ABSTRACT

RELATIONSHIPS BETWEEN COOKED TEMPERATURE AND TENDERNESS OR JUICINESS OF BONELESS TURKEY ROLLS AS MEASURED BY PHYSICAL, SENSORY AND CHEMICAL METHODS

by Raleigh James Wilkinson

This study was conducted to evaluate the effects of different meat temperatures on tenderness and juiciness of dark and light meat turkey rolls and to relate the differences found, to some chemical changes in the meat.

Tenderness of commercially prepared turkey rolls, cooked to different temperatures (60 to 88°C), was evaluated by physical (shear) and sensory (panel) methods. Juiciness was evaluated by a sensory panel. Chemical changes during cooking were determined by the extractability, or solubility, of protein and non-protein nitrogen. Total moisture of fresh and cooked meat was determined by dehydrating samples in a hot air oven. Water holding capacity (WHC) was determined by centrifugation and expressed as the ratio between free water after cooking plus the amount of moisture lost during cooking and total moisture of the muscle before cooking. Bound water was expressed as the amount of water remaining after free water was removed, or the difference between WHC and moisture remaining after cooking.

Shear force of dark meat samples decreased as temperature of cooked rolls increased from 60 to 88°C with largest differences occurring between tenderness of rolls cooked to 71 and 77°C. No significant differences were found in shear force of light meat cooked to different temperatures; however, the shear force for light meat approached that for dark meat when both were cooked to the lowest and highest

temperature used, i.e., 60 and 88°C.

Panel members scored dark meat more tender as temperature of cooked rolls increased. Light meat tenderness scores were more variable and tenderness increased until the temperature of cooked meat reached 82°C; however, light meat cooked to 88°C was less tender than all others evaluated. Panel members scored dark meat less tender than light meat cooked to all temperatures except 88°C.

Panel juiciness scores were the same for dark and light meat rolls until cooked meat temperatures reached 71°C. However, light meat samples were evaluated less juicy than dark meat when cooked to 77°C or higher. The greatest difference in juiciness was between light and dark meat cooked to 88°C in which the light meat was less juicy.

When turkey rolls were cooked to temperatures ranging from 60 to 88°C, total nitrogen (moisture free basis) increased. Grams of alkali soluble nitrogen in 100 g total nitrogen increased in dark meat as temperature increased. Values obtained from light meat remained relatively constant except for lower values obtained from meat cooked to 71°C. Grams of soluble protein nitrogen in 100 g total nitrogen increased in both dark and light meat cooked to the higher temperatures. Collagen nitrogen from dark meat remained relatively constant thru temperatures up to 71°C, then decreased at a constant rate with increased temperature. Collagen nitrogen from light meat was lower than from dark meat cooked to temperatures up to 71°C, but similar from samples cooked to higher temperatures.

Results have shown that although total moisture and bound water decreased during cooking the amount of bound water, expressed as a

fraction of total water, remained fairly constant. When turkey meat was subjected to higher temperatures, the rate of loss of bound water exceeded the release of free water and resulted in an increase loss of total water.

Shear values and panel scores of light meat samples were significantly related, but such a relationship was not found in dark meat samples. Collagen content and shear values were significantly related in dark meat samples, but not in light meat samples.

Panel juiciness scores agreed significantly with total moisture of cooked dark and light meat indicating that as moisture decreased, samples were found less juicy. Amount of bound water was related to juiciness scores for dark meat but not for light meat.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

# INTRODUCTION

In recent years the demand for pre-cooked, deboned turkey for institutional and home use has increased. Additional research is needed to improve such products, especially in terms of optimum cooking procedures, quality stability, and product composition. Deboned turkeys, in the form of raw and cooked rolls, are being manufactured and merchandised in an increasing volume. The advantages of such products were reported by Evans (1950) in a discussion on merchandising commercial type turkey rolls for use by hotels, restaurants, hospitals, and other institutions. Advantages reported were: 1) low cost per serving unit; 2) complete utilization of meat purchased (no waste); 3) less labor required to prepare meat for serving; 4) greater flavor retention in the product; 5) less storage and freezer space requirements; 6) lower transportation cost per pound of edible meat; 7) lower cooking shrink; and 8) less loss in food nutrients during cooking.

The rate and degree of cooking will affect tenderness which is perhaps the most important quality factor related to consumer acceptability. Similar cooking procedures have different effects on turkey rolls than on whole birds due to differences in size and shape of the two products. The degree of "doneness" of a whole turkey is commonly determined by measuring the temperature of the thigh meat nearest to the bone, or the center of the thickest portion of breast meat. These practices may result in a variation in doneness, in percentage shrink and in moistness of the different products. Boneless turkey meat formed into a roll is more uniform in shape and composition throughout, and can be cooked more uniformly, resulting in less total shrink and juicier

portions.

A number of investigators have reported the effects of various factors, such as breed, sex, age, feed, processing and aging, on the tenderness of whole turkey muscle, and some have examined protein changes which occur during rigor mortis and frozen or unfrozen storage. In recent years the effects of cooking on tenderness have been studied, primarily using meat from bovine animals. Little information is available, however, on the effects of cooking boneless turkey meat on tenderness and other quality factors.

Both objective (physical force) and subjective (sensory panel) measurements of boneless turkey meat have been determined; however, little information is available on the specific chemical changes which take place during cooking and how these changes are related to tenderness measurements. In addition, the effects of cooking on tenderness differences between dark and light turkey meat need investigation. Such data should be useful for determining whether to process, and how to process light meat rolls, dark meat rolls, or combination rolls.

In the past, the use of shear values and sensory scores has provided means for determining meat tenderness. Chemical analysis of meat and its relationship to tenderness has also proven to be useful in evaluating the biochemical reactions that occur in meat during changes in tenderness, and how desirable changes can be influenced.

The purposes of this study were: 1) to evaluate the effects of different meat temperatures on tenderness and juiciness of dark and light meat turkey rolls, as measured by physical (shear) forces and sensory (panel) methods; 2) to evaluate the effects of meat temperature on some chemical changes in dark and light meat; and 3) to evaluate the

inter-relationships between these physical, sensory, and chemical values.

## REVIEW OF LITERATURE

Turkey logs (turkey rolls) were introduced as early as 1950 (Evans, 1950). Because of their adaptability to portion control and ease of handling, the merchandising of turkey rolls increased greatly since 1950. Over 210 million lb of turkey meat were inspected for wholesomeness in "Official" plants for canning and other processed foods in 1964, as reported by the U. S. D. A. (1965). A large percentage was used in the form of convenience products, such as frozen prepared dinners and turkey rolls. Dawson (1964) reported consumption of 150,000 lb of boneless turkey rolls per year by one institutional user. To be acceptable, Fischer (1962) reported that boneless turkey must hold together when sliced, be easily identified as turkey, and be of a size and weight desired by users.

Since the introduction of various pre-cooked poultry products, lack of tenderness in these products has been reported as a major problem. (Goodwin et al., 1962 a). Tenderness has been reported as the most important factor in meat acceptability (Miyada and Tappel, 1956 a) and this factor was the main criteria affecting consumer acceptance of poultry products (Goodwin et al., 1962 a).

> Tenderness or toughness was defined by Deatherage (1963) as, "a quality representing the summation of properties of the various protein structures of skeletal muscle. --- Tenderness may be said to be the ease of mastication and in this respect is primarily a subjective quality. Now to reduce tenderness to concrete terms of chemistry, physics, anatomy, genetics, physiology, is rather challenging task since tenderness means different things to different people. Even some peoples of the world adapt their methods of preparation to make tenderness of secondary importance, but as we are concerned here today, we must make some attempt to understand that there are several types of tenderness. There is the tenderness of the broiled steak or roast, to the rare or well done

stage; there is the tenderness of the pot roast or braised meat; there is the tenderness of the canned, dehydrated and rehydrated and cooked products. So as we talk about tenderness it is necessary to define the meat product we are discussing and the manner of preparation. --- tenderness or toughness is a function of the solid or water insoluble structures of muscle and is directly related to the protein structures of muscle and the denaturation, coagulation and hydrolysis of these proteins."

I. Physical factors affecting meat tenderness

1. Slaughter procedures

Muscles of birds which struggled during slaughter were reported by Gainer et al. (1951) to be more tender than muscles from birds of the same group that did not struggle. Under normal conditions of processing, Dodge and Stadelman (1960 a), found that struggling does not exert an effect on post mortem tenderization. Koonz et al. (1954) and DeFremery and Pool (1960) reported that excising muscle before rigor induces a toughness which was only partially resolved by aging.

Goodwin et al. (1961) studied the effects on tenderness of six pre-slaughter treatments for turkeys. These treatments were: 1) carbon dioxide immobilization, 2) electrical stunning, 3) nembutal immobilization, by oral administration, 4) reserpine tranquilization, 5) debraining by knife puncture of the anterior lobe of the brain, and 6) control group. They reported no significant effect on shear values of breast meat and increased shear values for thigh meat when slaughtered after the nembutal treatment.

2. Scalding procedures

After evaluating specific turkey scalding conditions, Stadelman and McLaren (1954) reported greater toughness with low temperature-long time scalding (127°F, 55 second) than with high temperature-short time scald (165°F, 9 second). However, they reported that the greatest observed difference in tenderness was between hand picked (dry) controls and scalded machine picked turkeys, probably more a reflection of the toughening effect of machine picking than of scalding. Klose and Pool (1954) found that scalding temperature did not affect tenderness of

roasted muscles of Broad Breasted Bronze turkeys. However, increased scalding temperatures, produced marked increases in toughness and wrinkling of roasted skin, and that modifications in cooking were found to reduce the toughness of roasted skin from turkeys scalded at high temperatures. Others have reported that elevated scalding temperatures and prolonged scalding times did not adversely affect tenderness of chicken (Pool et al., 1959) and turkeys (Klose et al., 1956, 1959).

Shannon et al. (1957) reported that longer scald times and higher temperatures of scald water significantly reduced tenderness of poultry meat, and the interaction of time with temperature indicated that the effect of time was greater than that of temperature. After using various scald time-temperature combinations, Wise and Stadelman (1959) reported that resistance to shear of cooked meat was related (at a highly significant level) to the depth at which the samples were taken, to the temperature of the scald water, and to the scald time duration. They reported that the toughening of meat after a high temperature-long time scald was related to the depth at which the scald heat penetrates the muscle tissue.

3. Feather removal procedures

In general, the more severe the beating, or the longer the beating time for feather removal, the more adversely the tenderization process was affected (Wise and Stadelman, 1957). Klose et al. (1956) reported that prolonged aging did not completely resolve the toughness induced in chickens and turkeys by excessive beating. The effects of beating were reduced by limiting the beating action during feather removal. Pool et al. (1959) found that ultimate toughness, after aging

of chickens, increased with an increase in beating action during feather removal. Beating action exerted increased toughening when applied immediately after slaughter. Klose et al. (1959) found turkey meat from machine picked birds was about twice as tough as that from hand picked controls. Difference in shear values of meat from birds machine picked and those hand picked were essentially unaltered by extending the chill period.

Gainer et al. (1951) reported that muscles of birds aged 30 min were more tender when machine picked and hand massaged than when hand picked. DeFremery and Pool (1958) found that beating chickens by a feather picker resulted in less tender muscles than muscles of birds picked by hand.

4. Chilling procedures

Chilling in itself does not appear to have any important effect on rate of tenderization. However, aging received in some rapid chilling procedures may not be ample to assure adequate tenderness in large roasted turkeys (Klose et al., 1961 a).

Pool et al. (1959) reported that most tenderization of chickens takes place in the first four hr of chilling and very little occurs after 12 hr. Chilling by "spin-chill" or conventional immersion methods were reported by Kahlenberg et al. (1960) to result in no significant differences in shelf life, flavor, or tenderness of cooked thigh meat from freshly ice packed birds. No difference was found in the rate of tenderization of birds chilled either with or without mechanical agitation (Klose et al., 1960).

