Physico-chemical and sensory properties of polyphosphate-treated, irradiated, pre-cooked beef

by

NANDI NICOLENE DERSLEY

Submitted in partial fulfilment of the requirements for the degree

MSC FOOD SCIENCE

in the Department of Food Science
Faculty of Natural and Agricultural Sciences
University of Pretoria
Pretoria
South Africa

December 2003
I declare that the dissertation, which I hereby submit for the MSc degree in Food Science at the University of Pretoria is my own work and has not been previously submitted by me for a degree at any other University or institution of higher education.

[Signature]

2004/3/14
ABSTRACT

PHYSICO-CHEMICAL AND SENSORY PROPERTIES OF POLYPHOSPHATE TREATED,
IRRADIATED PRECOOKED BEEF

Candidate: Nandi Nicolene Dersley
Leader: Prof A Minnaar
Co-leader: Mrs C Erasmus
Department: Food Science
Degree: MSc Food Science

Irradiation sterilization of precooked, hermetically sealed meat provides a shelf-stable, ready-to-eat product that can be stored for long periods of time without refrigeration. The Atomic Energy Corporation of South Africa started to develop precooked, shelf-stable meat products during the late 1970’s, using gamma radiation from a $^{60}$Co source at dose levels of at least 45 kGy. A number of meat dishes were successfully developed though problems were experienced with the texture of dry-packed roast beef slices, as these were found to be slightly dry.

Polyphosphates can possibly be used to alleviate the textural problems found in precooked irradiation-sterilized meat because polyphosphates are known to increase the water binding properties of meat proteins, resulting in a juicy, tender product. The choice of cattle breed used for the preparation of precooked meat dishes may also affect cooked meat texture, due to genotypic differences in the amount and especially the solubility of collagen.

*Biceps femoris* and *semitendinosus* muscles obtained from Afrikaner (*Bos Indicus*), Hereford (*Bos Taurus*) and Simmenthal (*Bos Taurus*) steers were treated with low levels of sodium tri polyphosphate (0.3 % and 0.5 %) and tetrasodium pyrophosphate (0.22 % and 0.36 %) in combination with 0.7 % salt. The precooked meat was vacuum packed in flexible pouches and irradiated in the frozen state (-40 °C) with a...
$^{60}$Co gamma source until a minimum target dose of 45 kGy was reached. Various physico-chemical tests as well as descriptive generic sensory evaluation were performed on the samples to determine the effect of breed, polyphosphate treatment and irradiation on the physico-chemical and sensory properties of irradiated precooked beef.

Cattle breed affected the texture of precooked, irradiated, shelf-stable beef, with Afrikaner biceps femoris giving a more tender, juicy product than that of Hereford and Simmental. The low levels of polyphosphates used in combination with salt successfully increased the juiciness and tenderness of precooked, shelf-stable beef. There was little difference in the physico-chemical and sensory results obtained from samples treated with the two different polyphosphates, or the level at which the polyphosphates were administered.

Irradiation sterilisation of precooked beef resulted in a tender product. Comparison of irradiated and non-irradiated samples revealed that the irradiated samples had longer sarcomere and I-band lengths, and shorter A-band lengths, which explained the increased tenderness in irradiated samples. An increase in both soluble collagen and % collagen solubility after irradiation sterilization further substantiated the tenderness results. Treatment of the biceps femoris with low levels of sodium tripolyphosphate or tetrasodium pyrophosphate in combination with salt, prior to cooking and irradiation, resulted in a juicy, shelf-stable product.

Irradiation sterilisation did, however, produce a detectable wet dog flavour and aroma, and more research is required into improving the flavour and aroma of irradiation sterilized beef.

Although this research indicated that irradiation of cooked, polyphosphate treated Afrikaner meat resulted in the most tender and juicy end-products, it is recommended that sensory evaluation using a consumer panel also be conducted, in order to determine if this level of tenderness is acceptable, or if it is over tender due to excessive degradation of the connective tissue.
ACKNOWLEDGEMENTS

My heartfelt gratitude and appreciation go to the following individuals for their help and assistance with this project:

My Mother, whose love, encouragement and support enabled me to complete this project.

