

PROCESSING AND PRODUCTS

Effect of Meat Temperature on Proteins, Texture, and Cook Loss for Ground Chicken Breast Patties¹

R. Y. Murphy and B. P. Marks²

Department of Biological and Agricultural Engineering, University of Arkansas, Fayetteville, Arkansas 71701

ABSTRACT Soluble proteins, myofibrillar proteins, collagen, texture, and cook loss were evaluated at different meat temperatures by heating ground and formed chicken breast meat in brass containers in a water bath to temperatures of 40, 50, 60, 70, or 80 C. The soluble proteins decreased by approximately 90% as meat temperature increased from 23 to 80 C. The myofibrillar protein subunits of molecular weight greater than 43 kDa decreased with increasing temperature from 23 to 80 C

as analyzed *via* SDS-PAGE. Amount of soluble collagen more than doubled when meat temperature was increased from 50 to 70 C. The maximum peak shear force was obtained, *via* Warner-Bratzler shear test, at 60 C for ground chicken breast patties. The weight of patties decreased approximately 10.3% when meat temperatures were increased from 23 to 80 C. Overall, heating temperature affected the texture of the meat and caused changes in proteins and cook loss.

(Key words: texture, protein, thermal processing, cook loss, poultry)

2000 Poultry Science 79:99–104

INTRODUCTION

When manufacturing precooked meat products, process temperatures strongly influence texture, protein changes, cooking yield, and other important quality factors such as juiciness, color, and flavor (Bertola *et al.*, 1994; Bouton *et al.*, 1981; Dumoulin *et al.*, 1998; Martens *et al.*, 1982; Paul, 1963). The relationships between processing temperature and these quality factors are important in improving the design and operation of thermal processes for foods (Rao and Lund, 1986).

For example, heating temperatures have been shown to affect the texture of beef muscle. Bramblett *et al.* (1959), Marshall *et al.* (1960), and Penfield and Meyer (1975) believed that a lower cooking temperature yielded a more tender product with lower cooking losses. Davey and Gilbert (1974) evaluated the relationship between texture and heating temperature using small beef samples and found that the texture varied in a temperature range of 40 to 75 C. Machlik and Draudt (1963) studied the effect of heating temperature on changes in force required to shear small cylinders of beef and found a decrease in toughness from 58 to 60 C and an increase from 65 to 75 C.

Texture changes during processing are a result of complex chemical changes (Barrett *et al.*, 1998; He and Sebranek, 1996; DeFreitas *et al.*, 1997; Rao and Lund, 1986) related

primarily to the muscle fibers (Rowe, 1974) and connective tissue fibers (Hearne *et al.*, 1978). The relationship between texture and heat-induced denaturation of meat protein has been reported for beef (Martens *et al.*, 1982; Findlay *et al.*, 1986; Bertola *et al.*, 1994). Temperature also affects the solubility of the meat proteins (Bouton and Harris, 1972). However, results for heat-induced changes of connective tissue in relation to texture vary (Hearne *et al.*, 1978), and conflicting explanations have been given for the relationship between texture and protein changes during thermal processing of beef muscles (Bailey, 1984; Laakkonen *et al.*, 1970; Bertola *et al.*, 1994; Paul *et al.*, 1973; Bouton and Harris, 1972; Bouton *et al.*, 1974; Bailey, 1984). The texture of cooked meat is generally considered to be affected by heat-induced changes in connective tissue, soluble proteins, and myofibrillar proteins. The cross-linkage between the collagen molecules within the connective tissue is associated with collagen solubility (Zayas and Naewbanij, 1986). Changes in collagen solubility during heating could significantly influence the texture of poultry meat (Zayas and Naewbanij, 1986).

The Warner-Bratzler shear test is commonly used for determining meat texture (Lanari *et al.*, 1987; Zhang and Mittal, 1993). Bouton and Harris (1972) used peak shear forces from Warner-Bratzler tests to relate texture to changes in meat proteins. When there are large differences in collagen content (connective tissue) among meat samples, Warner-Bratzler shear force has correlated poorly with the texture assessment (Penfield and Meyer, 1975). How-

Received for publication June 8, 1998.

Accepted for publication August 11, 1999.

¹Published with the approval of the Director, Arkansas Agricultural Experiment Station, manuscript No. 98054.