Goodwin and Stadelman (1962) reported that two hr of

muscle flexing and massaging turkeys in tap water increased shear values and that massaging for less than two hr affected toms or fryers more than hens.

Spencer and Smith (1962) found that polyphosphate treated chickens were more tender and more juicy than controls, but no differences were found in flavor.

5. Freezing procedures

Marion and Stadelman (1958) reported that percentage drip, percentage total cooking loss, and tenderness of chicken breast muscle were not affected by the freezing methods of liquid, plate, moving air, or a combination of liquid freeze and plate.

Several studies have shown that freezing does not stop the chemical changes associated with tenderization (Hepburn, 1950; Monzini, 1953 a,b; Swanson and Sloan, 1953; and Colombo and Gervasini, 1956). Others have reported that freezing stops the chemical changes associated with tenderization (Koonz et al., 1954; Bouton et al., 1958; and Massi, 1958).

Carlin (1949) reported that the aging process continued in frozen meat and that tenderness beyond what was accomplished by aging was not increased by freezing. Carlin et al. (1949) also reported that aging continues in frozen meat resulting in increased tenderness.

Spencer et al. (1956) reported that freezing halts the tenderization process and, that without prior cooling, frozen turkeys were somewhat less tender than precooled turkeys.

6. Cooking procedures

Koonz and Robinson (1946) reported that cooking caused muscles

of poultry meat to become more tender. In contrast, beef muscles became less tender with moderate cooking.

Griswold (1955) found that losses of collagen from beef muscles during cooking increased as the internal temperature of the meat increased.

The amount of juice released from muscles during heating depends on temperature, and this loss of water influences juiciness and texture of meat (Wierbicki et al., 1954). Goodwin et al. (1962 a) found that turkey cooked to 55°C had significantly higher shear values (tougher) than meat cooked to 77°C or above. They found that rate of cooking had no significant effect on shear values. They also reported that breast meat cooked to 88 and 94°C was drier and crumbled more than breast meat cooked to lower temperatures.

Ginger et al. (1954) reported that the amount of amino nitrogen of the non-protein nitrogen fraction was higher in cooked steak plus the drippings than in raw meat, and they concluded that some proteolysis occurred during cooking. They found that cooking caused a marked decrease (4-30 fold) in the soluble nitrogen of steaks.

Cover et al. (1962 a) reported that beef longissimus dorsi muscle appeared to fragment less easily and adhered (cohered) more tightly with increasing internal temperature. In the biceps femoris muscle, an increase in temperature caused greater fragmentation and lack of adhesion between muscle fibers which resulted in increased tenderness. Cooking caused a decrease in moisture and extractable nitrogen as a result of loss of solubility of myofibrillar and sarcoplasmic proteins in chicken muscle (Khan and van den Berg, 1965).

Goodwin and Stadelman (1962) observed that the method of cooking had no significant effect on shear values of turkey meat. Mickelberry

and Stadelman (1960) reported that baking birds wrapped in aluminum foil in a convection heated oven resulted in more tender products than those deep fat fried. Pressure cooking gave significantly lower shear values for the breast meat of fowl than did either broiling or simmering (Kahlenberg and Funk, 1961). They also found that boiling, simmering, and pressure cooking old fowl in salt solutions had no advantage over cooking in unsalted water with respect to tenderness. Goodwin et al. (1962 b) and May et al. (1962) reported that chicken meat cooked in an electronic oven was less tender than when cooked in boiling water or steam.

DeFremery and Pool (1960) reported that meat irradiated before resolution of rigor was less tender than that irradiated after rigor had been resolved. Lawrie et al. (1961) reported that irradiation decreased soluble protein in beef and pork longissimus dorsi muscles, which indicated a denaturation of muscle proteins. Minor effects of gamma irradiation on tenderness of poultry meat were reported by Stadelman and Wise (1961).

Evidence was reported by Paul et al. (1952) that beef cooked immediately after slaughter (0 time) was tender, became less tender during cold storage up to 24 hr then returned to approximate original tenderness during storage for 144-149 hr.

Wierbicki et al. (1956) reported that expressed cooking juice decreased during post mortem aging and a significant relation was observed between this factor and tenderness at three and 13 days post mortem.

Mickelberry and Stadelman (1960) and Goodwin et al. (1962 b) reported that cooking prior to freezing resulted in reduced tenderness

of chicken meat.

Heat induced changes related to tenderness were described by Paul (1963). She stated that lean tissue decreased in moisture content and usually ether extractable material; the muscle fiber diameter decreased; and collagen was partially to completely solubilized, depending on heating duration and final internal temperature.

Bendall (1964) discussed the changes in meat proteins after cooking. He stated that when the temperature reached 62°C most "soluble proteins of the sarcoplasm and the actomyosin system of the fibrils," had denatured "giving a characteristic coagulated structure and appearance."

II. Physiological and biological factors affecting tenderness

1. Connective tissue

a. General

Muscle fibers and connective tissue are two of the meat components involved in meat tenderness, and have been studied by chemical, physical, and sensory methods. Connective tissue, recognized in the past as a major contributor to toughness in some muscle, has received more attention than any other part of meat (Ritchey et al., 1963).

Hiner et al. (1955) reported that muscles used extensively contained large amounts of connective tissue and muscles seldom used had small amounts of connective tissue.

Parrish et al. (1962) reported that, of all the factors influencing tenderness, perhaps connective tissue is the component in many beef cuts most responsible for tenderness variations.

Tuomy et al. (1962) reported that connective tissue was related to toughness of some meat cuts but not of others.

Several studies indicated that muscles which contained the least amount of collagen were the most tender (Mitchell et al., 1927; Irvin and Cover, 1959; Ritchey and Cover, 1962; Cover et al., 1962 b; and Ritchey et al., 1963).

Husaini et al. (1950 a,b) reported that alkali insoluble protein and muscle plasma, as represented by muscle hemoglobin (myoglobin), were closely related to changes in tenderness of beef muscle. They reported no increase in non-protein and TCA (trichloroacetic acid) soluble nitrogen during post mortem tenderization.

Wilson et al. (1954) concluded that collagen and elastin in

the longissimus dorsi of beef animals was not a critical measure of tenderness of meat.

Cover and Smith (1956) reported that collagen retention did not differ in beef longissimus dorsi (LD) or biceps femoris (BF) muscles. However, the actual content of the two muscles was different, with broiled LD having less collagen than broiled BF muscles. When shear values were measured on both muscles, differences in pounds of force were not found. They concluded that actual collagen content inside the muscle after broiling was not a major factor in determining relative tenderness from different positions in the carcass when steaks were broiled.

Koonz et al. (1954) and DeFremery and Pool (1960) found that tenderness of muscles from both sides of a bird were similar. Marion and Stadelman (1958) noted a significant difference in tenderness between the left and right pectoralis major muscles in chicken fryers. The right side was more tender. May et al. (1962) noted differences in tenderness between the right and left breasts of 72 week old birds aged at 0°C but did not indicate which side was more tender.

b. Nature of connective tissue

Hiner et al. (1955) reported that connective tissue contained two main parts: a) collagenous or white fibers, and b) elastic or yellow fibers which were embedded in an amorphous ground substance, jelly-like in nature, which "cements" them together. They stated that collagenous fibers were soft and flexible, resisted a pulling force and lacked elasticity. Collagenous fibers were long, straight or wavy, fine fibrils that run in many directions. They generally appeared in bundles,

cemented together, and branched into smaller bundles. The smaller bundles often branched out into single fibrils and appeared between fibers. Collagenous fibers were proteinaceous in nature, giving several but not all the typical protein reactions. Collagenous fibers swelled when placed in dilute acids and strong basis. They were easily digested by pepsin in acid solution but resisted trypsin in alkaline solution. When collagen was boiled in water, it dissolved and formed a colloidal solution of gelatin which became jelly-like when cooled. Wohlisch (1932), Gustavson (1954), and Keech (1955) found that collagen dissolved when boiled in water and became jelly-like when cooled.

Hiner et al. (1955) described elastic or yellow fibers which occurred in connective tissue as a loose network of fine fibers that branched and ran together. They were homogeneous and were not fibrillar as were collagenous fibers. Elastic fibers, as a rule, appeared as straight branching fibers and upon stretching, yielded readily, but returned to their normal length when released. They further stated that elastin, an albuminoid, was the principle constituent of elastic fibers and was resistant to boiling water, acids, and alkali, but could be digested slowly with pepsin and trypsin.

Koonz and Robinson (1946) found elastic connective tissue almost completely absent in poultry muscle. Strandine et al. (1949) reported that chickens had fewer and smaller elastic fibers than beef.

c. Determination of connective tissue

Gustavson (1955) reported that collagen was characterized by the prominence of proline and hydroxyproline, and the scarceness of aromatic residues. The large amount of hydroxyproline was unique in this protein, and was important in its characterization and for its

estimation.

Loyd and Hiner (1959) showed a significant correlation between total hydroxyproline content of beef muscles and measurements of tenderness by mechanical and panel methods. Hydroxyproline decreased as tenderness increased.

Considering the comparative severity of the alkaline treatment, Bowes and Kenten (1948) reported that the chemical modification of the collagen was comparatively small. Apart from the solubilization of about five percent of the collagen, the only reaction which took place to any appreciable extent was the hydrolysis of amide groups.

According to Ritchey and Cover (1962) the method of Lowry et al. (1941) was most frequently used for determination of collagen and depended upon the insolubility of collagen in dilute alkali and its conversion to gelatin on autoclaving. Irvin and Cover (1959) modified this method by using a more exhaustive extraction with water and alkali and then determined collagen by nitrogen in the autoclave soluble fraction. They found that this method, as far as consistency of duplicate samples was concerned, gave satisfactory results for raw as well as cooked samples.

According to Ritchey and Cover (1962) muscle proteins became more insoluble as meat was heated and extraction of all of the non-collagen nitrogen in cooked samples was more difficult. The difficulty of extraction increased as the time and temperature of cooking increased.

Miller and Kastelic (1956) reported that collagen determined by hydroxyproline corresponded closely to the total autoclave soluble nitrogen following alkaline extraction of raw samples. Collagen

nitrogen values measured by hydroxyproline were found by Ritchey and Cover (1962) to be consistantly lower than those measured by micro-Kjeldahl in raw samples.

2. Chronological age

Several researchers, using subjective methods of measuring tenderness, found that tenderness decreased with maturation of beef muscle (Hiner and Hankins, 1950; Jacobson and Fenton, 1956; Dunsing, 1959; Simone et al., 1959; Tuma, et al.,1961; and Goll et al., 1963). Mitchell and Hamilton (1933) and Mackintosh et al. (1936) reported that meat from young animals contained less collagen and was more tender than meat from older animals. Lornicz and Szeredy (1959) reported that certain tissues of young animals contained more connective tissue than those of older animals of the same kind.

Goll et al. (1963) did not find significant differences in the hydroxyproline content between beef animals, and presumably the connective tissue content, from any age group. They also reported that younger animals (veal) had significantly lower nitrogen and higher moisture content than muscle from older animals.

Khan (1962) reported that, depending on the age of the chicken, leg muscle had two to three times as much stroma nitrogen as breast meat, but less total, myofibrillar, sarcoplasmic, and non-protein nitrogen.

Dodge and Stadelman (1959) reported, among other factors, that the age of birds when slaughtered appeared to be an important factor in post-mortem tenderization.