Prof Amanda Minnaar and Mrs Corinda Erasmus, my supervisors, for their guidance, encouragement and critical review of this dissertation.

NECSA, previously AEC, for their financial assistance and irradiation of the samples.

Johanna Ramorola, who assisted me with the preparation for the sensory evaluation, as well as my trained panel: Betty, Sharné, Deliwe, Dimakatso, Elmarie, Josiah, Khosi, Lethabo, Lungisa, Mamodishe and Paballo.

Mr Alan Hall from the Electron Microscopy division at UP, for his kind assistance with the electron microscopy, and Mrs Lorinda Frylinck from ARC ANPI, for performing the collagen determinations.

Mrs Rene Ehlers and Dr Riëtte de Kock, for their help with the statistical analysis of my data.

Friends and colleagues in the Department of Food Science, for their interest and encouragement.

Most of all to my Heavenly Father, who blessed me abundantly.
## TABLE OF CONTENTS

**LIST OF TABLES** ............................... IV

**LIST OF FIGURES** ............................. VI

**1. INTRODUCTION** ........................ 1

**2. LITERATURE REVIEW** .................. 3

### 2.1 Meat structure and composition .......... 3
  2.1.1 Structure of meat ...................... 3
  2.1.2 Proteins of the muscle cell .......... 5

### 2.2 Meat texture .............................. 6
  2.2.1 Tenderness .............................. 7
    2.2.1.1 Myofibrillar tenderness .......... 8
    2.2.1.2 Connective tissue aspects .. 9
    2.2.1.3 Tenderness determination .... 10
  2.2.2 Juiciness ............................... 11
  2.2.3 Effect of cattle breed on texture ..... 12

### 2.3 Meat flavour and aroma ............... 14

### 2.4 Irradiation of meat and chemical consequences .......... 15
  2.4.1 Introduction ........................... 15
  2.4.2 Irradiation sterilisation of meat ...... 15
    2.4.2.1 Heating ....................... 16
    2.4.2.2 Vacuum/Modified Atmosphere ... 17
    2.4.2.3 Cryogenic temperature ...... 17
    2.4.2.4 Use of additives ............. 18
  2.4.3 Effects of ionising radiation on meat proteins ... 19
  2.4.4 Effect of irradiation on meat texture ...... 21
  2.4.5 Effect of irradiation on meat flavour .... 22

### 2.5 Polyphosphates .......................... 23
  2.5.1 Chemical properties and functions of polyphosphates ...... 23
2.5.2 Effect of polyphosphates on meat ................................................................. 24
2.5.3 Effect of polyphosphates on irradiated meat .................................................... 28

3. OBJECTIVES AND HYPOTHESES........................................................................ 29
3.1 Objectives ............................................................................................................. 29
3.2 Hypotheses ........................................................................................................... 29

4. MATERIALS AND METHODS ............................................................................. 30
4.1 Experimental design .......................................................................................... 30
4.2 Sample preparation ............................................................................................. 30
   4.2.1 Raw material ................................................................................................... 30
   4.2.2 Polyphosphate treatments ............................................................................. 30
   4.2.3 Cooking, packaging and freezing ................................................................. 33
   4.2.4 Irradiation processing .................................................................................... 33
4.3 Analyses of samples ......................................................................................... 34
   4.3.1 pH measurements .......................................................................................... 34
   4.3.2 % Total cooking loss ....................................................................................... 34
   4.3.3 Instrumental texture measurements .............................................................. 34
   4.3.4 Generic descriptive sensory evaluation ......................................................... 35
      4.3.4.1 Recruitment and introduction .................................................................. 35
      4.3.4.2 Screening of panellists ............................................................................. 36
      4.3.4.3 Training .................................................................................................... 37
      4.3.4.4 Sensory evaluation of test samples .......................................................... 41
   4.3.5 Collagen determinations ................................................................................. 42
   4.3.6 Determination of sarcomere, I-band and A-band lengths using electron microscopy 43
4.4 Statistical analysis ............................................................................................. 44

5. RESULTS ............................................................................................................... 45
5.1 Phase 1: The effect of breed, polyphosphate treatment and irradiation on the physico-chemical and sensory properties of cooked beef ............ 45
   5.1.1 pH measurements ......................................................................................... 45
5.1.2 Total cooking loss .......................................................................................... 45
5.1.3 Instrumental texture measurements ............................................................. 48
5.1.4 Descriptive sensory evaluation .................................................................... 51