²To whom correspondence should be addressed: marksbp@egr.msu.edu.

Abbreviation Key: MSE = mean standard error.

ever, chicken breast muscle contains a low level of collagen (Dawson *et al.*, 1991).

Collagen is distributed in a fine state of subdivision throughout the muscle, and changes in connective tissue during cooking are important to meat quality (Winegarden *et al.*, 1952). Although the collagen content of ground chicken breast patties is low in comparison to that of the various beef muscles evaluated by other researchers (Hearne *et al.*, 1978; Bertola *et al.*, 1994; Paul *et al.*, 1973), changes in collagen solubility with heating temperature could still affect the textural and water-binding properties of the product (Eilert and Mandigo, 1993).

Heat-induced changes in protein solubility also relate to changes in water-holding capacity of meat (Bouton and Harris, 1972). Because of protein changes with heating, water content within the meat myofibrils in the narrow channels between the filaments changes as meat shrinks within the tissue matrix (Bertola *et al.*, 1994), resulting in cook loss with heating. Meat can shrink in two dimensions (length and width) and expand in the third dimension (Offer *et al.*, 1984; Rowe, 1974). The extent of meat shrinkage and expansion varies with different muscles and the meat temperature (Winegarden *et al.*, 1952). The change in water content also contributes to changes in sarcomere length and juiciness with temperatures (Laakkonen *et al.*, 1970; Bouton *et al.*, 1975).

Most previous reports have focused on the effects of heat treatment on the structure of muscle fibers in relation to the texture of beef (Bertola *et al.*, 1994; Yu and Lee, 1986; Zayas and Naewbanij, 1986). Limited publications have been found on the effects of thermal processing on the texture of chicken (Dawson *et al.*, 1991) and chicken products. The objective of this study was to evaluate changes in proteins, texture, and mass of ground chicken breast patties at different meat temperatures.

MATERIALS AND METHODS

Approximately 5 kg 100% ground and formed chicken breast patties (114.3 mm diameter × 14.8 mm thick; average, 53 g) were obtained from a commercial processor. For proximate analysis, six original patties were tested. For the thermal treatments, the original patties were cut into smaller patties (50.8 mm diameter × 14.8 mm thick). For each thermal treatment, 21 of these samples were individually processed. From these processed samples, 12 were used to analyze cook loss. Then, a smaller (25.4 mm diameter) disc was bored, with a boring device, from the center of each of the 21 samples. From these 21 discs, 12 were used for texture analyses, three were used for the analyses of soluble proteins and SDS-PAGE, and six were used for collagen solubility analyses. For the uncooked meat, six patties were used for the analyses of soluble proteins, SDS-PAGE, and collagen solubility; 12 other raw patties were also subsampled *via* a 25.4 mm-diameter boring device and used for texture analysis.

Sample Composition

Proximate analyses on the chicken patties were carried out per AOAC procedures in sections 950.46B, 981.10, 985.15, and 900.02A (AOAC, 1990). The total water content was $78.6 \pm 1.2\%$ (w/w, wet basis), using an oven drying method at 110 C for 24 h. The total protein content was $95.2 \pm 0.6\%$ (w/w, dry basis), using the Kjeldahl method. The total lipid content was $0.15 \pm 0.08\%$ (w/w, dry basis), using the Soxhlet method. The total ash content was $2.1 \pm 0.3\%$ (w/w, dry basis), using a gravimetric method by heating the sample at 550 C in a muffle furnace for 24 h.

Temperature Treatment

Prior to the thermal treatments, the original meat patties were cut into discs (50.8 mm diameter × 14.8 mm thick), placed into a brass container (51 mm diameter × 15.0 mm height × 0.038 mm wall thickness), and immersed in a thermostatic water bath (± 0.1 C) at a temperature of 40, 50, 60, 70, or 80 C. Temperature was monitored at the center of the sample *via* a Type E thermocouple. The treatment was stopped when the meat center differed <0.2 C from the bath temperature (within 17 to 20 min). After each heat treatment, samples were removed from the thermostatic bath and cooled by immersing the sample container in an ice-water bath until the sample center reached 23 C (within 3 to 4 min). During each experiment, thermocouples were also used to monitor the temperatures of the sample surface, the midpoint between the center and the surface, and both water baths (heating and cooling).