3. Aging

a. General

Lehman (1907), used a mechanical device to shear meat between two cutting edges, and was the first to report that aging increased tenderness of beef. Since his report, many studies have reported the effects of aging on tenderness of poultry meat, and tenderness of poultry meat generally increased with the passing of rigor (Koonz et al., 1954; Klose et al., 1959; Dodge and Stadelman, 1960 b; Klose et al., 1960, 1961 a,b). However, the exact time of aging for the same degree of tenderness was found to vary from muscle to muscle and bird to bird (Koonz et al., 1954; Klose et al., 1956; Dawson et al., 1958; and Dodge and Stadelman, 1959).

b. Rigor mortis

Dawson et al. (1958) reported that the lack of tenderness, frequently called "toughness" of chicken meat was connected primarily with muscle fibers and the bio-physical changes which took place following slaughter. After slaughter, the pliable yet viscous muscle fibers of the living animal passed into a state of turgidity known as "rigor mortis". With resolution of rigor, the muscles became pliable again and normal aging changes followed. These changes apparently coincided with the development and resolution of rigor but may or may not have been directly responsible.

Lowe (1948) stated that post mortem changes were important since they resulted in a tenderizing action in muscles. After slaughter, the fat became firmer as the carcass cooled, and the muscles passed into a state of rigor mortis. With resolution of rigor the muscles became

pliant again and aging changes proceeded. With the development and resolution of rigor, other changes occurred. Among these changes were increasing acidity, lowering of the glycogen content, changes in elasticity, changes in the rate of conducting an electric current across the fibers, changes in the tenderness of the muscles, and changes in the microscopic appearance of the muscle fibers.

DeFremery and Pool (1960) reported that every treatment of chicken muscle that resulted in a more rapid loss of adenosine triphosphate (ATP) (more rapid development of rigor mortis), more rapid loss of pH and more rapid loss of glycogen also induced toughness. They postulated that the relative toughness of cooked muscle in otherwise uniform groups of birds increased with rigor mortis, or with some factor closely related to it. In an earlier study, Mellor et al. (1958) reported that muscles from birds high in glycogen concentrations were more tender than corresponding muscles from birds of low glycogen content.

Wierbicki et al. (1954) presented evidence which suggested that an increase in tenderness with post mortem aging may be related to a) the dissociation of actomyosin or some similar protein changes which increase protein extractability and b) redistribution of ions within muscles which resulted in increased hydration and tenderness. Whitaker (1959) stated that changes brought about by aging may be associated with either one or a combination of the following factors: a) changes in the connective tissue, b) dissolution of actomyosin, c) increased hydration of the proteins, and d) proteolysis.

Hanson et al. (1942) reported a correlation between tenderness of broiler breast and thigh muscles and microscopic post mortem

changes. They found the thigh muscle to be less tender than breast muscle.

The tenderness process in turkey and chicken leg muscle, resulting from post mortem changes, occurred in two phases according to van den Berg et al. (1964). Tenderization occurred in a short time during the first phase (lasting approximately one day), as indicated by both organoleptic tests and shear force measurements. During the second phase, which started two to five days later, extensive tenderization, as indicated by organoleptic tests, was accompanied by relatively small but significant decreases in shear force values. They stated that during the first phase of tenderization the increased tenderness of the individual fibers was most important, while during the second phase weakening of the transverse connections between the fibers was of major importance. They postulated that in breast meat, either both processes occurred simultaneously or the second phase was of little importance.

4. Proteolysis

Husaini et al. (1950 b) found a negative correlation between tenderness scores and the alkali insoluble proteins in beef muscles. They found no correlation between tenderness scores and total nitrogen, TCA soluble nitrogen, non-protein nitrogen or heat coagulated nitrogen. Paul et al. (1958) found that buffer extractable nitrogen from chicken meat increased with increased tenderness scores. They concluded that the correlation was high enough to be significant but too low to indicate decided usefulness for measuring tenderness. A relationship between tenderness in chicken leg meat and increased protein extractability during storage was reported by van den Berg et al. (1963).

Marion and Forsythe (1962) reported that changes were not found in amino nitrogen, TCA soluble nitrogen, protein nitrogen, and total soluble nitrogen when turkey muscles underwent rigor and subsequent storage.

Khan and van den Berg (1964) showed results of protein breakdown products during post-rigor tenderization of both breast and leg muscle of poultry. They reported that treatment of chicken muscle with chlortetracycline ruled out the possibility of microbial action, particularly in breast muscle where post-rigor tenderization was complete within 1-1 1/2 days. The small increase in protein-breakdown products suggested the possibility of limited proteolysis, and the increase in tenderness may have occurred from this specific attack.

Weinberg and Rose (1960) suggested that tenderization was not merely random autolysis but resulted from a specific cleavage of actin association responsible for the maintenance of the muscle matrix. Khan and van den Berg (1964) reported that tenderization in chicken breast and leg muscle appeared to be related to the differences in stroma protein content of muscle. Proteolysis appeared to weaken or break the bonds which bound myofibrils to the matrix of the muscle and caused protein changes that were responsible for the post-rigor tenderization.

5. Oxidizing reactions

Chajuss and Spencer (1962 a,b) reported that certain oxidizing reactions involving sulfhydryl groups were important in chicken meat tenderization during post mortem aging. Gawronski et al. (1964) indicated that oxidation of muscle sulfhydryl groups to disulfides contributed to the onset of rigor, and sulfhydryl-disulfide exchange had

an important role in post-rigor tenderization.

Khan and van den Berg (1965) reported that sulfhydryl-group content and tenderness decreased simultaneously. Their results indicated that the formation of protein-breakdown products was responsible for the development of off-odor in uncooked meat stored above- or below-freezing temperatures. The results also suggested that the sulfhydryl groups which survived heat denaturation in the muscle tissue may have contributed in some way to maintaining the eating quality of meat, and that loss in this sulfhydryl-group content during storage may serve as an index of tenderness. Under the conditions in their research, the tenderness changes became apparent when the sulfhydryl-group content of muscle tissue decreased to about 50% of its value in the fresh cooked meat.

6. Enzymes

After the death of an animal, enzymes in the muscles are still quite active. Proteolytic enzymes in tissues hydrolyze the peptide bonds of the proteins. These enzymes are called cathepsins to distinguish them from those of the digestive tract. They are amply supplied with substrate and at least one has been found active in frozen meat with a pH optimum of approximately 4.1 (Balls, 1938).

Wang et al. (1958) demonstrated a close relationship between enzyme induced changes in tissue structure and panel response to tenderness differences. The ability of an enzyme to hydrolyze hemoglobin and gelatin did not reflect its activity as a meat tenderizer. Enzymes of plant origin (ficin, papain, and bromelin) affected both muscle fibers and muscle extensibility. Microbial and fungal enzymes (Rhozyme P-11 and fungal amylase) affected principally the muscle fiber extensibility.

The injection of crystalline and/or crude papain caused chicken breast muscles to lack body or texture and were not fully acceptable (Huffman et al., 1961). Landman (1963) reported that enzyme preparations acted on the muscle fibers, breaking down the sarcolemma and nuclei, followed by disintegration of connective tissue (collagen and elastin), with complete disappearance of cross striations. During aging, histological changes consisted mainly of a disappearance of cross-striations and the appearance of transverse breaks.

Needlin and Rose (1964) suggested that additional components obtained from "sarcoplasm" of tenderized muscle indicated that soluble proteins were transferred into the extract during the breakdown of intracellular barriers or sub-cellular particles. These components may have included enzymes instrumental in initiating changes of the myofibril, ultimately evident in tenderization.

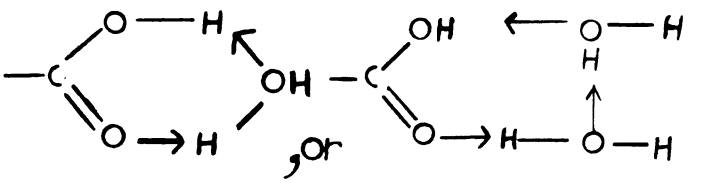
7. Moisture

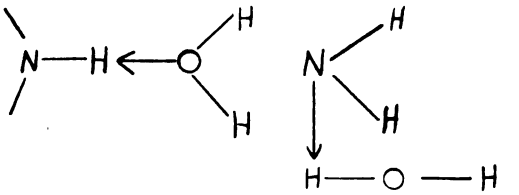
a. Nature of bound water

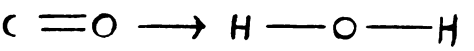
Cover et al. (1962 c) suggested that two kinds of water were present in beef muscles. One kind was relatively free to run or be pressed out as juice. Sources of this juice were the lymph and any liquid which remained in the blood vessels and perhaps some of the "capillary" or "immobilized" water referred to by Hamm (1960). Scores for juiciness may be based on this kind of juice. The second kind was absorbed water, in which the degree of binding varied greatly. Part of it was probably released during heating for the relatively short times employed in cooking. The larger amounts of bound water may have been responsible for softness to tongue and cheek at low steak temperatures,

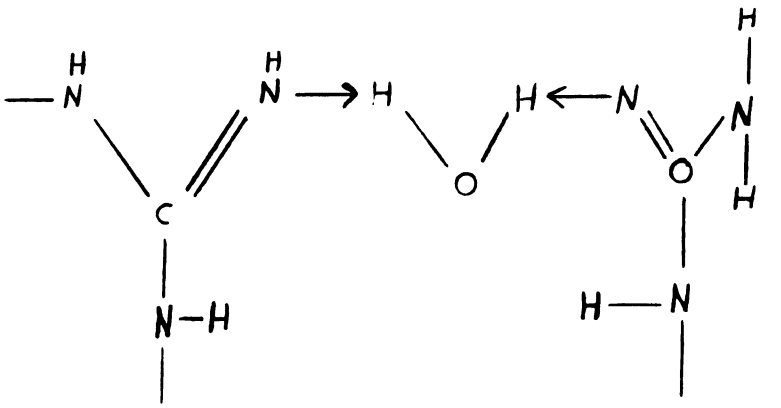
whereas hardness at the higher steak temperature may have been associated with small amounts.

Hamm (1960) reviewed the biochemistry of meat hydration. Changes in the "water-holding capacity" (WHC) of muscle tissue were reported to mainly concern actin and myosin of the "symplex" actomyosin. Different water binding forces existed in muscle tissue with apparently no sharp demarcation between tightly bound water and loosely bound water. The ability of muscle tissue to hold to its own or added water during application of any force (pressing, heating, grinding, etc.) was described as WHC. The WHC of meat could be expressed in terms of the amount of loose water related to the total moisture content in muscle tissue, or better, in terms of the amount of bound water related to muscle or muscle protein. Two types of hydrophilic groups were responsible for fast binding of water. The first type included the polar groups of the side chains of protein, such as the carboxyl-, amino-, and sulfhydryl-groups. The second type was made up of undissociated carbonyl- and amino-groups of the peptide bonds, in which the binding of water was due to the dipolar character of water. Water was considered a molecular magnet because the water molecule was a dipole with a negatively charged oxygen and a positively charged hydrogen which do not coincide. This magnet was attached by several kinds of polar groups in the protein. The water molecule was bound by hydrogen bonds (H), probably as follows:

Carboxyl group 

Amino and imidazol groups 

Carbonyl groups 

Guanido groups 

Processes that caused a loosening of protein structure also increased WHC and caused changes in the tenderness of meat. Increased hydration resulted in a greater distance between peptide chains in the protein structure, and more soft and tender meat. Formation of new cross linkages may have caused a decreased hydration in the isoelectric range of muscle. These linkages were split off by alkali or acids, thus they were not very stable. Therefore, the tightening of protein structures

was due to the formation of hydrogen or salt bonds. An unfolding of peptide chains may have caused increased hydration at higher (and lower) pH values. A structure tighter than that of normal tissue may have resulted from a mutual connection of these unfolded chains by hydrogen or electrostatic bonds in the isoelectric range of pH.