5.2 Phase 2: The effect of polyphosphate treatment and irradiation on the internal structure of myofibrillar components and collagen content and solubility of cooked beef ........................................................................................................... 57
5.2.1 Determination of sarcomere, I-band and A-band lengths using electron microscopy 57
5.2.2 Collagen determinations .............................................................................. 63

5.3 Principal component analysis (PCA) of average physico-chemical and sensory data ................................................................................................................................. 64
5.3.1 PCA for the effect of pH, cooking loss, instrumental texture measurements and sensory analysis over all the breeds and polyphosphate treatments .......................................................................................... 64
5.3.2 PCA for the effect of instrumental texture measurements and sensory analysis over all the breeds, polyphosphate treatments and irradiation treatment ........................................................................ 67
5.3.3 PCA for the effect of instrumental texture measurements, sensory analysis, sarcomere, A- and I-band lengths and collagen content and solubility for Hereford samples treated with selected polyphosphate treatments and irradiation treatment, analysed in Phase 2 .............................................................................................................. 70

6. DISCUSSION ..................................................................................................... 73
6.1 Effect of breed on physico-chemical and sensory properties of beef ............ 73
6.2 Effect of polyphosphate treatment on the physico-chemical and sensory properties of precooked beef .......................................................................................................................... 75
6.3 Effect of irradiation on the physico-chemical and sensory properties of precooked, shelf-stable beef ................................................................. 80

7. CONCLUSIONS AND RECOMMENDATIONS ............................................. 84

8. REFERENCES ................................................................................................. 86
LIST OF TABLES

Table 1: Concentrations of polyphosphate and NaCl in brine solutions that were administered to biceps femoris and semitendinosus samples from three cattle breeds.......................................................... 32

Table 2: Triangle tests used for the initial screening of candidates................................. 36

Table 3: Triangle tests used for further screening of candidates....................................... 37

Table 4: Training sessions for descriptive panel............................................................... 38

Table 5: Score sheet used by the descriptive panel ......................................................... 40

Table 6: Definitions of sensory attributes used in the score sheet................................. 41

Table 7: The effect of different polyphosphate treatments on the pH of raw beef semitendinosus and biceps femoris muscles from different cattle breeds................................. 46

Table 8: The effect of different polyphosphate treatments on the % total cooking loss that occurred during oven roasting of M. semitendinosus and M. biceps femoris from different cattle breeds.......................................................... 47

Table 9: The overall effect of irradiation on the texture of cooked of M. biceps femoris...... 49

Table 10: The overall effect of breed on texture of cooked M. biceps femoris.................. 49

Table 11: The overall effect of polyphosphate treatments on the objective texture measurements of M. biceps femoris.................................................................................. 50

Table 12: The overall effect of breed on the sensory characteristics of cooked beef M. biceps femoris .............................................................................................. 53

Table 13: The overall effect of polyphosphate treatments on the sensory characteristics of cooked beef M. biceps femoris .......................................................................................... 54

Table 14: Correlations between sensory texture characteristics and physico-chemical measurements of polyphosphate treated samples (Treatments 1 to 6).............. 57

Table 15: The overall effect of irradiation on the sensory characteristics of cooked beef M. biceps femoris .............................................................................................. 58

Table 16: The effect of different polyphosphate treatments on the Sarcomere, A-band and I-band lengths (µm) of precooked non-irradiated Hereford M. biceps femoris .................................................................................. 62

Table 17: The effect of irradiation on the Sarcomere, A-band and I-band lengths of precooked Hereford M. biceps femoris .............................................................................. 63
Table 18: The effect of different polyphosphate treatments on the collagen content (mg/g cooked meat) and % collagen solubility of frozen and irradiated, cooked Hereford M. biceps femoris ................................................................. 63

Table 19: Eigenvalues and percentage variance for the PCA performed on the average pH, cooking loss, instrumental texture measurement scores and sensory scores over all the breeds and polyphosphate treatments ........................................ 65

