It was recommended that ground beef be irradiated with a low dose (1.0 kGy or less).

C. Lipid Oxidation due to Irradiation

The development of oxidative rancidity has long been recognized as a problem occurring during the storage of meats. Common factors that effect lipid oxidation might include fatty acids, prooxidant and antioxidant content, not to mention processing conditions. The reduction of particle size, cooking and formula additions, such as nitrite, salt and phosphate, also influence oxidation levels (Gray et al., 1994). Govindarajan and Hultin
(1977) reported that lipid oxidation increased rather rapidly after grinding due to either the disruption of cellular structure or the exposure of more lipids to oxygen. Storage of beef samples at 4°C for nearly 3 weeks resulted in a substantial increase in the TBA numbers (Shahidi and Hong, 1991). Also, wide fluctuations in temperature and inadequate protection from oxygen can accelerate the development of rancidity (Love and Pearson, 1971). Lipid oxidation, occurring in red meat and poultry products, is generally associated with the development of rancid flavors and odors. Rancid flavors and odors can be extremely detrimental to the consumer acceptance of a product.

When assessing the extent of oxidation in lipid-containing foods, there are two traditional changes that are measured: primary change and the secondary change. The most frequently used method of assessing lipid oxidation is measuring the formation of malonaldehyde using the thiobarbituric acid (TBA) test (Gray et al., 1994; Husain et al., 1987). The formation of malonaldehydes is a secondary change that occurs during lipid oxidation in muscle foods, or more precisely from the decomposition of lipid hydroperoxides during the acid-heating stage of the test (Gray et al., 1994).

The effect of irradiation on lipid oxidation has been the subject of recent interest in many different studies using numerous red meat and poultry products (Luchsinger et al., 1996; Zhao and Sebranek, 1996; Hampson et al., 1996; Kanatt et al., 1997). The effect of irradiation on TBA data has been consistently low or nonexistent, if conditions were appropriate. Mattison et al. (1986) and Heath et al. (1989) reported that low dose (100 to 300 krad) had no effect on TBA values of pork loins or chicken meat, respectively. Mattison et al. (1986), also found no change in raw TBA values and cooked TBA values (due to
irradiation) of pork loins. The exception was Heath et al. (1989), who reported increased TBA values in chicken irradiated at 300 krad, at day 8 of storage.

Three recent studies have looked at the effect of irradiation (0.05 to 3.85 kGy) and packaging atmosphere on the changes in TBA values (Luchsinger et al., 1996; Zhao et al., 1996; Lambert et al., 1992). Fresh pork loins were used in all three studies and the researchers agreed that proper packaging (anaerobic packaging) could eliminate any change in TBA values. The researchers agreed with Urbain (1986) that irradiation in the presence of O₂ accelerates autoxidation during and after processing. The storage time of aerobically packaged, irradiated pork loins was decreased due to the increase in lipid oxidation. Lambert et al. (1992) reported no change in TBA values until day 7, with a constant increase until the end of the storage period. Zhao et al. (1996) reported similar results with air permeable packaging with a constant increase in TBA values starting at day 7. Luchsinger et al. (1996) reported that TBA values for aerobically packaged pork chops increased (P<0.05) as dose level increased at all display days. All researchers reported similar conclusions; optimum packaging conditions and control of film permeability can control rancidity changes in irradiated pork chops, thus decreasing TBA values.

Hampson et al. (1996) irradiated (0 to 10.0 kGy) five types of whole muscle meats (pork, lamb, beef, turkey leg, and turkey breast) to determine malonaldehyde concentration. Four out of five muscles showed no significant difference (P<0.05) between irradiated and nonirradiated samples or seemed dose-responsive, only turkey breast seemed dose-dependent. The turkey breast meat showed a slight increase, but no significant difference was found at the 90% confidence level. The investigators concluded that the minor changes would not affect product acceptance. Kanatt et al. (1997) agreed with this conclusion.
Irradiated (0 to 2.5 kGy) lamb, chicken and buffalo meat was used to determine lipid oxidation and sensory effects. The results showed a slight increase in immediate TBA values, but no increase (P<0.05) in the values of samples as storage time increased. The higher TBA numbers did not have a detrimental effect on sensory characteristics in any of the three meats. However, within 2 weeks, the off odor and signs of spoilage found in non-irradiated samples were considered nonacceptable by panelist, while irradiated samples were acceptable throughout the storage period.

D. Microbial Load and Shelf Life Effects

The sensitivity of foodborne pathogens and spoilage bacteria to irradiation has been well documented (Olson, 1998; CAST, 1996; Thayer, 1995). The D-values of microorganisms such as *E. coli* O157:H7, *Listeria monocytogenes*, *Salmonellae* and many others have been the subject of numerous research studies, as well as the relationship of spoilage organisms and their impact on shelf life.

Irradiation of fresh and frozen red meat and poultry products and the effect on foodborne pathogens has been reported in many studies (Thayer and Boyd, 1993; Rocelle *et al.*, 1994; Thayer *et al.*, 1998; Mattison *et al.*, 1986; Zhao *et al.*, 1996; Luchsinger *et al.*, 1996). Thayer and Boyd (1993) researched the effects of irradiation (0-3.0 kGy) on the colony forming units (CFU) of *E. coli* O157:H7 in mechanically deboned chicken and ground beef. Product was inoculated with $10^{4.8}$ CFU of *E. coli* O157:H7 per g and irradiated. Unlike non-irradiated samples, no measurable verotoxin was found in the finely ground beef. In chicken meat, 90% of viable *E. coli* O157:H7 was eliminated by doses of 0.27 kGy at +5°C and 0.42 kGy at -5°C. These results agreed with Rocelle *et al.* (1994), who inoculated ground beef patties (3100g) with cell suspensions of $>10^9$ CFU/ml of *E. coli* O157:H7,
**Salmonellae and Campylobacter jejuni.** The samples were irradiated, either fresh (3 to 5°C) or frozen (-17 to -15°C), with doses up to 2.5 kGy. In ascending order of irradiation resistance, the D-values ranged from 0.175 to 0.235 kGy (*C. jejuni*), from 0.241 to 0.307 kGy (*E. coli* O157:H7), and from 0.618 to 0.800 kGy (*Salmonellae*). *E. coli* O157:H7 had a significantly (P<0.05) higher D-value when irradiated at -17 to -15°C than when irradiated at 3 to 5°C. It was concluded that an applied dose of 2.5 kGy would be sufficient to kill $10^{8.1}$ of *E. coli* O157:H7, $10^{3.1}$ *Salmonella*, and $10^{10.6}$ *C. jejuni*. Mattison *et al.* (1986) concluded that irradiation at low dose (100 krad) significantly (P<0.01) decreased the number of CFU of mesophiles and psychrotrophs in fresh pork loins. The irradiated samples had lower numbers of CFU’s throughout the storage period.

Furthermore, studies have shown a significant (P<0.05) decrease in CFU’s of foodborne pathogens due to irradiation (Thayer *et al.*, 1998; Zhao *et al.*, 1996). Zhao *et al.* (1996) reported that irradiation (1.0 kGy) initially decreased the number of *Salmonella* by 0.3 to 1.4 log cycles, depending on packaging. The *Salmonella* counts were significantly (P<0.05) lower on irradiated samples than on non-irradiated samples throughout the storage period. Thayer *et al.* (1998) reported that an inoculum of *L. monocytogenes* ($10^3$ CFU/g) did not survive an irradiation dose of 3 kGy on raw turkey. The survival and multiplication of *L. monocytogenes* was greater on cooked meats than on raw meats kept in refrigerated temperatures.

The presence of microorganisms can have a detrimental effect on the shelf life of red meat and poultry products. Irradiation has been shown to significantly increase the shelf life of products, along with proper handling (Shamsuzzaman *et al.*, 1995; Kanatt *et al.*, 1997; Naik *et al.*, 1994). Shamsuzzaman *et al.* (1995) had a plate count limit of $10^5$ CFU/g that
was used to determine the shelf life of sous-vide chicken breast meat. The sous-vide unirradiated chicken had a shelf life of 16 days at 8°C, whereas the irradiated (3 kGy) samples were under the CFU limit for 8 weeks. Kanatt et al. (1997) and Naik et al. (1994) had similar results with chicken, lamb, and buffalo meat irradiated at 2.5 kGy. The researcher reported that irradiated meats were microbiologically safe and acceptable to panelists up to 4 weeks, at refrigerated temperatures (0-3°C), while nonirradiated meat were unacceptable at less than 2 weeks. The sensory characteristics and the CFU’s were above the set standards for each study.

Abu-Tarboush et al. (1997) reported a shelf life increase of 12 days in irradiated (2.5 kGy) chicken stored at 4°C. A sensory panel did not reject the chicken after 21 days of storage. The researchers also reported that increased irradiation had little effect on shelf life. Lambert et al. (1992) reported that irradiation (0-1.0 kGy) in the absence of oxygen increased the shelf life of pork chops from 9 to 26 days at 5°C. All researchers conclude that irradiation decreased the population of CFU’s of varies foodborne pathogens, producing a safer, more wholesome product. Most samples were acceptable to sensory panelist for the duration of their respective studies.