Hamm and Deatherage (1960) reported that the decreased water holding capacity (WHC) at pH > I.P. (isoelectric point) and the increased WHC at pH < I.P. suggested a disappearance of acetic groups when muscles were heated to 45 °C. The decrease in negative protein charges at pH values > I.P. resulted in a decrease in the electrostatic repulsion between the peptide chains, and a tighter network of protein structure and a lower WHC:

$$R\text{-}COO^- \; {}^-OOC\text{-} \; ' \longrightarrow R\text{-}COO^- + R'$$

At pH values < I.P., salt cross linkages were disrupted by a decrease in negative protein, resulting in a loosening of protein structure and, consequently in an increased WHC:

$$R\text{-}COO^- \; \text{-}\; \text{-}NH_3 \longrightarrow R' \longrightarrow R + NH_3 \; \text{-} \; R'$$

b. Determination of bound water

Hamm (1960) reported that differences in the immobilization of "free" water was the only method appropriate to study WHC. Such methods were based mostly on measuring the loose water liberated by applying pressure on the muscle tissue. This pressure included centrifugation.

Wierbicki and Deatherage (1958) reported that the exact amount of bound and free water could not be determined in meat because it contained different protein components and the water of hydration of each

was not known. Furthermore, the amount of physically absorbed water was changed by various laboratory and processing techniques. They did state, however, that relative changes in the water holding capacity properties of meat could be measured by considering the various muscle proteins as a single component and by using the same method under the same experimental conditions.

van den Berg et al. (1964) compared changes in water-holding and ion-binding properties in poultry with those for beef and reported that relations between ion-binding properties, water holding capacity (WHC), and tenderness were different. They reported that reduced loss of calcium (caused by binding of proteins) and increased loss of potassium were associated with reduced water binding capacity and reduced tenderness in beef. Reduced loss of calcium and increased loss of potassium during the first one to two days storage did not decrease tenderness in poultry leg meat, while increased loss of calcium and decreased loss of potassium did not improve WHC of breast meat.

Hamm and Deatherage (1960) reported that, "An investigation of the influence of temperature on the pH dependence of water-holding capacity will give information concerning changes in meat quality and also the mechanism of denaturation. This is because changes in protein net charge and in steric conditions affect meat hydration in a pH range of 3.0 to 7.5."

Several studies concerning consumer quality attributes have revealed that the important factors of tenderness, texture and drip on freezing are controlled by the water holding capacity of meat proteins (Wierbicki et al., 1954, 1955, 1956; and Arnold et al., 1956).

c. Effect of heating on bound water

Siemers and Hanning (1953) studied the vapor pressure of moisture in beef and found indications that more water was bound as the meat was cooked, but that the amount of bound water was comparatively small in either raw or cooked beef. Deatherage (1955) found that the water holding capacity (WHC) of meat proteins was directly related to shrinkage, drip on freezing and thawing, and tenderness. Wierbicki et al. (1957 a) found that sodium, potassium, calcium, and magnesium chlorides, when added to meat prior to heating, increased the WHC of meat proteins when they were heated to 70°C. Wismer-Pedersen (1959) found that raw pork with a low WHC was, in general, pale whereas taste and texture of the same meat when cooked was not essentially affected. Ritchey and Hostetler (1964) reported that as meat was heated, the muscle proteins were denatured and lost their ability to bind either their own water or added water. As a result of these alterations, the eating quality of meat was changed.

d. Free water

Weir (1960) considered that juiciness was a) the impression of wetness during the first chews produced by the rapid release of meat fluids, and b) a sustained juiciness due to slow release of serum and to the stimulating effect of fat on salivary flow.

Baker (1942) reported that juices were released by heating and, the amount of juice depended on temperature. This loss of water influenced juiciness and texture of meat. Variations in moisture content of chicken and beef muscles were noted by Strandine et al. (1949) but they did not correlate with tenderness.

Asselbergs and Whitaker (1961) reported very little variation in either drip loss or free moisture content of beef when cooking was varied from ten to 25 min. They found a definite trend toward increased drip losses from and decreased free moisture in cooked meat with prolonged cooking, giving a total moisture loss (drip and free moisture) of the same magnitude. Juiciness was not associated with any of the six components of tenderness reported by Cover et al. (1962 b). These components were softness to tongue and cheek, softness to tooth pressure, ease of fragmentation, mealiness, adhesion, and tenderness of connective tissue. Marquess et al. (1963) found no significant differences in juiciness when turkey rolls were cooked to internal temperatures of 80, 85, or 90°C in an oven set for 121, 149, or 177°C.

Ritchey and Hostetler (1964) found that muscles lost an increasing percentage of free water, bound water and weight as cooking temperatures increased from 70 to 80°C.

8. Fat

Strandine et al. (1949) noted that fat in chicken and beef, among other factors studied, did not correlate with tenderness values of the muscle.

Wierbicki et al. (1956) noted that at both three and 13 days post mortem, no significant relationship existed between intramuscular fat and tenderness. Paul et al. (1958) found that the correlation coefficient for the effect of fat on tenderness was rather small.

III. Measuring tenderness

> Pearson (1963) stated, "The sensation of tenderness is a complicated physical process since chewing involves not only cutting and grinding, but also includes squeezing, shearing and tearing. Tenderness is extremely difficult to measure, because the chewing motions involve both vertical and lateral movements of the jaws as well as various in between modifications, which all together produce the impression of tenderness. Thus, measurement of tenderness is complicated by the complexity of the chewing motions, as well as by the impressions of tenderness conveyed to the brain from numerous neurons located in the tongue, teeth, mouth, lips and cheeks. Since the brain must translate all these nervous impulses into a few simple terms, it is easy to comprehend the variability in the verbal or written descriptions of tenderness of the same piece of meat by different panelists."

Various mechanical devices for objective measurement of tenderness and its components have been developed. Warner (1928) reported a shearing device for measuring tenderness which was later described by Black et al. (1931). Bratzler (1932) modified this shear and it was later called the "Warner-Bratzler shear." Tressler et al. (1932 a,b) used a penetrometer for measuring tenderness. Two meat wedges containing artificial teeth were used by Volodkevich (1938). Winkler (1939) developed an instrument with two metal wedges which measured the force expressed as work per unit sample. Kramer et al. (1951) developed an instrument for lima beans that measured the maximum pressure required to force a plunger through the material. Proctor et al. (1956) made use of two dentures and simulated the frequency and motions of chewing for measuring tenderness. An orifice method using a Carver press with a modified cylinder was first used by Sperring et al. (1959) for measuring tenderness.

Evaluation methods for determining meat tenderness have been constantly changing. Meat softness and connective tissue tenderness were

reported by Cover et al. (1957), Ginger and Weir (1958), and Wilson et al. (1960). The three factors of softness, muscle fiber friability, and connective tissue tenderness were reported by Cover (1959) for evaluating tenderness, and Cover et al. (1962 b) included six factors, softness to tongue and cheek, softness to tooth pressure, fragmentation and mealiness of fibers, adhesion between muscle fibers and connective tissue tenderness in a similar study.

Several researchers have shown agreement between shear values and taste panels for poultry meat (Klose and Pool, 1954; Shannon et al., 1957; Klose et al., 1959; and Spencer and Smith, 1962).

Burrill et al. (1962) found a correlation coefficient of -0.83 between panel scores and Warner-Bratzler shear and a correlation coefficient of -0.72 between panel scores and Kramer shear from beef muscles. These differences were not significant. However, in almost every comparison the relationship between panel scores and Warner-Bratzler values was higher than a similar relationship between panel and Kramer shear values.

White et al. (1964) compared Warner-Bratzler shear values with turkey meat toughness as evaluated by a small trained panel (7 members) and by a consumer panel (355 members). The trained panel (triangle test) distinguished differences in toughness of light meat when shear resistance differed by four lb in a nine to 22 lb shearing range. The consumer panel detected definite toughness when the light meat had a shear resistance above 25 lb, and to some extent between 12 and 25 lb.

Several researchers have reported that panelists were influenced by the tenderness of the preceding samples (Nair, 1949; Hanson et al., 1955; Peryam and Pilgrim, 1957; and White et al., 1964).

Cover et al. (1962 d) reported that shear force values obtained across the grain of meat were not reliable for measuring connective tissue tenderness caused by heat or relating heat changes in collagen to connective tissue tenderness. They also reported that shear force values obtained across the grain of meat were not reliable as a means of relating collagen content in different muscles to the tenderness of their connective tissue. van den Berg et al. (1964) reported that muscle fiber toughness was detected when shear force was measured across the grain, whereas the strength of connections between muscle fibers was detected by organoleptic tests.

## PROCEDURE

This study was conducted in three parts. Part I involved relationships between temperature of cooked turkey rolls and physical measurements of tenderness (shear press), sensory measurements of tenderness (panel) and sensory measurements of juiciness (panel). Part II involved changes in the composition of turkey meat during cooking. The extractability, or solubility of protein nitrogen and non-protein nitrogen, and the total moisture, water holding capacity (WHC) and bound water were determined from samples of light and dark turkey meat cooked to different internal temperatures. Total moisture of fresh samples were also determined. Part III involved calculation of correlation coefficients between physical, sensory and chemical values.

### Part I: Heat Penetration, Tenderness and Juiciness

#### Turkey roll preparation and cooking

Commercially prepared, unseasoned, boneless turkey meat rolls, from male turkeys six months of age, were used in this study. Eighteen boneless turkey rolls were made primarily from *sartorius*, *tensor fascia*, *semimembranosus*, *semitendinosus*, *gluteus superficialis*, *gluteus medius*, *gluteus profundus* and *quadriceps femoris* muscles (hereafter referred to as dark meat rolls). Eighteen boneless rolls were made primarily from *pectoralis superfical* muscles (hereafter referred to as light meat rolls). Each light and dark meat roll approximated 11 in. in length and five in. in diameter. Each roll was prepared for cooking, prior to freezing, by wrapping in aluminum foil. As required, each roll was thawed at 16°C for approximately 48 to 60 hr prior to the cooking treatment. Six rolls

at a time were placed in a pre-heated institutional forced convection oven with a Minneapolis-Honeywell Versatronic (Model R7161B) temperature regulator set at 107°C. Internal temperature was measured continuously using iron-constantan thermocouples (Type J with stainless steel probes) attached to a 24 point recording potentiometer. Two probes were inserted into each roll approximately two in. each way from the mid-point of the long axis. Thermocouples were inserted approximately two and one-half in. into each roll. Temperature was recorded at five second intervals. Additional thermocouples were used to record oven temperature. Three dark and three light meat rolls were cooked to each internal temperature, 60, 66, 71, 77, 82 and 88°C.

When the center of each roll reached the predetermined end temperature, it was removed from the oven and the aluminum foil removed. Two-thirds of each roll was packaged in Cryovac* for sensory evaluation (panel) and physical (shear press) analysis, and one-third of each roll was packaged in Cryovac for chemical analyses. Since the rolls were cooked in one laboratory and evaluated in another, the air was partially removed by hand from each bag, the bags were sealed, and the packaged rolls were transferred to the second laboratory. At this time, the bags were reopened, air was partially removed from each bag by vacuum, the bags were sealed and the rolls were frozen at -34°C for 24 hr and stored at -23°C until needed.

Prior to all analyses rolls were thawed at 16°C for 36 hr.

Shear force determinations

Shear force values were determined with an Allo-Kramer shear press

*"Cryovac" is the registered trademark of the Cryovac Division of W. R. Grace and Co., Duncan, South Carolina.

equipped with an electronic recorder. A 3,000 lb ring and a 15 second down stroke were used on the press. The electronic recorder was set for 1,000.