The thermally processed samples were allowed to equilibrate at ambient temperature for 15 min prior to the analytical procedures for cook loss and texture. The samples for soluble proteins, SDS-PAGE, and collagen analyses were placed in a freezer (-20 C) immediately after the thermal treatments and subsequently analyzed within 3 d.

Soluble Proteins

Both cooked and uncooked meat samples were freeze-dried, ground, and dissolved in a 0.05 M potassium phosphate buffer solution with 0.1M NaCl, 5 mM EDTA, and 1 mM NaN₃ at pH 7.4 (Lan *et al.*, 1995). The sample solution (2%, w/v) was gently shaken on an oscillator for approximately 16 h to allow a complete extraction and then centrifuged for ~1 min at $8,000 \times g$. Soluble proteins were determined by analyzing the supernatant using the Bradford method (Bradford, 1976) and expressed as a percentage of the total soluble proteins in the sample (w/w, dry basis). Bovine serum albumin³ was used as the protein standard.

Sodium Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis

Cooked and uncooked meat samples were freeze-dried and subjected to SDS-PAGE (sodium dodecyl sulfate-polyacrylamide gel electrophoresis), according to the procedures described by Claeys *et al.* (1995). Protein solutions of

³Sigma Chemical Co., St. Louis, MO 63178.

0.1% (w/v) were obtained by dissolving the meat samples in 10% SDS solution. After mixing with the loading buffer at a ratio of 1:3 (sample solution:loading buffer), 10 μ l of each protein solution were loaded on a 4 to 20% acrylamide gel. The molecular weights of the protein subunits were determined using a densitometer by the comparison of their relative mobilities of migration with those of protein molecular weight standards (high range molecular weight standards⁴ for SDS-PAGE).

Collagen Solubility

Prior to collagen analysis, cooked and uncooked samples were thawed in the refrigerator (4 C) for 8 h and then allowed to equilibrate at ambient temperature for 30 min. The effect of meat temperatures on the connective tissue of the ground chicken breast patties was determined by the hydroxyproline solubility in the samples (Pool, 1967). Meat samples (6 g) were treated according to the preparation procedures of Eilert and Mandigo (1993) for analyzing the soluble and insoluble collagen in meat products. The soluble and insoluble hydroxyproline contents were determined using the rapid procedure of Bergman and Loxley (1963). Collagen values were expressed as milligrams collagen per gram sample (wet basis), using hydroxyproline conversion values of 7.25 and 7.52 for insoluble and soluble collagen, respectively. Solubility of collagen, which reflects the degree of collagen crosslinking, was expressed as a percentage of the soluble collagen in the total collagen (w/w).

Texture

The Warner-Bratzler shear test (Lyon *et al.*, 1998) was used to evaluate the texture of the ground chicken breast patties after thermal processing. Mechanical properties of the meat were tested by Warner-Bratzler shear on a universal testing machine,⁵ with a shear speed of 40 mm/min. The shear blade was applied perpendicularly to the disc axis, and peak force was determined as the maximum force during shearing.

Cook Loss

After heating, samples were removed from the container, blotted with a paper towel, and weighed to determine the cook loss. The mass changes were expressed as a percentage of initial mass (w/w, wet basis). Because the change in water content was evaluated with relatively small samples (30 g), the data obtained in this study would not fully represent the water diffusion that might occur in larger meat products or in different cooking environments. Nonetheless, the comparative study of mass change as presented in this study should still yield insight about the ability of the meat to hold water after various heating treatments.

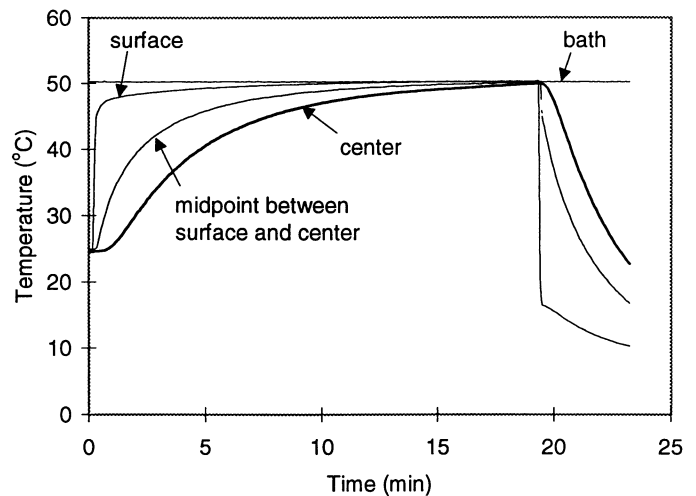


FIGURE 1. Example of thermal history of chicken breast patties ($n = 21$) at a bath temperature of 50 C for the sample surface, center, and midpoint between the surface and center.