IV. Processed Meats Irradiation

The irradiation of processed meats has not been researched to the extent of fresh meats. One reason may be the fact that some processed products already have ingredients, such as sodium nitrite, that prevent some toxin production and can help reduce lipid oxidation. Sodium nitrite is also largely responsible for typical characteristics such as color and flavor of cured meat products (Sebranek et al., 1977). Eakes and Blumer (1975) researched a decreasing level of nitrite in cured meat products due to the potential health
hazards from carcinogenic nitrosamines. The researchers concluded that the effect of low levels of nitrite on the growth of pathogenic microorganisms should be assessed in order to insure a high quality, consumer-safe product.

The process of irradiation may accomplish a consumer-safe product, but the effects on product quality are still in question. Shay et al. (1988) explained that the principles to be observed in treating processed meats and problems likely to be encountered due to irradiation are generally similar to those of raw meats. The problem of recontamination during slicing and packaging could result in a starting CFU count of $10^4$-$10^5$ bacteria per g. The lack of adequate storage life in some processed products, such as luncheon meats, also pose a problem that might make irradiation of processed products beneficial (Shay et al., 1988). There is little doubt that irradiation had a positive effect on the pathogenic microorganism load in processed meats. The effect of irradiation on processed product quality needs to be examined to determine detrimental effects, if any, on product quality.

A. Color Changes due to Irradiation

In processed products, such as cured ham or frankfurters, sodium nitrite is largely responsible for the cured color that consumers expect. Many studies in the late 70’s and early 80’s were focused on lowering the sodium nitrite in processed products via an attempt to decrease health hazards (Sebranek et al., 1977; Shults et al., 1977; Terrell et al., 1981a; Terrell et al., 1981b). The use of irradiation with decreased nitrite levels was attempted as a replacement for commonly used levels (156 ppm) of sodium nitrite (Terrell et al., 1981b; Terrell et al., 1982; Shults et al., 1977). Shults et al. (1977) irradiated corned beef briskets at three dose levels (2.5, 3.5, and 4.5 kJoules/kg) to determine by panelist for color and acceptability. The rating for discoloration was decreased with the lowering of the irradiation
temperature except for samples irradiated at 45 kJ/kg (as judged by a sensory panel). The
discoloration rating increased as irradiation dose increased, especially at higher temperatures
(0°C). Nitrite level changes and irradiation dose changes were independent of each other.
Shahidi et al. (1991) studied the effects of 5 and 10-kGy irradiation on the color and
oxidative stability of nitrite and nitrite-free meat systems. The Hunter a* values, for all
samples, regardless of treatment, decreased over the 3 week storage period. Irradiation had
no detrimental effects on the color of any cured meat samples.

Three studies completed in the early 1980’s studied the effects of irradiation (0.8 to
3.2 Mrads) and various nitrite levels on the properties of frankfurters (Terrell et al., 1981a;
Terrell et al., 1981b; Terrell et al., 1982). Terrell et al. (1981a) concluded that there were a
slight difference among all levels of irradiation when examining cured color values. As the
level of irradiation increased, the cured color values decreased, but not significantly. Terrell
et al. (1981b) determined that as doses increased the internal and external color scores of
irradiated frankfurters became less pink in 2 out of 3 treatments and did not change in the
third treatment. Researchers in each study concluded that irradiation to the 0.8 Mrad level
was more desirable than the higher dose (3.2 Mrads). Terrell et al. (1982) concluded that
pork/beef and chicken/turkey frankfurters had increased internal color values (although not
significant) with an increase in irradiation dose (0 to 3.2 Mrads). The results agreed with that
of previously mention studies; that irradiation of processed meat products, containing nitrite,
has little effect on cured meat color.

B. Sensory Changes due to Irradiation

Sensory evaluation of processed products is similar to that of fresh meat, in that the
qualities examined are the same (color, off-odor, off-flavor and overall palatability). Shay et
al. (1988) used a sensory panel to evaluate the characteristics of irradiated (2.0 to 5.0 kGy), vacuum packaged, sliced corn beef. The researchers evaluated flavor and aroma, determining that the acceptability of frozen irradiated meat was not significantly lower than non-irradiated frozen samples, except at week four. Excluding oxygen and irradiating at low temperatures could minimize organoleptic changes. Shults et al. (1977) also used a sensory panel to determine the effects of irradiation (2.5 to 4.5 kJoules/kg) on the color and acceptability of corn beef. The researchers concluded that increasing the irradiation temperatures resulted in decreased ratings for sensory characteristics (color, odor, flavor and texture) at a 1 and 4-week storage periods. Terrell et al. (1982) also agreed that lowering the irradiation temperature decreased the off-flavor and increased palatability of irradiated (0.8 and 3.2 Mrads) frankfurters. The researchers found a significant (P<0.05) decrease in acceptable sensory values as the irradiation level increased from 0.8 to 3.2 Mrad.

Both studies completed by Terrell et al. (1981a and 1981b) determined that increased levels of irradiation (0.8 to 3.2 M rad) had detrimental effects on sensory attributes of frankfurters. Off-odors, off-flavors, texture and overall palatability scores were lower in the 3.2 Mrad irradiated frankfurters. It was concluded that irradiation at 0.8 M rad would achieve the desired effects, while not significantly decreasing the quality attributes.

C. Lipid Oxidation in Processed Products

The extent of lipid oxidation in processed meat products may vary with the different ingredients used in different products. The variation in lipid oxidation due to irradiation in some products may also vary with the different product ingredients. Sodium nitrite and phosphates have been found to have an antioxidant effect in processed and cured products (Terrell et al., 1981a; Akamittath et al., 1990). Terrell et al. (1981a) reported TBA values
were lower (P<0.05) for frankfurters with 100% NO₂ than franks made with varying levels of nitrite and nitrate. Akamittath et al. (1990) found that phosphates were effective in inhibiting lipid oxidation in beef (4 wks), pork (8 wk), and turkey (6 wk) products, as compared to controls.

In contrast to the antioxidant effect of the nitrite and phosphates, salt has a prooxidant effect in meat products. Andersen and Skidsted (1991) studied the effects of salt and light on oxidative stability of frozen pork patties. The researchers concluded that oxymyoglobin oxidation and lipid oxidation were strongly accelerated by the addition of salt and slightly increased by light exposure.

The effects of irradiation on lipid oxidation in processed meat products have not been extensively researched. One study has shown that irradiation of ground pork did not increase (P<0.05) lipid oxidation (Ehioba et al., 1987). However, the addition of phosphates did not significantly (P<0.05) reduce the TBA values of irradiated pork. A possible negative effect, (on lipid oxidation) of irradiation, could have been negated by possible positive effects of the added phosphates. Shahidi et al. (1991) reported a beneficial effect of phosphates on oxidative stability in nitrite and nitrite free products. The researchers concluded that irradiation enhanced the antioxidant effect of nitrite and generally lowered the TBA values of nitrite free meats, containing sodium ascorbate.

D. Microbial Load and Shelf Life Effects

The microbial safety of processed and cured products, until recently, was not considered a consumer threat, due to the thermal processing of products. Because of recontamination during slicing, peeling and packaging, consumers are increasingly concerned. Also the possibility of microorganisms becoming more heat resistance has
increased questions about processed product safety. The irradiation of processed meat products has seen limited research, but some work has been done to determine effects of microbial contamination of processed products (McCarthy and Damoglou, 1993; Dickson and Maxcy, 1985; Hannah and Simic, 1985).

McCarthy and Damoglou (1993) used low dose (1.5 to 3.0 kGy) to determine the effect of irradiation on the yeast of British fresh sausage. A sulphite preservative was added to determine if the effects of irradiation would be enhanced. A significant reduction in yeast numbers in both sulphite and non-sulphite sausage after both irradiation treatments. Dickson and Maxcy (1985) reported a 2.2 log reduction in total aerobic bacteria counts in commercial sausage batter, irradiated (500 krad) prior to starter culture addition. Irradiation reduced the population of *Staphylococci* to less than 0.1% of the counts for the control samples, which were greater than $10^5$. The numbers of coliforms in the sausage batter were also reduced below detectable levels using irradiated. The population density of both *Staphylococci* and coliforms were considered safe after 24 hrs of incubation at 37°C in irradiated samples.

Hannah and Simic (1985) combined low nitrite curing (40 ppm), smoking, vacuum packaging, electronation (1-3 Mrad), and freezing (-10°C) to eliminate microbiological hazards associated with *Salmonella* and *Clostridium botulinum* in bacon. The researchers reported *C. botulinum* was undetectable at an irradiation dose of 1.5 Mrad, and concluded that *Salmonella*, a more sensitive organism, was completely eliminated at this level. Researchers also reported a shelf life of 2 1/2 years for bacon produced in this fashion.

Other researchers have reported shelf life extension in processed products irradiated and stored either fresh or frozen (Shay *et al.*, 1988; Ehioba *et al.*, 1987; Barbut *et al.*, 1987). Shay *et al.* (1988) reported a shelf life of 4-6 weeks in irradiated, vacuum packaged corned
beef stored at 5°C. A low-dose (2-5 kGy) irradiation was used to achieve a 2-3 week shelf life extension, when compared to non-irradiated products. Similar results were achieved by irradiating (0.5 or 1.0 Mrad) turkey frankfurters with varying levels of salt and polyphosphates (Barbut et al. 1987). The researchers determined that 2.5% NaCl level, along with irradiation had a substantial effect on inhibiting botulinal toxin up to 40 to 50 days. Under the conditions of this study (27°C, anaerobic environment, heat shock due to cooking and high inoculation levels) the one month delay in toxin production was considered very effective. Ehioba et al. (1987) irradiated vacuum packaged ground pork with added sodium phosphates. The samples that were irradiated without sodium phosphates had a 2.5-3.5 day increased shelf life. The irradiated samples with sodium phosphates had an additional 2 days, increasing the shelf life by a total of 4.5-5.5 days. All samples were held a 5°C throughout the study.