Dark and light meat turkey rolls, prepackaged for shear press and panel evaluations, were separated into either individual breast or individual thigh muscles. Shear force was evaluated on a 45 to 50 g portion, trimmed free of fat and skin, with the meat fibers positioned perpendicular to the shearing blades. The remaining meat was used for panel evaluations. Each portion of roll consisted of three muscles and each muscle was sheared separately. Mean shear force values for the three muscles were recorded for each roll.

Panel selection and training

Thirteen persons were asked to evaluate, by a triangle test under laboratory conditions, the tenderness and juiciness of dark and light turkey meat samples of known shear force values and moisture contents. The samples consisted of comparable slices cut perpendicular to the meat fibers, from the same muscles used for shear force values and moisture determinations. Three coded samples were presented to each panel member at a time, two from the same muscle of approximately the same shear value and moisture content, and the third sample from a different sample of unequal shear value and/or moisture content. However, all samples were either all dark or all light turkey meat. Three replications from three samples each of dark and light meat were evaluated.

Six members and one alternate were selected for further panels based on correct judgments of shear values and moisture content differences. Five members had previously evaluated chicken meat tenderness,

and their evaluation of tenderness in this previous study showed a high degree of correlation with measurements of shear force.

Panel sample testing

Each of the six panel members were given coded samples of either dark or light meat cooked to internal temperatures of 71, 77, 82, or 88°C. Members were asked to evaluate tenderness and juiciness based on a seven point hedonic scale as shown in Table 1. A numerical score was not given to the scale until after panel members had completed their evaluation. A copy of the score sheet as used by panel members is shown in Appendix Table 1.

Each panel member evaluated three samples from each dark and light meat roll resulting in a total of 72 tenderness and 72 juiciness evaluations for each panel member.

Part II: Chemical Analyses of Cooked Meat

General Methods Used:

Nitrogen analyses

All nitrogen analyses were determined by the micro-Kjeldahl method outlined by The American Instrument Company (1961). All nitrogen values were reported as g or mg of nitrogen or g non-protein nitrogen per 100 g of turkey meat sample, calculated on a moisture free basis. Nitrogen values were determined in duplicate. Nitrogen was calculated as follows:

$$\text{g N/100 g sample} = \frac{\text{Normality of acid X 0.014 X ml Normal acid}}{\text{Sample weight X Percentage moisture}} \text{ X } 100$$

pH Measurements

All pH measurements were determined using a Beckman Model 96

Table 1. Score card used by panel members for recording tenderness and juiciness of dark and light meat.

| Numerical rating[1] | Tenderness value | Juiciness value |
|---|---|---|
| 1 | Extremely tender | Very juicy |
| 2 | Very tender | Juicy |
| 3 | Tender | Slightly juicy |
| 4 | Slightly tender | Neither dry nor juicy |
| 5 | Slightly tough | Slightly dry |
| 6 | Tough | Dry |
| 7 | Very tough | Very dry |

[1]Numerical ratings were not printed on score cards, and were used only for statistical purposes.

Zeromatic pH meter. A 25 to 35 g sample of diced meat and 50 ml distilled water were blended in a micro blending cup for two min, then transferred to a 100 ml beaker. The electrodes were placed directly into the meat slurry and the observed pH values were recorded to the nearest 0.1 unit. The pH of drip from cooked meat was determined by placing the electrode into the drip and recording the observed pH values. All pH measurements were determined on triplicate samples.

Moisture determination

Each fresh meat sample was prepared for moisture analysis by grinding 50 g three times through a plate with one-eighth in. openings. Cooked meat was prepared for moisture analysis by chopping into approximately one-eighth in. cubes.

Moisture (in duplicate samples) was determined by placing two 12.5 g samples of ground or chopped meat into aluminum weighing containers (10 X 10 cm), and then drying to a constant weight for 12 hr at 100-102°C. The loss in weight was reported as moisture (A.O.A.C., 1960). (This method for determining moisture was also used to calculate water holding capacity and bound water.)

Moisture was calculated using the following formula:

$$\text{g moisture per 100 g sample} = \frac{\text{original weight - wt after drying}}{\text{original weight}} \times 100$$

Centrifugation

Model CS or V International centrifuges were used throughout this study. Samples were centrifuged at 2,500 rpm (1,000 X g) for 15 min except for water holding capacity determinations.

Statistical analyses

Standard errors, Duncan's Multiple-range test, and analysis of variance were calculated using procedures outlined by Snedecor (1959).

Reagents

Reagent grade chemicals and deionized water were used throughout this experiment.

Sample preparation:

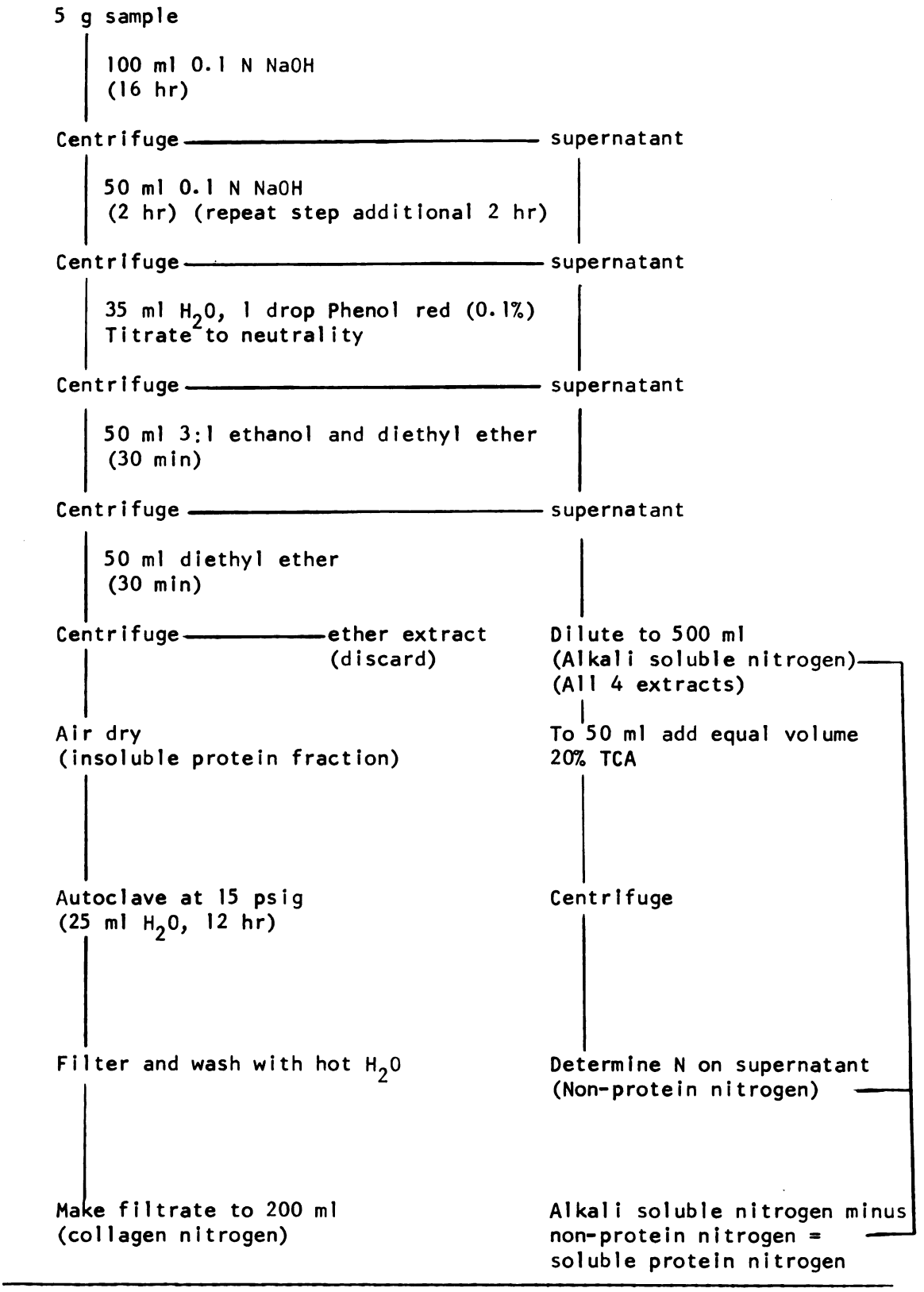
Nitrogen fractionation

Approximately 100-150 g of turkey meat were removed from each roll by taking a complete slice from the portion of the roll nearest the center, and trimmed free of visible fat, tendons and connective tissue. The samples were ground three times in a laboratory grinder, using a plate with one-eighth in. openings. The ground meat samples were then placed in air tight containers and stored at 1°C until evaluated.

Total nitrogen was determined by the micro-Kjeldahl method using a 150-200 mg sample of freshly prepared meat.

The procedure used for protein and non-protein fractionation was a modification of that reported by Miyada and Tappel (1956 b). A diagrammatic representation of the fractionation procedure appears in Figure 1. Five g of freshly prepared sample and 100 ml of 0.1 N NaOH were added to a 250 ml capacity heavy duty centrifuge bottle. The mixture was allowed to stand for 16 hr. The mixture was then centrifuged (2,500 rpm) and the supernatant decanted and saved for subsequent extractions. To the residue remaining, 50 ml of fresh 0.1 N NaOH was added and allowed to stand for two hr. This mixture was again centrifuged and the

Fig. 1. Diagrammatic representation of nitrogen fractionation.



supernatant combined with the first extraction. This extraction was repeated with another 50 ml of 0.1 N NaOH for two hr. Thirty-five ml water and one drop of 0.1% phenol red was added to the remaining residue and the resulting mixture was titrated to neutrality using 0.1 N HCl. Vigorous stirring was necessary to completely diffuse the NaOH from the meat particles. This neutralized mixture was centrifuged and the supernatant decanted and combined with previous extractions. Fifty ml of a mixture of 95% ethyl alcohol and diethyl ether (3:1) was added to the remaining residue and allowed to stand for 30 min. The mixture was centrifuged and the supernatant combined with previous extractions. This represents the soluble protein fraction. The residue remaining, representing the insoluble protein fraction, was extracted with 50 ml of anhydrous diethyl ether for 30 min (to remove the remaining fat), centrifuged, the supernatant discarded, and the residue air dried.

The first four combined extractions were made to 500 ml volume, and a five ml aliquot used for alkali soluble nitrogen determinations. To another 50 ml aliquot an equal volume of 20% trichloroacetic acid (TCA) was added and the solution was quantitatively transferred to a 250 ml heavy duty centrifuge bottle. The TCA precipitate was centrifuged and a five ml aliquot of the supernatant was used for non-protein nitrogen determinations.

Soluble protein nitrogen was determined by subtracting non-protein nitrogen from alkali soluble nitrogen.

The remaining air dried residue, after extraction, was placed in a 35 ml capacity tube with 25 ml water, sealed airtight, and autoclaved for 12 hr at 15 psig. This was the optimum time for maximum liberation of collagen nitrogen as determined previously by the method described.

The gelatin solution was removed, filtered while hot, and rinsed with hot water as recommended by Ritchey et al. (1963). When this solution cooled to room temperature it was made to 200 ml volume and a five ml aliquot was used for collagen nitrogen determinations.

Free water and bound water

For the purpose of this study a modification of the description by Hamm (1960) for water holding capacity (WHC) was used. He described WHC as the ability of muscle tissue to hold its own or added water during application of a force, expressed in terms of the amount of loose water related to the total moisture content in muscle tissue. For this study WHC was expressed as the amount of loose or free water after cooking plus the amount of moisture lost during cooking related to total moisture content of the muscle tissue before cooking.