Overall Statistics

For soluble proteins, collagen, toughness, and cook loss, averages and standard deviations were computed from 3, 6, 12, and 12 samples, respectively, at each temperature treatment. Analyses of variance and correlation analyses were performed among meat temperature, soluble proteins, soluble collagen, peak force, and cook loss. Model fitting was conducted using standard least squares. Statistical evaluation was performed *via* SAS software (SAS Institute, Inc., Cary, NC, 1998). For SDS-PAGE, based on the comparison analysis using a densitometer, the electrophoretic results were identical in all runs ($n > 6$) for the samples with the same temperature treatments.

RESULTS AND DISCUSSION

Thermal History

Meat samples were processed until center temperatures were in equilibrium with the bath temperature (i.e., within 0.2 C), which ensured that the final temperature profile was uniform within the sample (Figure 1).

Soluble Proteins

The total soluble proteins decreased ($P < 0.0001$) with increasing meat temperatures (Table 1). At 40, 50, 60, 70, and 80 C, the total soluble proteins in the ground chicken breast patties decreased 9.7, 39.0, 79.5, 88.2, and 89.7%, respectively, relative to the raw patties. These results agreed well with previous studies (Murphy *et al.*, 1998; Bouton and Harris, 1972). Murphy *et al.* (1998) observed several endothermic transitions in a range of 58.7 to 78.5 C for the sarcoplasmic proteins in chicken breast patties. Bouton and Harris (1972) found that the sarcoplasmic proteins in beef were almost completely denatured at 62 C and above.

⁴GIBCO Life Technologies, Rockville, MD 20850.

⁵Instron Corporation, Canton, MA 02021.

TABLE 1. Changes in ground chicken breast patties after heating to different temperatures

Temperature (C)	Soluble proteins (% w/w, dry basis)	Soluble collagen (% w/w total collagen)	Peak force (N)	Cook loss (% w/w, wet basis)
23 ¹	19.5 (0.4) ²	5.9 (0.1)	6.8 (0.8)	none
40	17.6 (0.5)	7.6 (0.1)	6.9 (0.3)	2.9 (0.1)
50	11.9 (0.6)	9.0 (0.2)	10.4 (0.5)	7.3 (0.2)
60	4.0 (0.2)	18.3 (0.1)	17.6 (0.8)	8.8 (0.1)
70	2.3 (0.1)	20.3 (0.5)	17.3 (0.2)	8.9 (0.1)
80	2.0 (0.1)	21.8 (0.3)	15.1 (0.3)	10.3 (0.3)

¹Uncooked patties after equilibration to room temperature.

²Numbers in parentheses are standard deviations.

Sodium Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis

In the study of Lan *et al.* (1995), skeletal muscle myosin had a molecular weight of 480 kDa, with two large subunits (heavy chains) and four small subunits (light chains). Each heavy chain had a molecular weight of 200 kDa, and the light chains had molecular weights of ~16 to 27.5 kDa. Actin was in its monomeric form of G-actin with a molecular weight of 42 kDa. In our study, SDS-PAGE demonstrated that the protein subunits with a molecular weight greater than 40 kDa decreased with increasing cooking temperature (Figure 2). Two endothermic transitions, as evidenced by differential scanning calorimetry (DSC), were observed in the ranges of 31.8 to 35.0 C and 50.9 to 54.1 C for the myofibrillar proteins in chicken breast patties (Murphy *et al.*, 1998). Those endotherms were assumed to correspond to protein denaturation and are consistent with the SDS-PAGE results from this study. The 200-kDa band decreased in the meat samples at 40 C, and the 43-kDa band decreased in the meat samples at 60 C. These two

bands corresponded to the myosin heavy chain and actin in myofibrillar proteins, respectively (Claeys *et al.*, 1995). At 80 C, the major remaining bands were at molecular weights of <38 kDa.