All researchers agreed that irradiation decreased microbial numbers and had a significant increase in product shelf life. The detrimental effects of irradiation need to be minimized so the benefits to food safety can be realized.

V. Listeria monocytogenes

Listeria monocytogenes is a gram-positive bacterium, motile by means of flagella and is found in almost all aspects of nature (Foodborne Pathogenic Microorganisms and Natural Toxins Handbook, 1999). This handbook reports that L. monocytogenes is found in 1-10% of humans, in at least 37 mammalian species, as well as at least 17 species of bird; other sources include soil, silage and most other environments. L. monocytogenes is resistant to freezing and drying, but grows well at refrigerated temperatures as low as 3°C. The optimum growth range is from 30-35°C, but refrigeration does not stop multiplication of the organism.
*L. monocytogenes* has been found in many dairy foods such as raw and pasteurized milk, cheese, ice cream, etc. ([Foodborne Pathogenic Microorganisms and Natural Toxins Handbook, 1999](#)). *L. monocytogenes* has also been isolated in fermented raw meat sausage, raw and cooked poultry, raw meats (all types) and fish ([Foodborne Pathogenic Microorganisms and Natural Toxins Handbook, 1999](#)). *L. monocytogenes* can be controlled by cooking products to proper internal temperatures, or time/temperature combinations such as 145°F for 2.56 minutes, but recontamination can occur due to poor sanitation and the wide distribution of the bacteria in the environment. Contamination of raw products can be minimized by proper sanitation procedures, but definite risks still exist because of *L. monocytogenes* wide spread distribution in the environment.

Irradiation can be an effective process in reducing *L. monocytogenes* found in food products. Strains of *L. monocytogenes* irradiated in different food medias and under various conditions have produced D-values that range from 0.25 to 0.77 kGy ([Thayer et al., 1998](#); [Gursel and Gurakan, 1997](#); [Patterson, 1989](#); [Huhtanen et al., 1989](#)). The average D-value for *L. monocytogenes* in chicken and beef has been reported to be 0.45 kGy ± 0.03 ([CAST, 1996](#); [Olson, 1998](#); [Huhtanen et al., 1989](#)). These values are well within the maximum dosages of irradiation authorized by FDA and proposed by the Food Safety and Inspection Service (FSIS) for refrigerated and frozen food products (4.5 and 7 kGy respectively) ([Federal Register, 1999](#)). The D-values for *L. monocytogenes* are similar to those of *Salmonella* and therefore, a dose of 2.5-7.0 kGy is sufficient to eliminate the bacteria, in similar medias and under similar conditions ([Patterson, 1989](#); [Mead et al., 1990](#)).

Many researchers have investigated the effects of irradiation on the survival of *L. monocytogenes* in various food products and under various conditions ([Mead et al., 1990](#); [Fu...](#))
et al., 1995a; Fu et al., 1995b). Mead et al. (1990) irradiated (2.5 kGy) inoculated (10^2 and 10^4 CFU) poultry carcasses and stored them at 5 to 10°C to determine the number of surviving organisms and their ability to recover from the low dose irradiation. The researchers found that only 1 of the 12 carcasses inoculated at 10^4 CFU were positive for *L. monocytogenes* and no other carcasses were found positive until day 14 at 5°C and until day 5 at 10°C. This was credited to the higher inoculate level, because only 1 of 18 carcasses with lower inoculate levels (10^2 CFU) were found positive at the end of the storage period (21 days). These results were similar to Fu et al. (1995a), which medium dose irradiation (1.5 to 2.0 kGy) was sufficient in eliminating *L. monocytogenes* from beef steaks and ground beef over a 7 day storage period. In the beef steaks and ground beef, 1 to 3 log reductions were seen, respectively. A 2.0 kGy was effective for reducing *L. monocytogenes* (in both products) for at least 7 days at 7°C. Fu et al. (1995b) found that low dose irradiation (0.75 to 0.90 kGy) reduced *L. monocytogenes* by 2 logs and medium dose irradiation (1.5 to 2.0 kGy) reduced pathogen populations to undetectable levels in cooked pork chops and cured ham. A storage period of 7 days at 7°C was used to determine the irradiation effect. The presence of salt and nitrite in the cured hams added to the effectiveness of irradiation.

The lag phase of *L. monocytogenes* in cooked poultry meat stored at 6°C can be extended from 1 to 18 days with the use of 2.5 kGy irradiation (Patterson et al., 1993). A general increase in lag duration was reported as the dose level increased from 1.0 to 2.5 kGy. Gursel and Gurakan (1997) found that irradiation (2.5 kGy) of chicken breast and raw ground beef could retard the growth of *L. monocytogenes* stored at 4°C. Samples were inoculated at 10^3 to 10^4 CFU/gram and held for 7 days. *L. monocytogenes* was found to be more resistant to irradiation in ground beef, but an approximately 2 to 4 log reduction was achieved. This
reduction allowed samples to be stored up to 11 days at 4°C before a slight increase in surviving *L. monocytogenes* was noticed, but no increase was noticed in chicken breast samples.

Irradiation along with sous-vide treatments had an even greater effect on the survival of *L. monocytogenes* in inoculated (10^6 CFU) chicken breast meat (Shamsuzzaman *et al.*, 1995). Samples treated with a 3.1 kGy dose of irradiation and cooked with sous-vide methods (internal temperature of 71.1°C) had no detectable *L. monocytogenes* when stored at 8°C for 5 weeks. The samples that were treated only with sous-vide cooking were found to have high levels of *L. monocytogenes* at the end of the storage treatment. This displays the pathogen’s ability to withstand heat and recover from cooking damage over time. Thayer *et al.* (1998) investigated the differences between cooked and raw turkey breast meat inoculated with *L. monocytogenes* (10^3 CFU/g), irradiated (3 kGy) and stored at either 2 or 7°C for 21 days. The population of *L. monocytogenes* was undetectable immediately after irradiation. However, populations increased in cooked, but not raw samples held under the previous conditions. The D-values changed significantly (P<from 0.70 ± 0.04 to 0.60 ± 0.02 kGy when product was packaged and cooked before irradiation.

The research has shown that irradiation has a detrimental effect on the population of *L. monocytogenes* in red meat and poultry products. With medium dose irradiation, commonly occurring levels of *L. monocytogenes* can be controlled and a safe product can be produced.

**VI. Antioxidants**

Lipid oxidation can be a major problem in processed and fresh meat products. Rancidity can be detrimental to product quality and drastically shorten the shelf life of
susceptible products. Fat oxidation involves the generation of unstable free radicals that catalyze the production of more free radical (Bacus, 1991). Fat oxidation starts a chain reaction that leads to the problems associated with rancidity, such as off flavors and decreased consumer acceptance. The oxidation reaction rate can be slowed or suppressed by such factors as the reduction in the number of active reaction sites, decreasing the pressure of oxygen, decreasing the reaction temperature and storage under inert gas (Pokorny, 1987). The presence of trace metals and light affect oxidation, as well as variation in pH levels. The most important step in decreasing oxidative rancidity is the reduction of the initiation rate, or the slowing of the chain reaction (Pokorny, 1987).

Antioxidants delay the onset of fat oxidation by reacting with, or intercepting, free radicals and severing the “chain” reaction (Bacus, 1991). Typical ingredients in processed meat products, such as nitrite, phosphates and some spices (sage and rosemary), do provide an antioxidant effect. Hasiak et al. (1984) reported that TBA values, in turkey hams, were significantly decreased by the addition of nitrite or erythorbate. However, as the length of storage time increase, the TBA values also increased. Synthetic or natural antioxidants are often added to processed products to aid in the prevention of lipid oxidation and thus increasing the shelf life.

A. Synthetic Antioxidants

Synthetic antioxidants are chemically created, typically from petroleum products, and are used in combinations to decrease lipid oxidation in fats and oils (Bacus, 1991). Examples of synthetic antioxidants are butylated hydroxy anisole (BHA), butylated hydroxy toluene (BHT) and propyl gallate (PG). These products are often used in combination with one another to combine the carry-through capacity of the antioxidants. PG is regarded as the
most effective synthetic antioxidant used in products containing animal fats, but negative
effects on color can sometimes arise with the formation of black/purple complexes (Bacus,
1991). BHA is more effective than BHT in suppressing oxidation in products containing
animal fats and is particularly useful in protecting the flavor and color of products (Dziezak,
1986). Dziezak (1986) reported that PG has a relatively low melting point (148°C) and loses
its effectiveness under heating conditions. PG is useful in inhibiting oxidation in products
containing animal fats, meat products (fresh or frozen) and processed meats. BHA and BHT
are perhaps the most frequently used antioxidant (usually at levels around 0.02% of the fat
content) due to the carry-through ability of these products (Pokorny, 1987).

Resurreccion and Reynolds (1990) used both natural and synthetic antioxidants to
determine the effect on TBA values in frankfurters. The frankfurters with a combination of
BHA/BHT had lower TBA values and lower sensory scores for off flavor when compared to
control treatment throughout the 35-day storage period. Only at day 35, did the TBA values
of this treatment approach those of the controls and the off-flavor scores were still the lowest
of all treatments.