The procedure used for determining WHC was a modification of the method reported by Wierbicki et al. (1957 b). A specially constructed tube was used for this determination. Overall length was 180 mm; the top section was 30 mm in diameter, 100 mm in length and the bottom section was 18 mm in diameter, 80 mm in length. Quantity of expressed juice was determined by transferring it to a graduated cylinder calibrated in 0.1 ml divisions. A course fritted glass disc was placed at the intersection of the large and small diameter sections of the tube.

Approximately 25.0 g of previously cooked meat was placed in the upper portion of the tube, equilibrated in a water bath at 20 to 25°C for ten min and centrifuged for 20 min at 1,000 rpm (170 X g) which was previously determined (optimum time necessary to give minimum variability in results from triplicate samples).

Water holding capacity (WHC) was calculated as follows:

$$WHC = \frac{(\text{ml juice} \times F) + \text{g moisture lost from 25 g during cooking}}{\text{moisture in 25.0 g fresh sample}} \times 100$$

Moisture in 25.0 g fresh and cooked samples was determined in duplicate by taking two 12.5 g samples of meat and drying them at 100 to 102°C for 12 hr. F represents the water fraction of the juice. Wierbicki *et al*. (1957 b) reported F to equal 0.951 ± 0.004 for juice expressed at 70°C. This value was used for all appropriate determinations in this study.

Part III: Correlation Coefficients

Simple correlation coefficients (Snedecor, 1959) were calculated between selected factors on the basis of the results obtained from turkey meat cooked to different internal temperatures.

## RESULTS AND DISCUSSION

### Part I: Heat Penetration, Tenderness and Juiciness

Heat Penetration:

The mean temperature recorded in the convection type oven during the period of cooking was relatively constant when the attached temperature regulator was set at 107°C. The actual oven temperature was cyclic in nature; however, both the magnitude and time per cycle decreased during the cooking period. The temperature variations are shown in Figure 2 by typical temperature cycles obtained 15 min and three hr after the turkey rolls were placed in the oven. The magnitude of one complete cycle 15 min after rolls were placed in the oven was three degrees above and two degrees below the thermostat setting, a five degree variation. After three hr, the magnitude of one complete cycle was one degree above and one degree below the thermostat setting, a variation of only two degrees. Temperature cycled in this manner throughout the remainder of the cooking time.

During cooking, temperature in each roll was determined using a potentiometer with an attached recorder. Typical time-temperature curves were constructed through data plotted on rectangular coordinate paper for similar sized dark and light meat turkey rolls, and are presented in Figure 3. The temperature at the center of each roll remained constant for about one hr, then increased rapidly. Times for internal temperatures to reach the pre-established end-point temperatures are presented in Table 2. The highest internal temperature (88°C) was obtained in 6.4 hr in dark meat and 5.5 hr in light meat. Marquess *et al.* (1963) cooked turkey rolls at different oven temperatures to

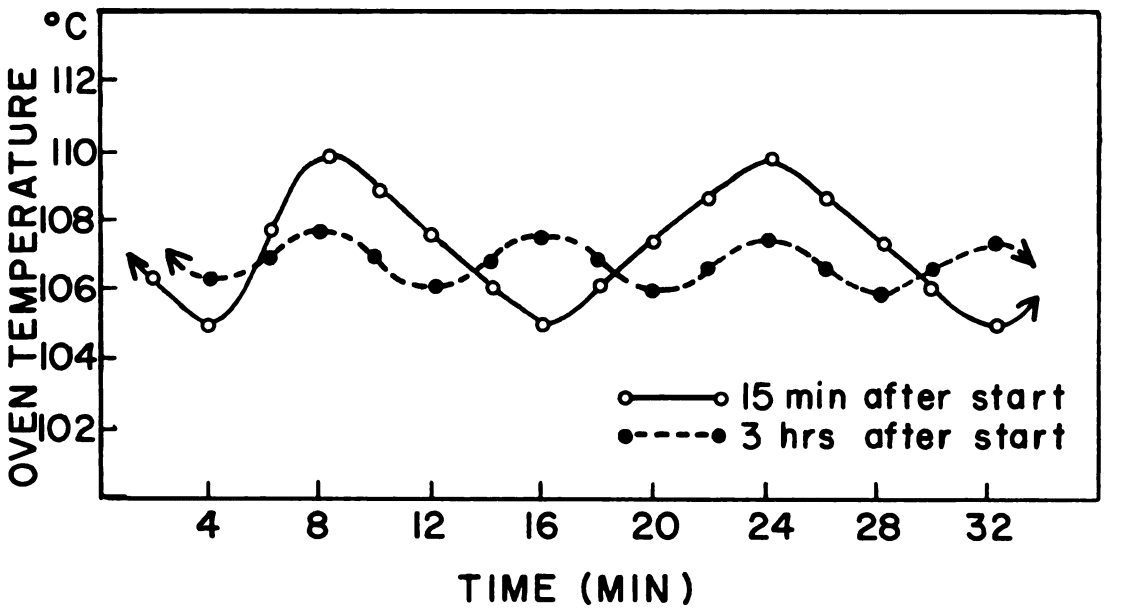



Figure 2. Oven temperature cycles 15 min and 3 hr after loading.

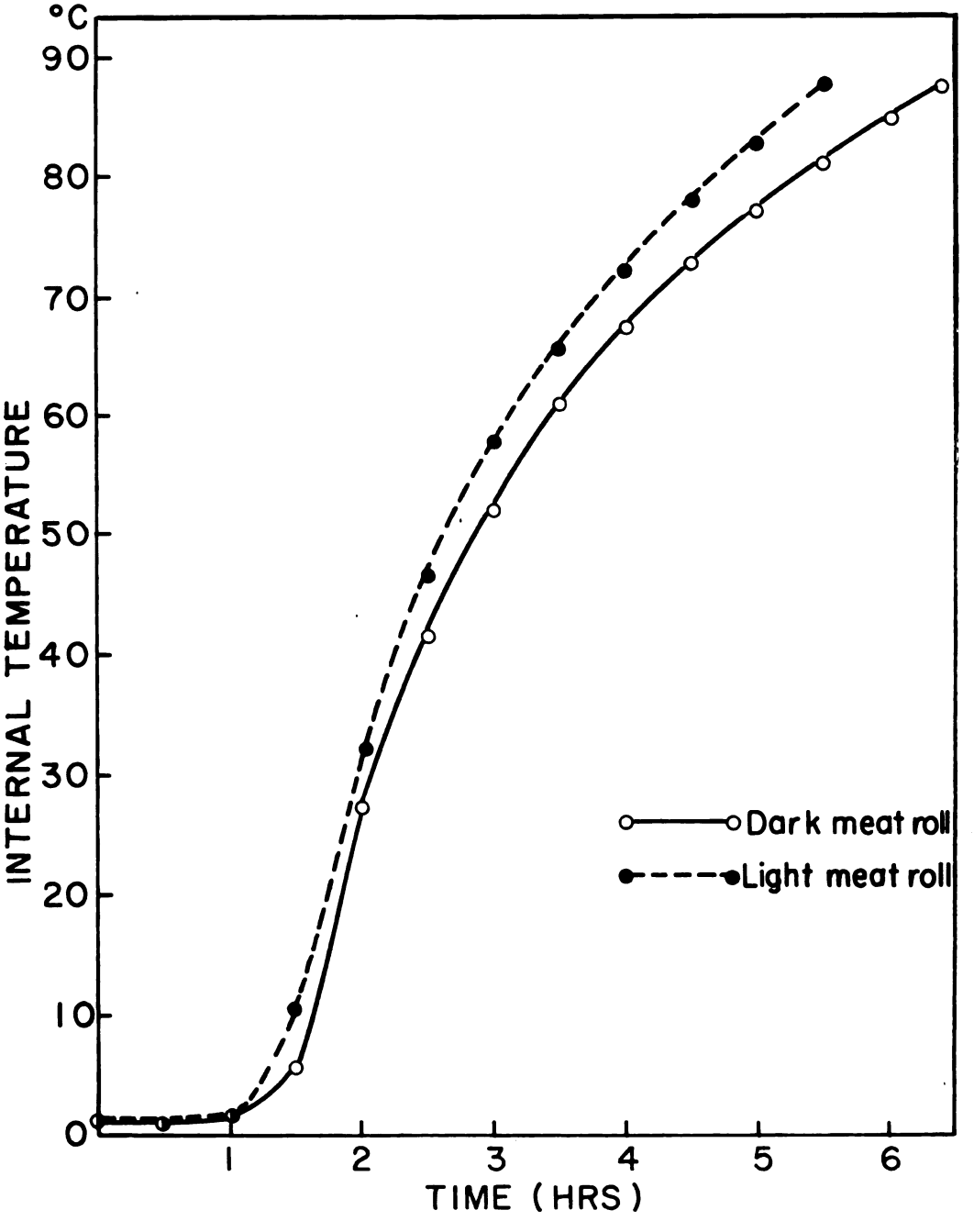



Figure 3. Heat penetration curves for dark and light turkey rolls.

Table 2. Time for turkey rolls to reach different end-point temperatures.

| Internal end-point temperature | Time | |
|---|---|---|
| | Dark meat rolls | Light meat rolls |
| °C | hr | hr |
| 60 | 3.4 | 3.1 |
| 66 | 3.8 | 3.5 |
| 71 | 4.3 | 3.9 |
| 77 | 4.9 | 4.4 |
| 82 | 5.5 | 4.9 |
| 88 | 6.4 | 5.5 |

different internal temperatures, and found that dark meat turkey rolls required more time per pound to reach final temperatures than light meat turkey rolls.

Each turkey roll was removed from the oven when a predetermined temperature was reached. Wilkinson et al. (1965) found that temperature at the center of turkey rolls increased, after removal from oven, and remained above the temperature when removed for as long as 90 min, even when rolls were immersed in ice water.

Evaluation of Tenderness:

Shear force measurements:

Kramer shear force values were determined for dark and light turkey meat cooked to each end-point temperature (60-88°C). Pounds of force (per g of sample) required to shear a sample of each roll are presented in Figure 4. Shear values were higher for all dark meat samples than for light meat samples cooked at the same temperatures.

Shear force, expressed as lb of force per g of sample, of dark meat samples decreased as temperature of cooked rolls increased from 60 to 88°C. Differences in shear values were highly significant (1% level) and the largest decrease in shear force occurred between rolls cooked to 71 and 77°C (12.3 lb to 10.7 lb). Tenderness of dark meat rolls cooked to 60, 66 and 71°C did not differ significantly, neither did tenderness of rolls cooked to 77, 82 and 88°C (Table 3). Goodwin et al. (1962 a) (using mean shear force values of both dark and light turkey meat) reported no significant differences in shear values of dark and light meat from whole birds cooked to 77, 82, 88 or 94°C; however, meat cooked to 55°C had significantly higher shear values than

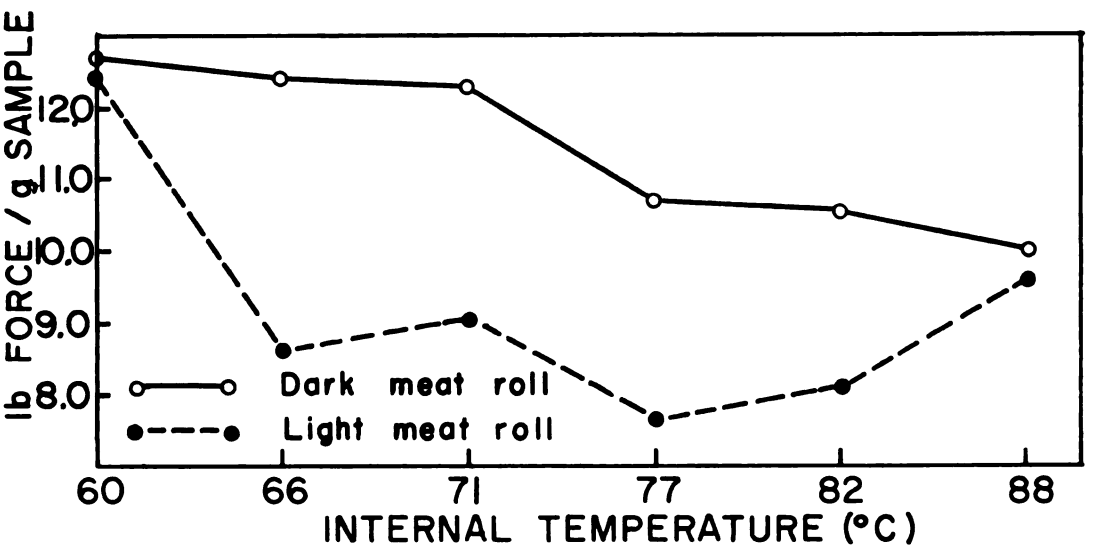



Figure 4. Shear force of dark and light turkey meat cooked to different temperatures.