Our results could be explained as increasing cooking temperature resulting in fragmentation of muscle proteins with higher MW. Similarly, disintegration, shortening, and unfolding of protein polypeptide chains have also been observed in heated beef samples (Hearne *et al.*, 1978; Dube *et al.* 1972) and pork samples (Zayas and Naewbanij, 1986).

Collagen Solubility

Collagen content in the ground chicken breast patties was 3.0 ± 0.6 mg/g (w/w, wet basis). Soluble collagen in the uncooked ground chicken breast patties was 0.18 ± 0.05 mg/g sample (wet basis). Amount of soluble collagen increased ($P < 0.0001$) with increasing meat temperature from 50 to 70 C (Table 1). This result agreed with that of Murphy *et al.* (1998), in which an endothermic transition was observed at a temperature range of 59.6 to 68.4 C for collagen in chicken breast patties. Similar results were also obtained by Winegarden *et al.* (1952) for strips of collagenous material heated in distilled water.

Texture

Meat temperature affected ($P < 0.0001$) the texture of the ground chicken breast patties as indicated by peak force (Table 1). From 40 to 60 C, the peak force for the ground chicken breast patties increased approximately 150%. In contrast, the peak force decreased 14.2% with increasing temperature from 60 to 80 C. These changes in texture with meat temperatures could be affected by changes in the soluble proteins, myofibrillar proteins, and connective tissue of the ground chicken breast patties.

Heating produced a softening of connective tissue caused by conversion of collagen to gelatin and a toughening of meat fibers caused by heat coagulation of myofibrillar proteins (Bouton and Harris, 1972). From past studies in beef, it was suggested that meat texture increased with fragmentation of myofibrillar proteins (Paul, 1963; Laakkonen *et al.*, 1970; Bailey, 1984; Davey *et al.*, 1976) and decreased with increasing collagen solubility (Rao and Lund, 1986; Zayas and Naewbanij, 1986; Davey and Gilbert, 1974). Myofibril-

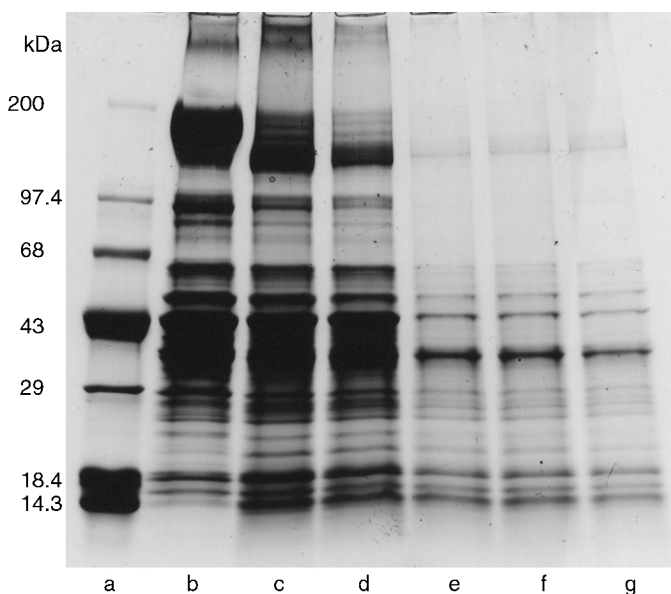


FIGURE 2. SDS-PAGE of the ground chicken breast patties. a) Standard; b) raw ground chicken breast patties; c, d, e, f, and g are patties cooked to 40, 50, 60, 70, and 80 C, respectively.

TABLE 2. Parameter estimates for peak force and cook loss

Response	Term	Estimate	SE	P value	Lower 95%	Upper 95%
Peak force ¹	a ₁	17.7034	0.6854	<0.0001	16.2334	19.1733
	b ₁	-1.8636	0.1892	<0.0001	-2.2694	-1.4578
	c ₁	0.2950	0.0440	<0.0001	0.2006	0.3895
	d ₁	-0.0032	0.0005	<0.0001	-0.0043	-0.0022
Cook loss ²	a ₂	7.6692	0.4649	<0.0001	6.6783	8.6602
	c ₂	-0.1192	0.0037	<0.0001	-0.1271	-0.1113
	d ₂	0.0022	0.0001	<0.0001	0.0019	0.0025

¹For peak force: R² = 0.9858, mean square error (MSE) = 0.485. The a₁, b₁, c₁, and d₁ are the coefficients for the intercept, soluble proteins, soluble proteins × collagen, and temperature × soluble proteins × collagen terms, respectively.