Kosaric et al. (1973) reported that PG and BHA significantly lowered lipid oxidation
values in irradiated beef fat. PG was the most effective of these two antioxidants, with
samples resisting autoxidation for up to 42 days after irradiation. In addition, all antioxidants
were credited with decreasing the odor intensity scores of the irradiated samples during the
storage period. Chen et al. (1999) reported that BHT was effective in reducing oxidation in
irradiated pork patty samples. BHT samples had a 53% reduction in TBARS values over the
control samples. Kanatt et al. (1998) also reported a significant decrease in oxidation in
irradiated chicken samples. BHT and tocopherol was used to determine the effects on TBA
values during a 4-week storage period. BHT had the lowest TBA values of all samples displaying TBA values < 1 when stored at 4°C for up to 35 days.

B. Natural Antioxidants

Rosemary oleoresins were the first widely used natural antioxidant due to its relative “activity,” cost effectiveness and flavor benefits (Bacus, 1991). The use of rosemary oleoresins has interested people due to the fact that they are a natural compound and an effective antioxidant. Lacroix et al. (1997) reported that rosemary effectively reduced radiolysis of unsaturated linoleic and arachidonic acids irradiated to 10 kGy. Furthermore, a quantitative and qualitative reduction in hydrocarbon production was reported. Chen et al. (1999) reported similar results when they irradiated (4.5 kGy) pork patties with added rosemary. Rosemary oleoresin was effective at reducing oxidation of raw pork by 40% (over controls) at day 3. However, at day 7 the effect of rosemary oleoresin was nonexistent, indicating that rosemary does not have good carry-through characteristics.

Additional studies used rosemary and sodium tripolyphosphate (STPP) in combination to determine the antioxidant effects in restructured beef and pork steaks (Stoick et al., 1991; Liu et al., 1992). In both cases the combination was considered to be effective at slowing oxidation. However, rosemary was not as effective when added without STPP, so the antioxidant effect was given to the STPP and rosemary was considered ineffective. In contrast, Ho et al. (1995), Barbut et al. (1985), and Resurreccion and Reynolds (1990) found that rosemary oleoresin had similar antioxidant effects as combinations of BHA, BHT, PG and citric acid (CA). Resurreccion and Reynolds (1990) reported similar TBA values between rosemary oleoresin with natural tocopherols and a BHA/BHT combination treatment at 35 days of storage. Chicken and pork frankfurters were used to determine that all
antioxidant samples had lower TBA values than the controls. Furthermore, rosemary extract had the same antioxidant effects as a BHA/PG/CA combination when added to pork sausage during a 16-week storage period (Ho et al., 1995). Barbut et al. (1985) added rosemary oleoresin and a combination of BHA, BHT and CA to turkey sausage to determine the effect on TBA numbers. The researchers agreed that there were no differences between the effects of the natural and synthetic antioxidants. Both treatments had substantially lower TBA values than the samples without antioxidants.

VII. Summary

The irradiation of fresh and processed meats can produce a microbially safer product. The ability of irradiation to eliminate pathogenic microorganisms such as *L. monocytogenes* makes it a useful tool in improving food safety. There is concern of reduced product quality (sensory, organoleptic) because of irradiation. Irradiation has been shown to have a detrimental effect on some aspects of products under certain conditions. These effects may be reduced or controlled with the use of antioxidants. It was hypothesized that irradiation would have detrimental effects on the quality of frankfurters. It was also hypothesized that natural and synthetic antioxidants could control/prevent detrimental effects caused by irradiation. This research could be very beneficial in the processed meats industry by increasing shelf life and decreasing possible pathogenic contamination. Irradiation could also be a great benefit in controlling recontamination of frankfurters by administrating a low dose (2.0-3.0 kGy) after peeling and packaging. *L. monocytogenes* can be virtually eliminated in product by irradiation. If handled properly, irradiated product can be pathogen-free and of the highest quality, when consumed.
VIII. References


Dziezak, J. D., 1986. Preservatives: Antioxidants, the ultimate answer to oxidation. Food Technol. 94-103.


CHAPTER 3. PHYSICAL, CHEMICAL, AND SENSORY CHARACTERISTICS OF IRRADIATED, PRE-PACKAGED FRANKFURTERS WITH NATURAL AND SYNTHETIC ANTIOXIDANTS

A paper to be submitted to the Journal of Meat Science

W. J. Fields, J. C. Cordray, D. G. Olson, J.G. Sebranek and P. M. Dixon

I. Abstract

The effects of irradiation (2.5 kGy) and addition of rosemary oleoresin or a combination of butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA) and citric acid (CA) on frankfurter characteristics were measured. The characteristics measured included oxidation (TBA values), color (CIEL*, a*, b*), pH, purge, texture and sensory attributes. Characteristics were measured over a 60-day storage period at refrigerated (0-2°C) temperatures. Both antioxidants significantly (P<0.05) lowered TBA values, increased a* values and had no significant effect on sensory color or flavor. Irradiation had no effect on TBA values, but increased L* values and decrease a* values. Also, irradiation had no effect on sensory color, but negatively affected flavor in frankfurters containing BHT/BHA/CA.

Keywords: Irradiation, antioxidants, frankfurters, sensory, color

II. Introduction

In the past, food safety concerns have focused mainly on fresh meat and poultry products, especially ground products. Contamination of fresh product with pathogenic microorganisms like E. coli O157:H7, Listeria monocytogenes, and Salmonella was the main concern. However, recent problems with the safety of ready-to-eat meat products have arisen
due to contamination with *L. monocytogenes*. *L. monocytogenes* has been reported to have a thermal D-value of 2.56 min. at 63°C (Wilson, 1989). Using proper time/temperature combinations, ready-to-eat meat products are *L. monocytogenes*-free after thermal processing. The challenge with *L. monocytogenes* is due to recontamination of the product in slicing and packaging areas (Wang and Muriana, 1994). Wang and Muriana (1994) reported finding *L. monocytogenes* in the exudate of 7.5% of 19 different brands of retail frankfurters. These researchers concluded that the product was recontaminated after thermal processing, because *L. monocytogenes* was found in the exudate and not internally within the frankfurters.

The Food and Drug Administration (FDA) employs a “Zero Tolerance” policy for *L. monocytogenes* in ready-to-eat meat products. This, coupled with the abundance of *L. monocytogenes* throughout the environment, is the reason for the recent ready-to-eat product recalls. In 1999, there were 27 recalls of ready-to-eat meat products due to *L. monocytogenes* (USDA, FSIS Homepage, 2000). These recalls together included over 30 million pounds of recalled, contaminated product. Consumer safety and economical reasons call for a procedure that can ensure a *L. monocytogenes* free-product after product handling and packaging has been completed.

One procedure that could be used to eliminate *L. monocytogenes* after packaging is irradiation. Currently, irradiation is not approved for use in processed meats, but it has been shown to eliminate or reduce *L. monocytogenes* in these products. Irradiation has been shown to produce D-values for *L. monocytogenes* ranging from 0.25 to 0.77 kGy under various conditions (Thayer *et al.*, 1998 and Huhtanen *et al.*, 1989). Irradiation levels of 1.5
and 2.0 kGy reduced *L. monocytogenes* to a virtually undetectable level in cured ham (Fu *et al.*, 1995).

If irradiation is to be used to eliminate *L. monocytogenes* in ready-to-eat meat products, the consumer must consider it acceptable. Consumer’s opinion toward irradiation increases with consumer awareness of the specific advantages of irradiation. Bruhn (1995) stated that in the United States the number of consumers concerned about the safety of irradiated food has decreased from the early 1980’s to the early 1990’s. Furthermore, the number of concerns with irradiation is less than the number of concerns about pesticide residues, microbiological contamination and other food-related concerns. Resurreccion *et al.* (1995) reported that 95% of the 446 people surveyed considered bacteria a problem in food products. Irradiation was considered a problem by less than 15% of the people (446) surveyed. Consumers seem willing to accept the use of irradiation to provide a pathogen-free food product. Moreover, 45% of the consumers would buy irradiated food products, 19% would not, and 36% were undecided.

It is clear that the irradiation process produces a safer product and that consumer attitudes toward irradiation are improving. The questions surrounding the use of irradiation to pasteurize ready-to-eat meat products are more focused on quality aspects. The effect of irradiation on processed product quality has not been extensively researched. However, one study reported that as the irradiation dose increased acceptable sensory values of frankfurters decreased (Terrell *et al.*, 1982). Frankfurters were irradiated at a temperature of -34.4 to -51.4°C. Quality aspects, such as color and lipid oxidation, have also been reported (Terrell *et al.*, 1981, and Terrell *et al.*, 1982). The results were inconsistent, with irradiation exerting conflicting effects on color and lipid oxidation. Shay *et al.* (1988) reported the sensory
values of corn beef were not significantly different by an irradiation dose of 2.0 kGy. However, the product was irradiated in the frozen state and vacuum packaged. The researcher reported that organoleptic changes became significant at doses over 2.0 kGy.

It has been reported that antioxidants can minimize quality changes of frankfurters during storage time (Barbut et al., 1985; Resurreccion and Reynolds, 1990). These researchers reported that both natural and synthetic antioxidants are effective at decreasing lipid oxidation in processed meat products. Barbut et al. (1985) reported that butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and citric acid (CA) and rosemary oleoresins were equally effective at reducing TBA values of turkey sausage up to 16 days of storage. Resurreccion and Reynolds (1990) added the BHA/BHT and rosemary oleoresins to frankfurters and reported similar results. All antioxidants were credited with producing lower TBA values and less off-flavors in products up to 35 days of storage, which suggests that antioxidants may minimize the quality deterioration associated with irradiation.