Table 3. Analysis of variance and Duncan's Multiple-range test for shear force of dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Light meat |
|---|---|---|---|
| Internal temperature | 5 | 4.11** | 8.75 |
| Shear force | 12 | 0.67 | 3.14 |
| Total | 17 | | |

Duncan's Multiple-range test

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| Dark meat shear force (lb) | 12.7[a] | 12.4 | 12.3 | 10.7 | 10.5 | 9.9 |
| Light meat shear force (lb) | 12.4[a] | 8.6 | 8.7 | 7.7 | 8.1 | 9.6 |

**Significant one percent level.

[a] All values reported as lb of shear force per g sample. All values underscored by the same line are not significantly different at the five percent level.

meat cooked to 77°C or above. They also found higher shear values for dark meat than for light meat at all temperatures of cooked meat.

In this study, no significant differences were found in shear force of light meat cooked to different temperatures; however, the pounds of force for light meat approached that for dark meat when both were cooked to 60 and 88°C. Shear force at 60°C was 12.4 lb for light meat; 12.7 lb for dark meat, whereas shear force of light and dark meat cooked to 88°C was 9.6 and 9.9 lb respectively (Table 3).

Panel Evaluations:

After the panel was selected and trained, they were presented with samples of either dark or light turkey meat for tenderness and juiciness evaluations. In a previous study using turkey rolls, Wilkinson *et al.* (1965) found that turkey rolls inoculated with pathogenic bacteria, were free from viable pathogens after cooking to an internal temperature of 71°C in an oven set at 107°C. Therefore, panel members were asked to evaluate samples from turkey rolls cooked to temperatures at or above 71°C.

Panel scores of tenderness, based on a 7-point hedonic scale (1 extremely tender; 7 very tough) for light meat rolls varied from 2.9 to 4.0 (slightly tender) and for dark meat rolls varied from 3.6 to 4.9 (slightly tough) (Figure 5). Panel scores of dark meat decreased (increased tenderness) as temperature of cooked rolls increased. Scores of light meat were more variable and decreased (increased tenderness) until the temperature of cooked meat reached 82°C; however, light meat cooked to 88°C was less tender than all other samples evaluated.

Panel scores for tenderness were higher (less tender) for dark

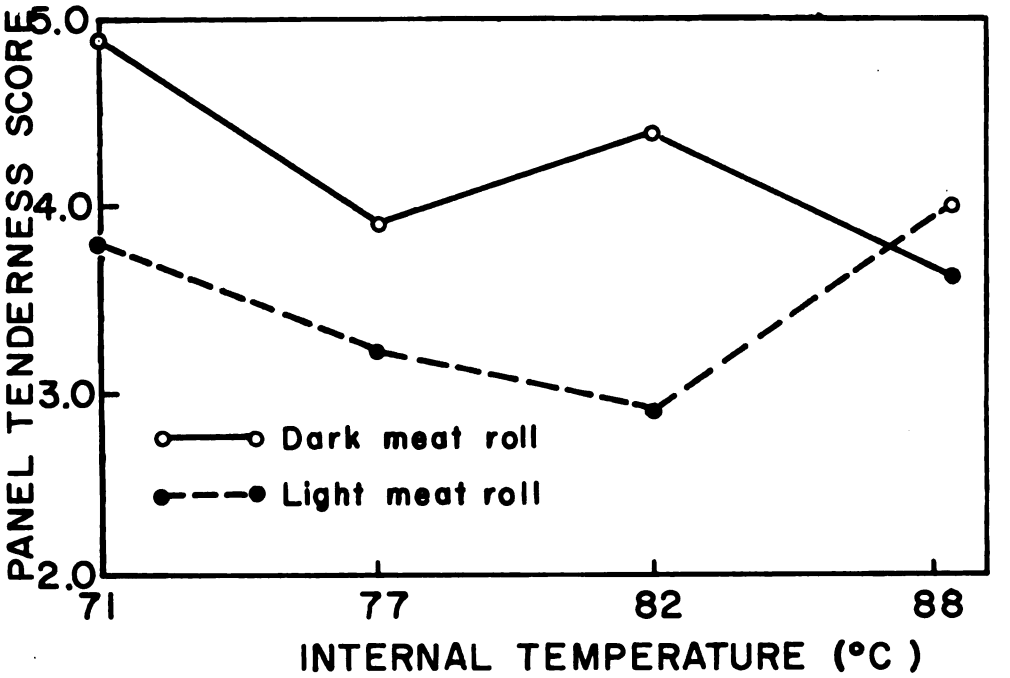



Figure 5. Panel tenderness scores for dark and light turkey meat cooked to different temperatures.

meat samples than for light meat samples cooked to all temperatures except 88°C. When the temperature of the roll reached 88°C, light meat samples were rated less tender than dark meat samples. This interaction of panel scores and composition (dark or light meat) was found to be highly significant as shown in Table 4. Highly significant differences were also found between panel members and tenderness scores for rolls cooked to the different temperatures evaluated.

Panel scores for juiciness of light and dark meat, based on a 7-point hedonic scale (1 very juicy; 7 very dry) increased with an increase in temperature of cooked meat (Figure 6). Average panel scores of light meat increased from 3.2 (slightly juicy) to 4.5 (slightly dry) for light meat cooked to temperatures from 71 to 88°C. Panel scores for juiciness of dark meat averaged 3.1 at 71°C and increased to 3.9 and 3.8 when meat was cooked to 82 and 88°C, respectively.

The average panel juiciness scores were the same for dark and light meat rolls cooked to 71°C. However, juiciness scores for light meat samples were higher (less juicy) than dark meat when cooked to 77°C or higher. The greatest difference in panel juiciness scores was found between light meat and dark meat cooked to 88°C. At this temperature the light meat was less juicy. Highly significant differences were found between mean scores of rolls cooked to different temperatures, and dark meat was significantly more juicy than light meat (5% level). Highly significant differences were found between juiciness scores of individual panel members (Table 4).

## Part II: Chemical Analyses of Cooked Meat

The extractability, or solubility of different protein and

Table 4. Analysis of variance for tenderness and juiciness scores.

| Source of variation | Degrees of freedom | Mean square Tenderness score | Mean square Juiciness score |
|---|---|---|---|
| Replication | 2 | | |
| Internal temperature (°C) | 3 | 5.23** | 8.84** |
| Panel members | 5 | 4.58** | 3.64** |
| Composition (dark or light meat) | 1 | 19.14** | 4.34* |
| IT X P | 15 | 0.78 | 0.55 |
| IT X C | 3 | 5.30** | 1.06 |
| P X C | 5 | 0.98 | 1.48 |
| IT X P X C | 15 | 0.67 | 0.30 |
| Error | 47 | 0.85 | 0.70 |

* Significant five percent level.

** Significant one percent level.

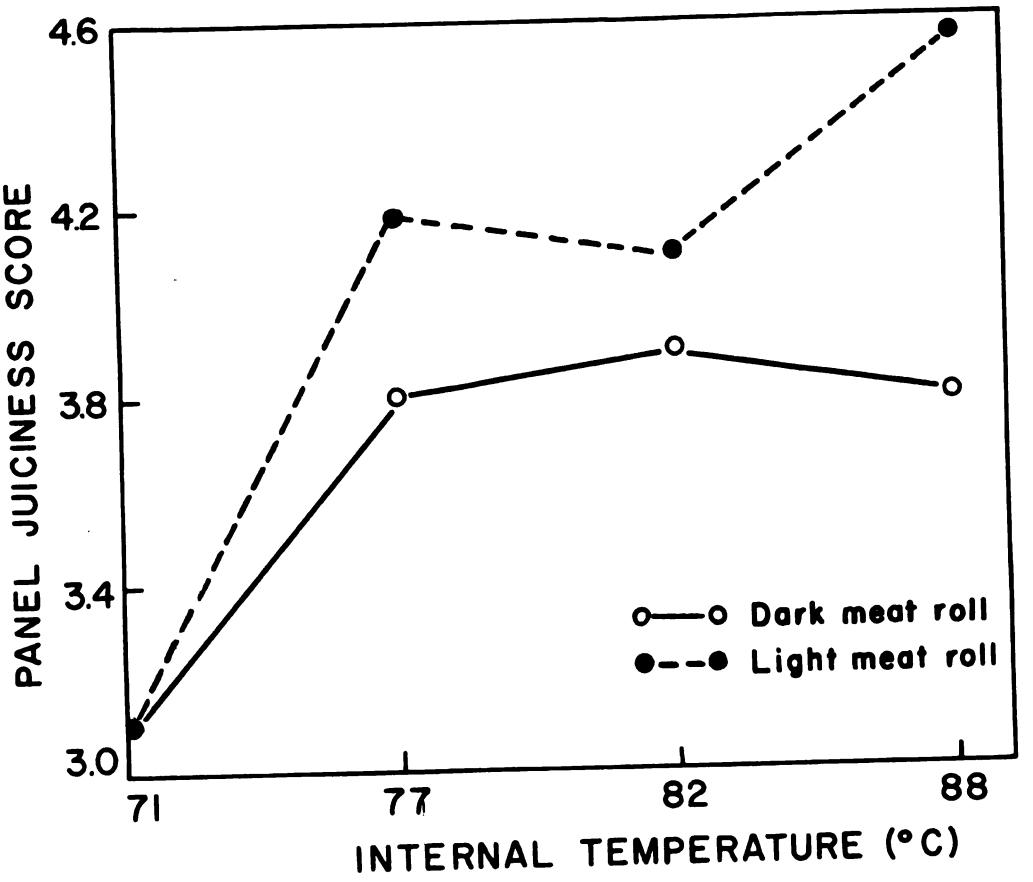



Figure 6. Panel juiciness scores for dark and light turkey meat cooked to different temperatures.

non-protein nitrogen fractions was determined to evaluate their occurrence in relationship to changes in tenderness or juiciness during cooking.

Total Nitrogen:

Total nitrogen values (moisture free basis) from dark and light meat samples cooked to different temperatures are presented in Figure 7. When the rolls were cooked to temperatures ranging from 60 to 88°C, total nitrogen increased from 6.80 to 8.04 g per 100 g in dark meat and from 6.38 to 8.00 g in light meat. These differences were found to be highly significant as reported in Table 5. The apparent increase in total nitrogen may partially be due to increased loss of fat during cooking, as reported by Snyder and Orr (1964). Scharpf and Marion (1964) also reported that a change in fat content could more than compensate for percentage changes in total nitrogen.

Total nitrogen in dark meat was as high or higher than total nitrogen in light meat cooked to each temperature from 60 to 88°C. However, when calculated on a moisture basis, mean total nitrogen values (shown in Table 6) were higher in light meat than in dark meat cooked to those same temperatures (except 60°C). Total nitrogen values in dark meat were higher than in light meat samples cooked to 60°C. The slightly higher total nitrogen content of light meat over dark meat is in agreement with results of Millares and Fellers (1948) and Hepburn (1950).