²For cook loss: R² = 0.9858, mean square error (MSE) = 0.230. The a₂, c₂, and d₂ are the coefficients for the intercept, soluble proteins × collagen, and temperature × soluble proteins × collagen terms, respectively.

lar protein shortening during heating could also result in increasing toughness in chicken (Dawson *et al.*, 1991). In this study, the maximum peak force value was at ~60 C, at which drastic changes occurred in soluble proteins, collagen solubility, and myofibrillar proteins (Table 1 and Figure 2). These results suggested that texture of the ground chicken breast patties could be attributed to a combined effect of soluble proteins, myofibrillar proteins, and collagen. Larick and Turner (1992) stated that collagen began to shrink at 60 to 70 C and was converted to gelatin at 80 C and that these changes weakened the connective tissue. Therefore, the reduction in toughness above 60 C could also be due to the increase in collagen solubility, as reported by Rao and Lund (1986) and Zayas and Naewbanij (1986).

From statistic analysis, a linear model of $y_1 = a_1 + b_1x_2 + c_1x_2*x_3 + d_1x_1*x_2*x_3 + \epsilon_1$ was obtained with R² = 0.9819 and mean standard error (MSE) = 0.485. In this model, y₁ is peak force; x₁ is temperature; x₂ is soluble proteins; x₃ is collagen; a₁, b₁, c₁, and d₁ are estimated coefficients; and ε₁ is the error term (Table 2). Therefore, the texture of chicken breast meat is significantly influenced by soluble protein; the interaction of soluble proteins and collagen; and the interaction of temperature, soluble proteins, and collagen.

Cook Loss

Increasing temperature causes denaturation of myofibrillar proteins, primarily the actomyosin complex, and consequently results in shrinkage of the muscle fiber (Bailey, 1984). Our data (Table 1) showed that the change in cook loss was significant (P < 0.0001) from 23 to 80 C because of a reduced water-holding capacity. Similar re-

sults were also reported for beef muscle (Laakkonen *et al.*, 1970; Bouton *et al.*, 1975; Bertola *et al.*, 1994). Dawson *et al.* (1991) reported a moisture loss of 0.8 to 2.9% for broiler meat and 2.9 to 7.4% for hen meat during aseptic processing at high temperature (120 to 145 C) and short time (~10 s). Zayas and Naewbanij (1986) also found that total losses from beef increased with heating temperature because of changes in water-holding capacity.

Water-holding capacity of muscle tissue has been related to the extent of heat denaturation of myofibrillar proteins during thermal processing (Larick and Turner, 1992). With increasing temperature, the denaturation of myosin and actin caused structural changes and expelled the sarcoplasmic fluid from the muscle fibers, resulting in water losses from meat tissue (Bertola *et al.*, 1994). A linear model of $y_2 = a_2 + c_2x_2*x_3 + d_2x_1*x_2*x_3 + \epsilon_2$ was obtained with R² = 0.9858 and MSE = 0.230. In this model, y₂ is cook loss; x₁ is temperature; x₂ is soluble proteins; x₃ is collagen; a₂, c₂, and d₂ are the estimated coefficients; and ε₂ is the error term (Table 2).

From the analysis of variance, components in models for both texture and cook loss did not include the main effect term of collagen, which might be due to the small content of collagen in tested meat samples. In summary, increasing the meat temperature from 23 to 80 C reduced soluble proteins, dissociated myofibrillar proteins, increased collagen solubility, increased cook loss, and affected the texture of ground chicken breast patties. A strong linear correlation was obtained between heating temperature and soluble proteins, heating temperature and collagen, heating temperature and toughness, and heating temperature and cook loss (Table 3). The results suggest that both muscle and connective tissue changes during heating may influence texture and cook loss from processed poultry meat.