Therefore, one objective of this study was to determine the extent to which irradiation influences the quality of frankfurters. A second objective was to evaluate the potential of antioxidants for minimizing irradiation’s effects on the quality of frankfurters. This study will thus provide information regarding the effects of irradiation on frankfurters and how those effects can be minimized. This is important because if the effects can be controlled, then irradiation can be used to produce safer, more wholesome frankfurters.

III. Materials and Methods

A. Raw materials

Beef trim (85/15) and pork trim (50/50) were obtained from the Iowa State University Meat Laboratory. The beef and pork trim were ground (Biro grinder, Model 7552) through a
½ inch (1.27 cm) plate and blended in appropriate rations to reach a beginning fat content of 30% for the meat block. The fat content of both the beef and pork trim was determined using an Anyl Ray Fat Analyzer (Kartridg Pak, model 316-48). The formulation target with all ingredients was 25% fat content in the finished product. For each replication, six 13.6 kg (30 lbs) batches of meat were randomly assigned to each treatment. The same base emulsion (Table 1) was used for all six treatments, except for the addition of the antioxidants. Six 18.6 kg (41.0 lb) batches were produced after the addition of non-meat ingredients.

Table 1. Ingredients used to produce basic frankfurter emulsion.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef (85/15)</td>
<td>36.88</td>
</tr>
<tr>
<td>Pork (50/50)</td>
<td>36.88</td>
</tr>
<tr>
<td>Ice/water</td>
<td>22.13</td>
</tr>
<tr>
<td>Seasoning(^a)</td>
<td>2.46</td>
</tr>
<tr>
<td>Salt</td>
<td>1.48</td>
</tr>
<tr>
<td>Curing Salt(^b)</td>
<td>0.18</td>
</tr>
</tbody>
</table>

\(^a\) Iowa State University Frankfurter Seasoning (Blend No. EJ-93-150-001, A. C. Legg Inc.)

\(^b\) (6.25% sodium nitrite)

BHA/BHT/CA (Eastman Chemical Company) were used in combination as the synthetic antioxidant for the respective treatments. Rosemary oleoresin (Kalsec Inc., Herbalox Type O) was used as the natural antioxidant. Each of the three synthetic antioxidants was added individually at a level of 0.01% of the finished fat content (25%) and the natural antioxidant was added at a 0.2% level of the finished fat content (25%). The
antioxidants were added to the spices, at the appropriate level, prior to the addition of the spice pack to the meat batter.

**B. Frankfurter preparation**

All emulsions were prepared using in a bowl chopper (Kramer-Grebe bowl chopper, model VSM65) and were chopped under a vacuum. The beef trim, salt, curing salt and half of the cold water (0°C) was added and chopped until the product temperature reached 5°C.

At this point the pork trim, spices (with antioxidants premixed) and the rest of the cold water (0°C) were added. The emulsion was chopped under vacuum until the product temperature reached 16°C. The product was stuffed into 22 mm cellulose casings (Devro-Teepak Wienie-Pak RP 22/95) using a vacuum stuffer (Risco stuffer, model RS 4003-165). Each treatment was labeled and randomly hung on smokehouse trucks before thermal processing. Thermal processing and smoking (natural smoke) was done using an Alkar thermal processing unit (Model MT EVD RSE 4, Alkar Engineering Corp.). The final internal temperature of the product was brought to 71°C using the cooking schedule in Table 2.

<table>
<thead>
<tr>
<th>Step Type</th>
<th>Step Time</th>
<th>Dry bulb (°C)</th>
<th>Wet Bulb (°C)</th>
<th>RH (%)</th>
<th>IT* (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cook</td>
<td>00:30</td>
<td>65</td>
<td>0</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>Smoke Cook</td>
<td>00:30</td>
<td>71</td>
<td>59</td>
<td>55</td>
<td>---</td>
</tr>
<tr>
<td>Cook</td>
<td>00:10</td>
<td>71</td>
<td>0</td>
<td>0</td>
<td>---</td>
</tr>
<tr>
<td>Steam Cook</td>
<td>00:01</td>
<td>77</td>
<td>74</td>
<td>90</td>
<td>71</td>
</tr>
<tr>
<td>Cold Shower</td>
<td>00:12</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>---</td>
</tr>
</tbody>
</table>

*: IT = Internal Temperature
The product was then moved to the cooler and held overnight at a temperature of 0°C prior to peeling. A Townsend peeler (model 2600, Townsend Engineering) was used to peel the product prior to packaging. Eight frankfurters were packaged (in a single layer) in vacuum bags (B2550 6½ X 8, Cryovac Division, W.R. Grace & Co.) using a Multivac double chamber-packaging machine (model AG800). The frankfurters were then boxed, returned to the cooler (0°C) and held overnight until irradiation.

Six 18.6 kg (41.0 lb) batches were produced; two with no antioxidants, two with rosemary oleoresin and two with a combination of BHA/BHT/CA. One of each of the treatments was irradiated at a dose of 2.5 kGy and one of each treatment was not irradiated. The six treatments were as follows:

- No irradiation (0 kGy), No antioxidants (0%)
- No irradiation (0 kGy), Synthetic antioxidants (0.01%)
- No irradiation (0 kGy), Natural antioxidants (0.2%)
- Irradiation (2.5 kGy), No antioxidants (0%)
- Irradiation (2.5 kGy), Synthetic antioxidants (0.01%)
- Irradiation (2.5 kGy), Natural antioxidants (0.2%)

For each of the three replication, the treatments were held for 60 days for physical, chemical and sensory analysis. The sensory analysis was performed on days 7, 30 and 60 of storage; while physical and chemical analysis was performed on days 7, 15, 30, 45 and 60 of storage.

C. Irradiation

Irradiation was conducted at the Iowa State University Linear Accelerator Facility (LAF). Product was held overnight (after packaging) and transferred from the cooler to the
LAF immediately before irradiation. Product was exposed to ambient temperatures approximately 45 minutes during irradiation. For consistency purposes, control samples were also exposed to this ambient temperature for the same time. Product was placed in single layers on stainless steel transfer carts for irradiation. Product was irradiated using a CIRCE IIIR electron beam irradiator (Thomson-CSF). A dose rate of 91.6 kGy/minute was used to achieve a dose level of 2.5 kGy in the final product. Due to the thickness of the product, only a single sided irradiation pass was necessary. Alanine dosimeters were placed on the top and bottom of one sample per transfer cart. The dosimeters were read using a 104 Electron Paramagnetic Resonance instrument (Bruker Instruments Inc.). After irradiation, product was returned to the boxes and stored at 0-3°C for the duration of the study.

D. pH Analysis

Frankfurter samples were prepared for pH analysis by homogenizing each treatment using a household food processor (Sunbeam Oskar, model 14181). The pH of the product was determined by adding 90 ml of distilled water to a 10g sample of homogenized frankfurter and mixing thoroughly for 30 seconds. The solution was passed through filter paper (Whatman No.125) and the pH of the filtrate was measured using a pH/ion meter (Accumet 925, Fisher Scientific Company). For each treatment measurements were made in duplicate.

E. Chemical Analysis (Fat, Moisture, Protein and TBA)

Fat, moisture and protein determinations were performed for each replication using the Soxhlet apparatus (hexane extraction) (AOAC, 1990), gravity oven drying (AOAC, 1990) and combustion method (AOAC, 1993), respectively.
Lipid oxidation was measured using two thiobarbituric acid reactive substance (TBARS) methods. The first method used to determine oxidation was the TBARS method for cured meats (Zipser and Watts, 1962). Three franks per treatment were homogenized using a household food processor. Samples for proximate analysis and TBARS were taken from the homogenized product.

The second procedure used to measure lipid oxidation was a modified spectrophotometric method of Jo and Ahn (1998). The sulfanilamide reagent of Zipser and Watts (1962) was added because the samples contained nitrite. The meat homogenate was prepared with 15 g of frankfurter, 15 ml of distilled water and 50µL of 7.5% BHT. The meat homogenate (2 mL) was added to 4 mL of 15% TBA/TCA solution and 100µL of sulfanilamide. The treatments were placed in a hot-water bath followed by a cold-water bath and then centrifuged. The procedure was then performed using the Jo and Ahn (1998) method with the only other difference being the increase of centrifuge speed from 2000 rpm to 3110 rpm.

F. Texture Analysis

Texture analysis was performed to determine the outer surface toughness and interior firmness using a TA.XT2 Texture Analyzer (Texture Technologies Corp.). The tests were conducted using a 3 mm diameter stainless steel puncture probe (Model TA-52). The 3 mm probe was programmed to penetrate 12 mm into each frankfurter after the sample’s surface was detected at 12 grams of resistance. The penetration speed was 1.5 mm/second with a pre-test speed of 3.0 mm/second and a post-test speed of 10.0 mm/second. No measurements were conducted within the last 3.2 cm of the end of the frankfurters. The product was removed from the cooler and left at ambient temperatures for 2.5 hours to ensure consistency.
between treatments. Frankfurters were measured for penetration peak force and average interior firmness. The peak force was determined to be the force required to break the outer surface or skin of the frankfurter. The average interior firmness was the force required to penetrate each frankfurter from peak force to 12 mm. For each treatment, two readings were taken per frankfurter and five frankfurters were measured giving a total of 10 measurements per treatment.