Table 20: Factor loadings for the PCA performed on the average pH, cooking loss, instrumental texture measurement scores and sensory scores over all the breeds and polyphosphate treatments ........................................ 65

Table 21: Eigenvalues and percentage variance for the PCA performed on the average instrumental texture measurement scores and sensory scores over all the breeds, polyphosphate treatments and irradiation treatment ........................................ 68

Table 22: Factor loadings for the PCA performed on the average instrumental texture measurement scores and sensory scores over all the breeds, polyphosphate treatments and irradiation treatment ........................................ 68

Table 23: Eigenvalues and percentage variance for the PCA performed on the average instrumental texture measurement scores, sensory scores, A- and I-band lengths and collagen content and solubility for Hereford samples treated with selected polyphosphate treatments and irradiation processing ........................................ 71

Table 24: Factor loadings for the PCA performed on the instrumental texture measurement scores, sensory scores, A- and I-band lengths and collagen content and solubility for Hereford samples treated with selected polyphosphate treatments and irradiation treatment ........................................ 71
LIST OF FIGURES

Figure 1: Structural hierarchy of a muscle (Tornberg, 1996) .................................................................. 3

Figure 2: Characteristic striated appearance of a longitudinal section of a muscle fibril (Foegeding et al., 1996) .................................................................................................................. 4

Figure 3: Basic structure of tetrasodium pyrophosphate (Na₄P₂O₇) (Dziezak, 1990) ................. 23

Figure 4: Basic structure of sodium tripolyphosphate (Na₃P₃O₁₀) (Dziezak, 1990) ............... 23

Figure 5: Experimental design for determining the effect of breed, polyphosphate treatment and irradiation on the physico-chemical and sensory properties of precooked beef ........................................................................................................................................ 31

Figure 6: The effect of cattle breed and polyphosphate treatment on % total cooking loss of semitendinosus and biceps femoris muscles, showing interaction between breed and polyphosphate treatment ........................................................................................................... 48

Figure 7: Interaction between breed and polyphosphate treatments in terms of maximum load (N) ........................................................................................................................................ 51

Figure 8: Interaction between breed and polyphosphate treatments in terms energy at break point (J) ........................................................................................................................................ 52

Figure 9: Electron micrographs (magnification x 9,800) of longitudinal sections of cooked M. biceps femoris muscles treated as follows: (A) no additives, non-irradiated; (B) no additives, irradiated; (C) salt only, non-irradiate; (D) salt only, irradiated ........................................................................................................................................ 59

Figure 10: Electron micrographs (magnification x 9,800) of longitudinal sections of cooked M. biceps femoris muscles treated as follows: (A) 0.5 % sodium tripolyphosphate, non-irradiated; (B) 0.5 % sodium tripolyphosphate, irradiated; (C) 0.36 % tetrasodium pyrophosphate, non-irradiated; (D) 0.36 % tetrasodium pyrophosphate, irradiated ........................................................................................................................................ 61

Figure 11: PCA plot for the mean pH, cooking loss, instrumental texture measurement scores and sensory scores over all the breeds and polyphosphate treatments, as defined by the first two principal components ........................................................................................................... 66

Figure 12: Combined PCA plot for the mean pH, cooking loss, instrumental texture measurement scores and sensory scores over all the breeds and polyphosphate treatments, as defined by the first two principal components .... 66
Figure 13: PCA plot for the mean instrumental texture measurement scores and sensory scores over all the breeds, polyphosphate treatments and irradiation treatment, as defined by the first two principal components .................. 69

Figure 14: Combined PCA plot for the mean pH, cooking loss, instrumental texture measurement scores and sensory scores over all the breeds, polyphosphate treatments and irradiation treatment, as defined by the first two principal components ................................ 69

Figure 15: PCA plot for the mean instrumental texture measurement scores, sensory scores, A- and I-band lengths and collagen content and solubility for Hereford samples treated with selected polyphosphate treatments and irradiation processing, as defined by the first two principal components ....................... 72

Figure 16: Combined PCA plot for the mean instrumental texture measurement scores, sensory scores, A- and I-band lengths and collagen content and solubility for Hereford samples treated with selected polyphosphate treatments and irradiation processing, as defined by the first two principal components .......... 72