TABLE 3. Pearson product-moment correlation coefficients for temperature, soluble proteins, collagen, peak force, and cook loss

Variable	Temperature	Soluble proteins	Collagen	Peak force	Cook loss
Temperature	1.0000	-0.9532	0.9418	0.8470	0.9575
Soluble proteins	-0.9532	1.0000	-0.9761	-0.9609	-0.9483
Collagen	0.9418	-0.9761	1.0000	0.9307	0.8833
Peak force	0.8470	-0.9609	0.9307	1.0000	0.8773
Cook loss	0.9575	-0.9483	0.8833	0.8773	1.0000

ACKNOWLEDGMENTS

This research was partially supported by the USDA NRI Competitive Grants Program, award No. 96-35500-3550. The chicken patties were graciously provided by Tyson Foods, Inc., Springdale, AR.

REFERENCES

- AOAC, 1990. Official Methods of Analysis, 15th rev. ed. Association of Official Analytical Chemists, Washington, DC.
- Bailey, A. J., 1984. The chemistry of intramolecular collagen. Pages 22–40 *in*: Recent Advances in Chemistry of Meat. A. J. Bailey, ed. The Royal Society of Chemistry, London.
- Barrett, A. H., J. Briggs, H. Richardson, and T. Reed, 1998. Texture and storage stability of processed beefsticks as affected by glycerol and moisture levels. *J. Food Sci.* 63:84–87.
- Bergman, I., and R. Loxley, 1963. Two improved and simplified methods for the spectrophotometric determination of hydroxyproline. *J. Anal. Chem.* 35:1961–1965.
- Bertola, N. C., A. E. Bevilacqua, and N. E. Zaritzky, 1994. Heat treatment effect on texture changes and thermal denaturation of proteins in beef muscle. *J. Food Process. Preserv.* 18:31–46.
- Bouton, P. E., and P. V. Harris, 1972. The effect of cooking temperature and time on some mechanical properties of meat. *J. Food Sci.* 37:140–144.
- Bouton, P. E., P. V. Harris, and D. Ratcliff, 1981. Effect of cooking temperature and time on the shear properties of meat. *J. Food Sci.* 46:1082–1087.
- Bouton, P. E., P. V. Harris, and W. R. Shorthose, 1974. Changes in the mechanical properties of veal muscles produced by myofibrillar contraction state, cooking temperature and cooking time. *J. Food Sci.* 39:869–875.
- Bouton, P. E., P. V. Harris, and W. R. Shorthose, 1975. Changes in shear parameters of meat associated with structural changes produced by aging, cooking, and myofibrillar contraction. *J. Food Sci.* 40:1122–1126.
- Bradford, M. M., 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Anal. Biochem.* 72:248–254.
- Bramblett, V. D., R. L. Hostetler, G. E. Vail, and H. N. Fraudt, 1959. Qualities of beef as affected by cooking at very low temperatures for long periods of time. *Food Technol.* 13:707–710.
- Claeys, E., L. Uytterhaegen, B. Buts, and D. Demeyer, 1995. Quantification of beef myofibrillar proteins by SDS-PAGE. *Meat Sci.* 39:177–193.
- Davey, C. L., and K. Gilbert, 1974. Temperature-dependent cooking toughness in beef. *J. Sci. Food. Agric.* 25:931–938.
- Davey, C. L., A. F. Niederer, and A. E. Graaffhuis, 1976. Effect of aging and cooking on the tenderness of beef muscle. *J. Sci. Food Agric.* 27:251–257.
- Dawson, P. L., B. W. Sheldon, and J. J. Miles, 1991. Effect of aseptic processing on the texture of chicken meat. *Poultry Sci.* 70:2359–2367.
- DeFreitas, Z., J. G. Sebranek, D. G. Olson, and J. M. Carr, 1997. Carrageenan effects on thermal stability of meat proteins. *J. Food Sci.* 62:544–547.
- Dube, G., V. D. Bramblett, M. O. Judge, and R. B. Harrington, 1972. Physical properties and sulphhydryl content of bovine muscle. *J. Food Sci.* 37:23–29.
- Dumoulin, M., S. Ozawa, and R. Hayashi, 1998. Textural properties of pressure-induced gels of food proteins obtained under different temperatures including subzero. *J. Food Sci.* 63:92–95.
- Eilert, S. J., and R. W. Mandigo, 1993. Procedure for soluble collagen in thermally processed meat products. *J. Food Sci.* 58:948–949.