G. Purge Loss

Purge loss was determined, for each replication, by weighing each package prior to opening. The packages were opened and the frankfurters and vacuum bag were dried with absorbent towels. The package and frankfurters were then reweighed to determine purge lose. Purge loss was calculated using the following equation:

\[
\frac{\text{Dried frankfurter} - \text{Dried package}}{\text{Initial package} - \text{Dried package}} \times 100
\]

H. Color Analysis

Instrumental color analysis was conducted in triplicate to determine internal frankfurter color. Color readings were taken using a Hunterlab Labscan instrument (model LS, 1500). Color readings evaluated were L* (lightness), a* (redness/greenness) and b* (yellowness/blueness). A port size of 1.27 cm was used with the A illuminant as a light source. Frankfurters were sliced in half longitudinally. The samples were then covered with Saran and readings were taken through the Saran film. Calibrations were conducted after covering the calibration plates with the Saran film. Two reading were taken per frankfurter and three frankfurters were measured giving a total of six measurements per treatment.
I. Sensory Analysis

A nine-member, trained sensory panel was used to evaluate color (both internal and external), flavor, texture and off flavor. The attributes measured and the parameters used as anchored descriptors were internal color (pale-pink), external color (non uniform-uniform), firmness (soft-firm), chewiness (mushy-chewy), off-flavors (intense off-flavors-no off-flavors) and overall frankfurter flavor (bland-full flavor).

The panelists were trained in three separate sessions, prior to the first replication, to evaluate off-flavors by exposing them to frankfurters that had been irradiated at a level of 10.0 kGy and to product that had not been irradiated. Panelists were also exposed to control product and product that was formulated with 80% of the original spice level for training on overall flavor. For all other attributes, training was performed using commercial products that were determined to represent the extremes of each respective parameter. Commercial products were purchased and sampled prior to panel training. Three digit number codes were assigned randomly to each treatment and a 150 mm scale was used (Figure 1).

Frankfurters were cooked in boiling water for 2 minutes then cut into 2-3 cm sections and allowed to cool to ambient temperatures before serving. For color determination, the panelists were given whole cooked frankfurters, one that had been sliced longitudinally and one that was left intact. After color values were determined, the panelists were given two additional 2-3 cm samples to evaluate firmness, chewiness, off-flavors and overall flavor.

J. Statistical Analysis

The experiment was replicated three times over a three-month period. Replications were considered blocks and the six treatments were set up as a 2 X 3 factorial design with the main effects being irradiation and antioxidants. For each response, all sub samples were
Panelist __________
Sample __________
Date __________

Sensory Evaluation of Frankfurters

Step one: Evaluate the internal and external color of the sliced frankfurter provided. Mark with a vertical line your evaluation on the scoring line.

Internal Color:

| Pale | Pink |

External Color:

| Non-uniform | Uniform |

Step Two: Sample the product and follow the instructions given for each attribute. Mark your evaluation with a vertical line on the appropriate scoring line.

Firmness: Place the sample between incisors and bite down evenly. Evaluate the force needed to penetrate through the surface.

| Soft | Firm |

Chewiness: Place the sample between molars and chew. Evaluate the force required to chew through the sample.

| Mushy | Chewy |

Step Three: Sample the second frankfurter, and follow the instructions given for each attribute. Mark your evaluation on the line.

Off flavor: Chew sample normally and swallow or discard. Evaluate any displeasing flavors not normally associated with frankfurters.

| Intense off flavors | No off flavors |

Overall flavor: Chew sample normally and swallow or discard. Evaluate the overall flavor of the sample.

| Bland | Full flavor |

Add any additional comments here:

Figure 1: Sensory form used for Frankfurter evaluation.
arranged to give one mean response per replicate and treatment. Statistical analysis was performed using PROC GLM (SAS, 1990). Proximate analysis data was analyzed using a randomized complete block design without repeated measures because the data was not gathered over the shelf life period. All other data were analyzed using a randomized complete block design with repeated measures that were the storage days.

IV. Results and Discussion

The least square (LS) mean values and least significant differences (LSD) for fat, moisture and protein are presented in Table 3. There is no evidence of any treatments effects on the fat, moisture, or protein content of frankfurter treatments. Tests of the main effects of irradiation, the main effects of antioxidant and the interaction all had p-values larger than 0.05. The proximate analysis results for antioxidants were consistent with those of Resurreccion and Reynolds (1990) who reported no change in percentages.

Table 3. The effect of irradiation dose and antioxidants on the Least Square Means of fat, moisture and protein of frankfurter treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Irradiation (kGy)</th>
<th>Antioxidant</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>LSD^a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>None</td>
<td>Natural</td>
<td>Synthetic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat (%)</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
<td>1.58</td>
</tr>
<tr>
<td></td>
<td>26.62^b</td>
<td>26.17^b</td>
<td>26.75^b</td>
<td>26.87^b</td>
<td>27.47^b</td>
<td>27.60^b</td>
<td></td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>56.25^b</td>
<td>56.71^b</td>
<td>56.30^b</td>
<td>56.33^b</td>
<td>55.86^b</td>
<td>55.64^b</td>
<td></td>
</tr>
<tr>
<td>Protein (%)</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>12.94^b</td>
<td>12.99^b</td>
<td>12.78^b</td>
<td>12.68^b</td>
<td>12.69^b</td>
<td>12.72^b</td>
<td></td>
</tr>
</tbody>
</table>

^a Least Significant Difference
^b Means within a row with different letters are significantly different at P<0.05
Least square means for both TBA methods are reported in Table 4 and varying results were observed. The Zipser and Watts (1962) method showed a significant (P<0.05) decrease in the TBA values of frankfurters with added antioxidants as compared to controls. There was no significant difference between the types of antioxidant whether rosemary oleoresin or the combination of BHT/BHA/CA was used. These results were consistent with those of Resurreccion and Reynolds (1990) and Barbut et al. (1985) who reported a similar decrease in TBA values due to both natural and synthetic antioxidants. This was expected due to the ability of the antioxidants to interrupt the free radical chain of lipid oxidative reactions.

Neither irradiation nor storage time had a significant (P<0.05) affect on TBA values of any frankfurter treatment. This is consistent with the results of Fu et al. (1995) who found no increase in TBA values (due to these factors) in cured ham and cooked pork chops.

Table 4. The effect of irradiation dose and antioxidants on the Least Square Means of thiobarbituric acid values of frankfurter treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Irradiation (kGy)</th>
<th>Antioxidant</th>
<th>None</th>
<th>Natural</th>
<th>Synthetic</th>
<th>LSD^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBA Values^b</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>.315^d</td>
<td>.305^df</td>
<td>.250^e</td>
<td>.254^e</td>
<td>.248^e</td>
<td>.268^ef</td>
</tr>
<tr>
<td>TBA Value^c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>.717^d</td>
<td>.737^d</td>
<td>.618^d</td>
<td>.673^d</td>
<td>.621^d</td>
<td>.634^d</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^a Least Significant Difference
^b Zipser and Watts (1962) method, measured in mg malonaldehyde per kg of sample
^c Jo and Ahn (1998) method, measured in mg malonaldehyde per kg of sample
^d,e,f Means within a row with different letters are significantly different at P<0.05
The second method of Jo and Ahn (1998) produced similar trends, but the differences were not significant with p-values higher than 0.05. Results indicated lower values for antioxidant treatments than controls and higher values for irradiated treatments opposed to the non-irradiated treatments (Table 4) but p-values were greater than 0.05 because the variability between replications was larger than for the Zipser and Watts (1962) TBA values. Both sets of results were in contrast to the work of Shahidi et al. (1991), who reported a beneficial effect of irradiation on TBA values in cured meat. However, they used cooked homogenized pork loins with varying levels of nitrite and irradiation dose levels of 5 and 10 kGy. These differences are probably due to the higher levels of irradiation.

Hunterlab was used to objectively measure the CIE L* (lightness), a* (redness) and b* (yellowness) characteristics taken internally and the effects of irradiation and antioxidants are reported in Table 5. L* values for synthetic antioxidant, non-irradiated frankfurter

<table>
<thead>
<tr>
<th>Item</th>
<th>Irradiation (kGy)</th>
<th>None</th>
<th>Natural</th>
<th>Synthetic</th>
<th>LSD^a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>L *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>70.39^bc</td>
<td>70.72^c</td>
<td>70.53^bc</td>
<td>70.56^c</td>
<td>70.03^b</td>
</tr>
<tr>
<td>a *</td>
<td></td>
<td>18.56^de</td>
<td>18.14^b</td>
<td>18.71^ef</td>
<td>18.43^cd</td>
</tr>
<tr>
<td></td>
<td>17.23^bc</td>
<td>17.10^b</td>
<td>17.48^c</td>
<td>17.25^bc</td>
<td>17.32^bc</td>
</tr>
</tbody>
</table>

^a Least Significant Difference
^b,c,d,e,f Means within a row with different letters are significantly different at P<0.05
treatments was significantly lower (P<0.05) when compared to all other irradiated treatments. Neither antioxidant type had a significant (P<0.05) effect on L* values, when compared to the control. These results are in contrast to those of Fu et al. (1995) who reported that irradiation had no effect on instrumental L* color of cured ham. These differences could be due to the different products and ingredients studied. Resurreccion and Reynolds (1990) also reported no significant difference in L* values due to antioxidants. Also, L* values for irradiated and non-irradiated treatments significantly (P<0.05) increased over storage time (Figure 2).

The a* values for frankfurter treatments were effected by both irradiation and antioxidants. The a* values for the synthetic non-irradiated treatment was significantly higher (P<0.05) than all other treatments with the exception of the natural, non-irradiated treatment, meaning that the use of either antioxidant produced a redder product, when

![Graph showing the effects of irradiation and storage time on L* values.](image-url)
compared to controls. Irradiation had the reverse affect, as a* values were significantly
(P<0.05) decreased, producing a less red product. This is in contrast to the results of Shahidi
et al. (1991) who reported that irradiation did not affect a* values over 3 weeks of storage.
This could be due to the increased irradiation dose used by Shahidi et al. (1991). Also, Chen
et al. (1999) reported an increase in a* values due to irradiation, but this was in raw pork
patties irradiated at 4.5 kGy. Storage time had no significant affect on a* values over the 60
day period, shown by p-values higher than 0.05.

The b* values were found to be lower for irradiated treatments as apposed to non-
irradiated, but the only significant (P<0.05) differences were between the non-irradiated,
natural antioxidant treatment and the irradiated, synthetic antioxidant treatment, and the
irradiated control treatment. This is in contrast to the results of Fu et al. (1995) who reported
no change in b* values of cured ham due to irradiation. These differences could be due to
the different product or the lower irradiation dose used. However, Chen et al. (1999)
reported that irradiation decreased yellowness (b* values) of pork patties. Furthermore,
antioxidants had no effect on the yellowness values of patties. Similar results are reported in
this study, with neither antioxidant type having a significantly (P<0.05) affect on the b*
values of frankfurters. Also, there was no significant (P<0.05) effect on b* values due to
storage time.

The pH of frankfurters was significantly (P<0.05) decreased due the addition of
antioxidants, when compared to the controls (Table 6). Also, there was no difference
between antioxidant types. However, the LSD was 0.03, so the changes in pH were minimal.

Contrasting results were reported by Ho et al. (1995) who showed that antioxidants
had no effect on overall pH of pork sausage as compared to controls. Neither irradiation nor
Table 6. The effects of irradiation dose and antioxidant on the Least Square Means of pH values of frankfurter treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Irradiation (kGy)</th>
<th>Antioxidant</th>
<th>None</th>
<th>Natural</th>
<th>Synthetic</th>
<th>LSD&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH values</td>
<td></td>
<td></td>
<td>6.20&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.19&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>6.17&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>6.19&lt;sup&gt;ed&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Least Squared Means

<sup>b,c,d</sup>Means within a row with different letters are significantly different at P<0.05

storage time affected the pH of frankfurter treatments. These results are similar to those of Fu et al. (1995) who reported no change in pH due to irradiation or storage time.

Purge loss was measured and calculated for each treatment and the results are presented in Table 7. Irradiation had no significant (P<0.05) affect on the of percentage purge loss per treatment. However, on average, antioxidants did lower the percentage purge lose over the control treatments. Rosemary oleoresin did decrease purge lose, but only the combination of BHT/BHA/CA treatments significantly (P<0.05) decreased purge lose when compared to the control. The LSD was .19, so the variation between treatments was relatively small. These differences show that both natural and synthetic antioxidants have an ability to increase water retention.

Texture analysis was conducted to determine the effects of irradiation and antioxidants on the peak force and internal firmness of frankfurters. The results of the texture analysis are presented in Table 8. Irradiation had no significant (P<0.05) affect on the peak force required to penetrate the external skin of each frankfurter treatment. Also,
Table 7. The effects of irradiation dose and antioxidant on the Least Square Means of purge values of frankfurter treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Irradiation (kGy)</th>
<th>None</th>
<th>Natural</th>
<th>Synthetic</th>
<th>LSD^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purge (%)</td>
<td></td>
<td>1.27^c</td>
<td>1.31^c</td>
<td>1.14^b,c</td>
<td>1.15^b,c</td>
</tr>
</tbody>
</table>

^a Least Significant Difference  
^b,c Means within a row with different letters are significantly different at P<0.05

Irradiation did not significantly (P<0.05) affect the interior firmness of frankfurters. Similar results were found in irradiated corn beef brisket and irradiated ground beef (Shults et al., 1977 and Lefebvre et al., 1994). In both studies irradiation had no effect on the texture characteristics, however, they were determined by a sensory panel. Heath et al. (1989) reported no change in the shear force values of irradiated chicken meat due to irradiation.

Antioxidants had conflicting affects on the peak force and interior firmness of frankfurter treatments. The natural antioxidant treatment had a significantly (P<0.05) higher peak force when compared to all other treatments with the exception of synthetic, non-irradiated treatment and the no antioxidant, irradiated treatment. The effect of each type of antioxidant on meat proteins could be the cause of the discrepancy. The combination of BHT/BHA/CA could increase protein denaturation producing a weaker outer surface and a less firm frankfurter internally.

Sensory characteristics were measured using a nine member sensory panel and evaluated over a 60-day period. The sensory characteristics measured included color
Table 8. The effects of irradiation dose and antioxidant on the Least Square Means of peak force and internal firmness values of frankfurter treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Antioxidant</th>
<th>Irradiation (kGy)</th>
<th>None</th>
<th>2.5</th>
<th>Natural</th>
<th>None</th>
<th>2.5</th>
<th>Synthetic</th>
<th>None</th>
<th>2.5</th>
<th>LSD&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Force (g of force)</td>
<td>454.0&lt;sup&gt;b&lt;/sup&gt; 466.7&lt;sup&gt;bc&lt;/sup&gt; 483.7&lt;sup&gt;c&lt;/sup&gt; 482.6&lt;sup&gt;e&lt;/sup&gt; 469.7&lt;sup&gt;bc&lt;/sup&gt; 450.1&lt;sup&gt;b&lt;/sup&gt; 28.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Firmness (g of force)</td>
<td>175.0&lt;sup&gt;d&lt;/sup&gt; 167.9&lt;sup&gt;bc&lt;/sup&gt; 174.7&lt;sup&gt;cd&lt;/sup&gt; 176.7&lt;sup&gt;d&lt;/sup&gt; 167.1&lt;sup&gt;b&lt;/sup&gt; 167.3&lt;sup&gt;bc&lt;/sup&gt; 7.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Least Significant Difference
<sup>b,c,d</sup> Means within a row with different letters are significantly different at P<0.05

(Color evaluation was completed on cooked frankfurters. Internal color was ranked from pale to pink, while external color was judged from non-uniform to uniform. The results of the sensory color evaluation are presented in Table 9. Antioxidant type or presence did not have a significant (P<0.05) effect on the internal or external color of frankfurter treatments. Also, irradiation effects on internal and external color were not significant (P<0.05). These results are consistent with those of Fu et al. (1995) who reported no change in the sensory color scores of irradiated, cooked pork chops and irradiated cured ham. Contrasting results were found in irradiated frankfurters (Terrell et al., 1981). Researchers reported that increased irradiation dose decreased the intensity of frankfurter pinkness, as determined by a sensory panel. These results could be contributed to the irradiation doses
Table 9. The effects of irradiation dose and antioxidants on the Least Square Means of sensory color (internal and external) of frankfurter treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Irradiation (kGy)</th>
<th>Antioxidant</th>
<th>None</th>
<th>Natural</th>
<th>Synthetic</th>
<th>LSD&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td></td>
<td></td>
<td>0</td>
<td>2.5</td>
<td>0</td>
<td>2.5</td>
</tr>
<tr>
<td>Color (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>89.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>88.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>93.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>96.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>96.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>89.4&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>External</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color (mm)</td>
<td></td>
<td></td>
<td>97.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>102.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>98.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>98.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Least Significant Difference
<sup>b</sup>Means within a row with different letters are significantly different at P<0.05

that were 8 and 32 kGy. All frankfurter treatments were deemed visually acceptable, with values on the high end of the 150 mm line scale indicating increased pinkness for internal color and uniformity for external color.

Sensory texture analysis was completed to evaluate the exterior strength (firmness) and the interior composition (chewiness) of the frankfurter treatments. The results of the sensory evaluation of texture are presented in Table 10. A contrasting antioxidant affect (on firmness) was that irradiated and non-irradiated treatments with rosemary oleoresin were significantly (P<0.05) higher than irradiated treatments with a combination of BHA/BHT/CA. No differences were seen in firmness between the non-irradiated treatments with synthetic or natural antioxidants and the control. Overall, irradiation did not significant (P<0.05) affect the firmness values of frankfurter treatments. Neither antioxidant type had a significant (P<0.05) affect on the sensory values of chewiness.
Table 10. The effects of irradiation dose and antioxidants on the Least Square Mean of sensory texture (firmness and chewiness) of frankfurter treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Irradiation (kGy)</th>
<th>None</th>
<th>Natural</th>
<th>Synthetic</th>
<th>LSDa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firmness (mm)</td>
<td>0 2.5</td>
<td>89.5bc 86.5bc 99.1d 96.8cd 92.1cd 79.7b</td>
<td>11.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chewiness (mm)</td>
<td>90.0c 89.8c 94.3c 91.3c 93.6c 80.1b</td>
<td>9.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

aLeast Significant Difference
b,c,d Means within a row with different letters are significantly different at P<0.05

Irradiation did not have a significant (P<0.05) effect on chewiness, except in the treatment with a combination of BHT/BHA/CA. The irradiated, synthetic antioxidant treatment had significantly (P<0.05) lower chewiness value, when compared to all other treatments. In synthetic antioxidant treatments, the use of irradiation appears to produce a mushier frankfurter. With the exception of the irradiated, synthetic antioxidant treatment, these results are consistent with the findings of Shults et al. (1977). These researches reported no significant changes in the texture of corn beef brisket, due to irradiation. However, Terrell et al. (1982) reported a decrease in texture values as irradiation doses were increased. These differences could be due to increased doses of 8 and 32 kGy applied in the study by Terrell et al. (1982).