- Findlay, C. J., D. W. Stanley, and E. A. Gullet, 1986. Thermo-mechanical properties of beef muscle. *Meat Sci.* 16:57–70.
- He, Y., and J. G. Sebranek, 1996. Functional protein components in lean finely textured tissue from beef and pork. *J. Food Sci.* 61:1155–1159.
- Hearne, L. E., M. P. Penfield, and G. E. Goertz, 1978. Heating effects of bovine semitendinosus: Shear force muscle fiber measurements and cooking losses. *J. Food Sci.* 43:10–12, 21.
- Laakkonen, E., G. H. Wellington, and J. W. Sherbon, 1970. Low-temperature, long time heating of bovine muscle. 1. Changes in tenderness, water-binding capacity, pH, and amount of water soluble components. *J. Food Sci.* 35:175–177.
- Lan, Y. H., J. Novakofski, R. H. McCusker, M. S. Brewer, T. R. Carr, and F. K. McKeith, 1995. Thermal gelation properties of protein fractions from pork and chicken breast muscles. *J. Food Sci.* 60:742–747, 752.
- Lanari, M. C., A. E. Bevilacqua, and N. E. Zaritzky, 1987. Changes in tenderness during aging of vacuum-packaged beef. *J. Food Process Preserv.* 11:95–109.
- Larick, D. K., and B. E. Turner. 1992. Aseptic processing of beef particulates: Flavor development/stability and texture. *J. Food Sci.* 57:1046–1050.
- Lyon, C. E., B. G. Lyon, and J. A. Dickens, 1998. Effects of carcass stimulation, deboning time, and marination on color and texture of broiler breast meat. *Appl. Poult. Sci. J.* 53–60.
- Machlik, S. M., and H. N. Draudt. 1963. The effect of heating time and temperature on the shear of semitendinosus muscle. *J. Food Sci.* 28:711–718.
- Marshall, N., L. Wood, and M. B. Patton, 1960. Cooking choice grade to beef roasts. *Am. Diet. Assoc.* 36:341–345.
- Martens, H., E. Stabursvik, and M. Martens, 1982. Texture and color changes in meat during cooking related to thermal denaturation of muscle proteins. *J. Texture Studies* 13:291–309.
- Murphy, R. Y., B. P. Marks, and J. A. Marcy, 1998. Specific heat of chicken breast patties and their constituent proteins by differential scanning calorimetry. *J. Food Sci.* 63:88–92.
- Offer, G., D. Restall, and J. Trinck, 1984. Water-holding in meat. Pages 71–83 *in*: Recent Advances in Chemistry of Meat. A. J. Bailey, ed. The Royal Society of Chemistry, London.
- Paul, P., 1963. Influence of methods of cooking on meat tenderness. Pages 225–242 *in*: Proc. Meat Tenderness Symposium. Campbell Soup Co., Camden, NJ.
- Paul, P. C., S. E. McCrae, and L. M. Hofferber, 1973. Heat-induced changes in extractability of beef muscle collagen. *J. Food Sci.* 38:66–68.
- Penfield, M. P., and B. H. Meyer, 1975. Changes in tenderness and collagen of beef semitendinosus muscle heated at two rates. *J. Food Sci.* 40:150–154.
- Pool, M. F., 1967. Objective measurement of connective tissue tenacity of poultry meat. *J. Food Sci.* 32:550–553.
- Rao, M. A., and D. B. Lund, 1986. Kinetics of thermal softening of foods—A review. *J. Food Process. Preserv.* 10:311–329.
- Rowe, R.W.D., 1974. Collagen fibre arrangement in intramuscular connective tissue. Changes associated with muscle shortening and their possible relevance to raw meat toughness measurements. *J. Food Technol.* 9:501–508.
- Winegarden, M. W., B. Lowe, J. Kastelic, E. Kline, A. Plagge, and P. Shearer, 1952. Physical changes of connective tissue of beef during heating. *Food Res.* 17:172–184.
- Yu, L. P., and Y. B. Lee, 1986. Effects of postmortem pH and temperature on bovine muscle structure and meat tenderness. *J. Food Sci.* 51:774–780.
- Zayas, J. F., and J. O. Naewbanij, 1986. The effect of microwave heating on the textural properties of meat and collagen solubilization. *J. Food Process. Preserv.* 10:203–214.
- Zhang, M., and G. S. Mittal, 1993. Measuring tenderness of meat products by Warner-Bratzler shear press. *J. Food Process. Preserv.* 17:351–367.