The flavor of frankfurter treatments was also evaluated using a sensory panel. The flavor characteristics measured were off flavors intensity (intense to no off flavor) and overall flavor strength (bland to full flavor). The results of the sensory evaluation are
presented in Table 11. Antioxidants did not significantly (P<0.05) affect off-flavors or overall flavor, when compared to controls. The interaction between antioxidants and irradiation and the effects on off flavors is shown in Figure 3. These results are in contrast of those of Resurreccion and Reynolds (1990) who reported antioxidant treatments decreased

Table 11. The effects of irradiation dose and antioxidants on the Least Square Means of sensory flavor (off-flavor and overall) of frankfurter treatments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Irradiation (kGy)</th>
<th>Antioxidant</th>
<th>LSD^a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Natural</td>
<td>Synthetic</td>
</tr>
<tr>
<td>Off-Flavor (mm)</td>
<td>0</td>
<td>2.5</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>109.8bcd</td>
<td>102.9bc</td>
<td>109.0bcd</td>
</tr>
<tr>
<td>Overall Flavor (mm)</td>
<td>89.5^bc</td>
<td>86.0^b</td>
<td>93.2^bc</td>
</tr>
</tbody>
</table>

^a Least Significant Difference
^b,c,d Means within a row with different letters are significantly different at P<0.05

off-flavors in frankfurters when compared to controls. Irradiation had no affect on off-flavors or overall flavor, except for the treatment with the combination of BHT/BHA/CA. In the treatment with synthetic antioxidant and irradiation; irradiation significantly (P<0.05) increased off-flavor intensity and decreased overall flavor producing a more bland frankfurter. However, off-flavors and overall flavor of irradiated treatments with synthetic antioxidants were not significantly (P<0.05) different from controls. This indicates that the negative effects of irradiation can be masked by the positive attributes of antioxidants. The
Figure 3. The effects of irradiation dose and antioxidants on the off-flavors of frankfurter treatments.

Irradiated control was higher in off-flavors than the non-irradiated controls, but the difference was not significant (P<0.05).

In summary, vacuum packaged frankfurters with and without antioxidants became lighter (higher L* values) and less red (lower a* values) due to the addition of a 2.0 kGy dose of electron beam irradiation. Also, all treatments became lighter (higher L* values) over the 60-day storage period. Antioxidants decreased TBA values (Zipser and Watts, 1962) when compared to controls. Both rosemary oleoresin and a combination of BHT/BHA/CA produced TBA values in irradiated frankfurters that were lower than either irradiated or non-irradiated controls. Neither antioxidants nor irradiation had effects on the sensory evaluation of internal and external color. Sensory evaluation of texture showed that irradiated frankfurters with a combination of BHT/BHA/CA were softer and mushier than any of the other treatments. Furthermore, the irradiation of synthetic antioxidant treatments produced
higher levels of off-flavors and lower values for overall flavor than non-irradiated synthetic antioxidant treatments. The flavor values were similar to the values for the control treatment.

V. Conclusions

The results of this study indicate that natural antioxidants can be used in irradiated frankfurters to reduce lipid oxidation, without significantly affecting product quality. This study also indicates that synthetic antioxidants can reduce lipid oxidation, but processors need to be aware of the possibility of texture and flavor differences. There may also be instrumental color differences because of the use of irradiation and antioxidants, but these changes were not noticeable to the sensory panelists used in this study. These results would indicate that antioxidants could be used in irradiated frankfurters to produce a pathogen free, high quality product.

VI. References


Table 12. P values for significance of irradiation treatments, antioxidant treatments, and irradiation*antioxidant interactions.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Antioxidant</th>
<th>Irradiation</th>
<th>Antioxidant*Irradiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat (%)</td>
<td>0.12</td>
<td>0.88</td>
<td>0.80</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>0.21</td>
<td>0.78</td>
<td>0.70</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>0.35</td>
<td>0.96</td>
<td>0.91</td>
</tr>
<tr>
<td>TBA Values&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.0005</td>
<td>0.71</td>
<td>0.64</td>
</tr>
<tr>
<td>TBA Values&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.25</td>
<td>0.57</td>
<td>0.94</td>
</tr>
<tr>
<td>L *</td>
<td>0.42</td>
<td>0.034</td>
<td>0.29</td>
</tr>
<tr>
<td>a *</td>
<td>0.037</td>
<td>0.0001</td>
<td>0.36</td>
</tr>
<tr>
<td>b *</td>
<td>0.15</td>
<td>0.023</td>
<td>0.72</td>
</tr>
<tr>
<td>pH values</td>
<td>0.0025</td>
<td>0.34</td>
<td>0.21</td>
</tr>
<tr>
<td>Purge (%)</td>
<td>0.0052</td>
<td>0.72</td>
<td>0.97</td>
</tr>
<tr>
<td>Peak Force</td>
<td>0.036</td>
<td>0.75</td>
<td>0.28</td>
</tr>
<tr>
<td>Internal Firmness</td>
<td>0.0089</td>
<td>0.46</td>
<td>0.20</td>
</tr>
</tbody>
</table>

**Sensory Values**

<table>
<thead>
<tr>
<th></th>
<th>Antioxidant</th>
<th>Irradiation</th>
<th>Antioxidant*Irradiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Color</td>
<td>0.15</td>
<td>0.54</td>
<td>0.20</td>
</tr>
<tr>
<td>External Color</td>
<td>0.14</td>
<td>0.66</td>
<td>0.59</td>
</tr>
<tr>
<td>Firmness</td>
<td>0.0078</td>
<td>0.08</td>
<td>0.39</td>
</tr>
<tr>
<td>Chewiness</td>
<td>0.22</td>
<td>0.05</td>
<td>0.13</td>
</tr>
<tr>
<td>Off-Flavor</td>
<td>0.57</td>
<td>0.023</td>
<td>0.049</td>
</tr>
<tr>
<td>Overall Flavor</td>
<td>0.60</td>
<td>0.036</td>
<td>0.63</td>
</tr>
</tbody>
</table>

<sup>a</sup> Zipser and Watts (1962) method
<sup>b</sup> Jo and Ahn (1998) method
CHAPTER 4. GENERAL CONCLUSION

The use of irradiation to produce a pathogen-free frankfurter after packaging is a beneficial procedure that can be accomplished. However, detrimental effects on product color were seen in this study when irradiated treatments were compared with non-irradiated treatments. Irradiation produced a lighter (increased L*) and less red (decreased a*) product when compared to non-irradiated product. Antioxidants increased a* values when compared to controls and increased the values in irradiated treatments as well, but were not always significant. Irradiation did not have negative effects on the TBA values of frankfurter treatments as was expected. The antioxidant effect of normal frankfurter ingredients, such as sodium nitrite and sodium erythorbate, may be responsible for the similar results. As expected, antioxidants significantly (P<0.05) decreased TBA values when compared to irradiated and non-irradiated controls. These beneficial effects of antioxidants can be utilized to decrease oxidative rancidity, which can only improve product quality and consumer acceptance.

Objective color differences were not noticeable to the trained sensory panel. Panelists saw no differences in internal or external frankfurter color due to irradiation, antioxidant type or presence of antioxidants. Both rosemary oleoresin treatments (irradiated and non-irradiated) and the non-irradiated treatment with a combination of BHT/BHA/CA lowered off-flavors and improved overall flavor when compared to controls. However, these changes were not significant (P<0.05). On the other hand the irradiated treatment with a combination of BHT/BHA/CA had significantly (P<0.05) higher off-flavors than the non-irradiated, BHT/BHA/CA treatment. The overall flavor of the irradiated, BHT/BHA/CA treatment was lower than that of the non-irradiated BHT/BHA/CA treatment. This may be
the result of an unknown reaction in the BHT/BHA/CA combination caused by irradiation. Processors need to be aware of these changes caused by synthetic antioxidants when used in irradiated frankfurters. Another option is natural antioxidants that can be utilized in irradiated frankfurters to reduce lipid oxidation without significantly affecting product quality. Sensory panelists found no detrimental effects resulting from the addition of natural antioxidants. These results indicate that the addition of antioxidants to irradiated frankfurters produces a high quality, safe product.
ACKNOWLEDGEMENTS

There are many people who need to be recognized for their contribution to this project and the completion of my Master’s degree. First, I would like to thank Dr. Joe Cordray for showing me guidance and direction over the past two years of school. Your professional advice, encouragement, assistance and friendship have been extremely valuable. I also appreciate the opportunities and responsibilities you allowed me to partake in, both at Iowa State University and abroad.

I need to give special recognition to the Iowa State Meat Laboratory staff and crew for the help and support provided not only throughout this project, but also for as long as I’ve been at the Meat Laboratory. The aid during this project covered everything from raw materials to the irradiation of finished product and clean up, for that I am very appreciative. Randy Petersohn, Jim O’Brien, Jerry Knight, Mike Holtzbauer, Vail Olson and Pat Hosch: I am especially thankful for all you have done for me and all you have taught me in these past few years.

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