Alkali Soluble Nitrogen:

Alkali soluble nitrogen (moisture free basis) in turkey meat cooked to temperatures ranging from 60 to 88°C are shown in Figure 8. These values were similar for dark and light meat; however, the values per

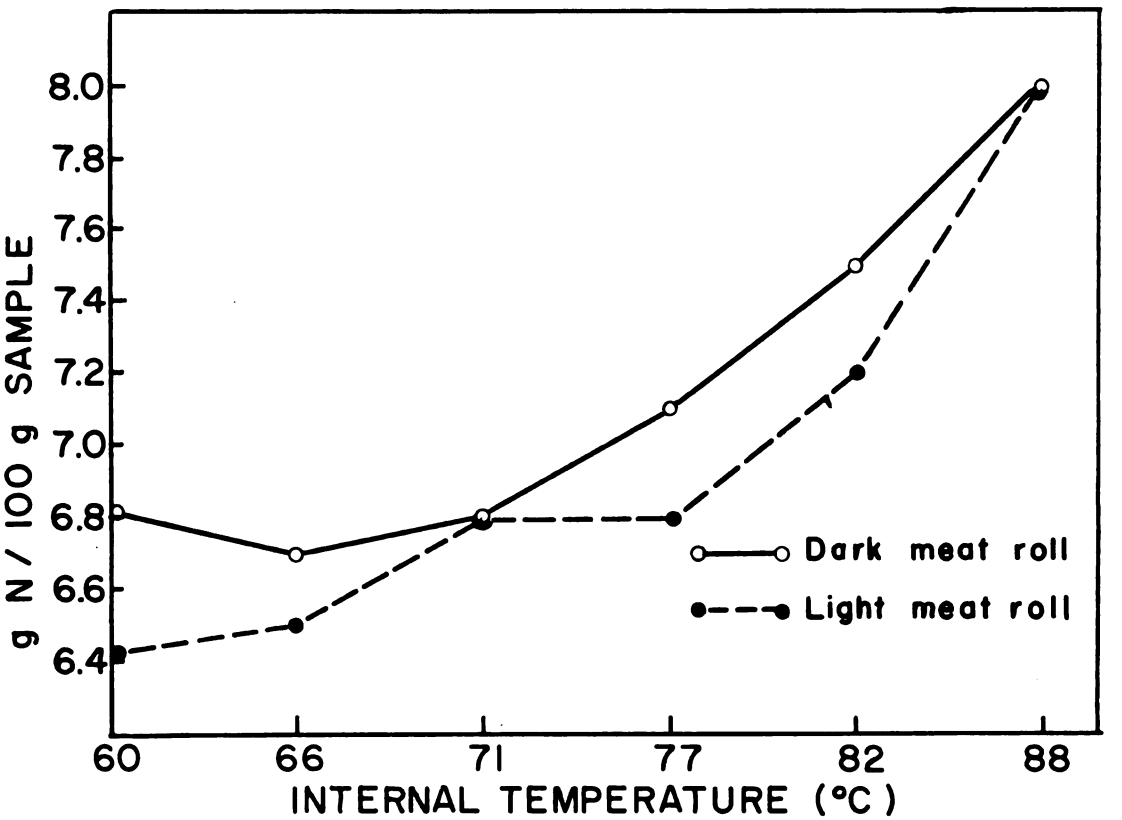



Figure 7. Total nitrogen in dark and light turkey meat cooked to different temperatures.

Table 5. Analysis of variance and Duncan's Multiple-range test for total nitrogen in dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Mean square Light meat |
|---|---|---|---|
| Internal temperature | 5 | 0.84** | 1.06** |
| Total nitrogen | 12 | 0.08 | 0.11 |
| Total | 17 | | |

Duncan's Multiple-range test

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| Dark meat total nitrogen (g) | 6.80[a] | 6.67 | 6.81 | 7.14 | 7.51 | 8.04 |
| Light meat total nitrogen (g) | 6.38[a] | 6.49 | 6.79 | 6.77 | 7.20 | 8.00 |

** Significant one percent level.

[a] All values reported as g total nitrogen per 100 g sample. Any two means underscored by the same line are not significantly different at the five percent level.

Table 6. Mean total nitrogen values (moisture basis) for dark and light turkey meat cooked to different temperatures.

| Internal temperature | Total nitrogen[a] | |
|---|---|---|
| | Dark meat | Light meat |
| °C | g | g |
| 60 | 4.63 | 4.37 |
| 66 | 4.49 | 4.53 |
| 71 | 4.62 | 4.66 |
| 77 | 4.68 | 4.76 |
| 82 | 4.76 | 4.81 |
| 88 | 5.06 | 5.19 |

[a] All values reported as g total nitrogen per 100 g sample.

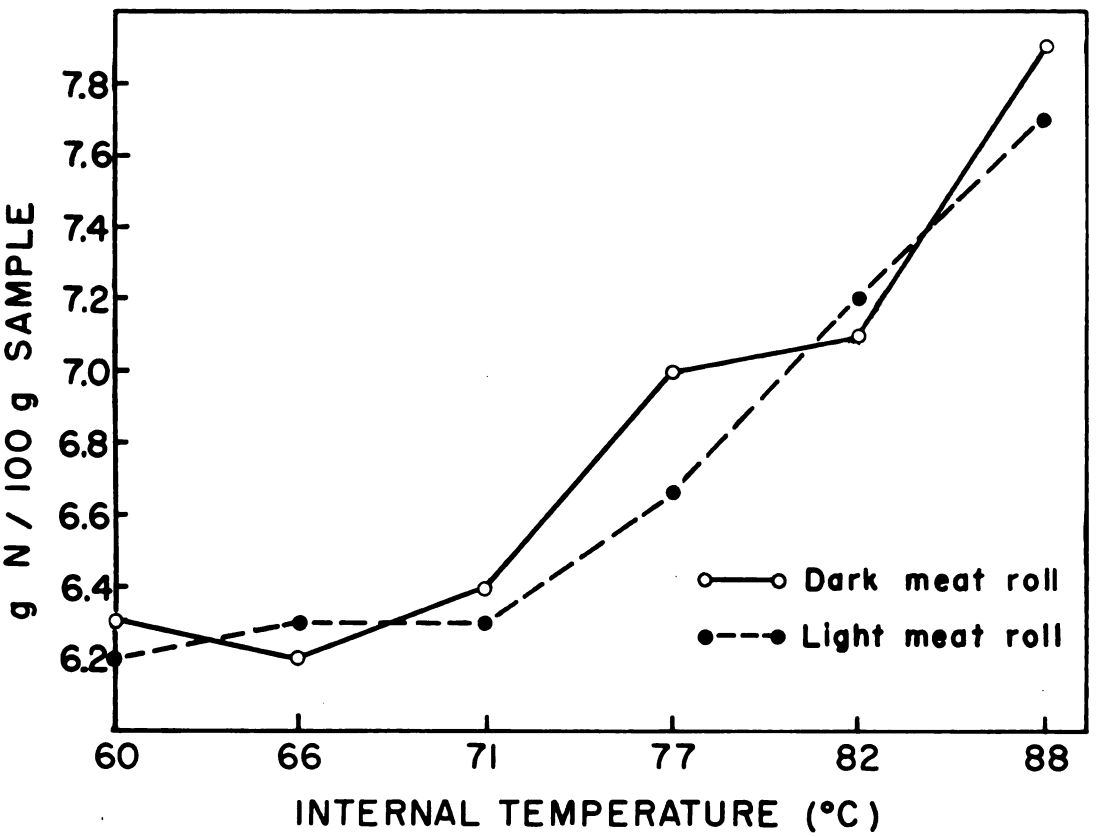



Figure 8. Alkali soluble nitrogen in dark and light turkey meat cooked to different temperatures.

100 g sample increased with an increase in cooked meat temperature. These differences were found to be highly significant as reported in Table 7.

Alkali soluble nitrogen in dark meat was higher than in light meat from all samples cooked to all temperatures except 66 and 82°C. However, when calculated on a moisture basis, mean alkali soluble nitrogen values (shown in Table 8) were higher in light meat than in dark meat at all internal temperatures except 71°C. The slightly higher alkali soluble nitrogen value from light over dark meat is in agreement with results reported by Scharpf and Marion (1964).

Grams of alkali soluble nitrogen in 100 g of total nitrogen are shown in Table 9. Alkali soluble nitrogen (as a percentage of total nitrogen) increased in dark meat from 93.1 to 98.2 g as temperature of cooked meat increased from 60 to 88°C. Values from light meat remained relatively constant, except for the lower value obtained from light meat cooked to 71°C.

Non-Protein Nitrogen:

Non-protein nitrogen values (TCA soluble) for light and dark meat cooked to different temperatures are presented in Table 10. Less than two percent of the total sample was non-protein nitrogen in composition. Significant differences in non-protein nitrogen values were found in dark meat cooked to different temperatures as presented in Table 11. Even though significant differences exist, a relationship with increasing internal temperature was not apparent.

Grams of non-protein nitrogen (NPN) per 100 g total nitrogen are shown in Table 9. These values vary slightly, but do not appear to be

Table 7. Analysis of variance and Duncan's Multiple-range test for alkali soluble nitrogen in dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Mean square Light meat |
|---|---|---|---|
| Internal temperature | 5 | 1.27** | 1.10** |
| Alkali soluble nitrogen | 12 | 0.07 | 0.06 |
| Total | 17 | | |

Duncan's Multiple-range test

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| Dark meat alkali soluble nitrogen (g) | 6.33[a] | 6.17 | 6.42 | 6.97 | 7.14 | 7.90 |
| Light meat alkali soluble nitrogen (g) | 6.25[a] | 6.32 | 6.26 | 6.81 | 7.19 | 7.73 |

** Significant one percent level.

[a] All values reported as g alkali soluble nitrogen per 100 g sample. Any two values underscored by the same line are not significantly different at the five percent level.

Table 8. Mean alkali soluble nitrogen values (moisture basis) in dark and light turkey meat cooked to different temperatures.

| Internal temperature | Alkali soluble nitrogen[a] | |
|---|---|---|
| | Dark meat | Light meat |
| °C | g | g |
| 60 | 4.28 | 4.47 |
| 66 | 4.15 | 4.42 |
| 71 | 4.35 | 4.31 |
| 77 | 4.40 | 4.62 |
| 82 | 4.56 | 4.73 |
| 88 | 4.92 | 4.99 |

[a] All values reported as g alkali soluble nitrogen per 100 g sample.

Table 9. Grams alkali soluble, soluble protein, non-protein and collagen nitrogen in 100 g total nitrogen from dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | g N per 100 g total nitrogen | | | | | |
| Dark meat | | | | | | |
| ASN[a] | 93.1 | 92.5 | 94.3 | 97.6 | 95.1 | 98.2 |
| SPN[a] | 76.8 | 76.5 | 81.0 | 78.2 | 81.6 | 80.7 |
| NPN[a] | 16.2 | 16.0 | 14.7 | 19.7 | 13.4 | 17.4 |
| CN[a] | 3.5 | 3.0 | 3.8 | 2.7 | 1.7 | 0.6 |
| Light meat | | | | | | |
| ASN[a] | 98.0 | 97.4 | 92.3 | 98.5 | 99.8 | 96.6 |
| SPN[a] | 78.4[b] | 75.6 | 74.5 | 78.1[b] | 84.2[b] | 81.1 |
| NPN[a] | 19.6 | 21.6 | 17.8 | 20.0 | 15.7 | 16.1 |
| CN[a] | 2.8 | 2.0 | 2.6 | 3.4 | 1.7 | 1.9 |

[a] ASN (alkali soluble nitrogen); SPN (soluble protein nitrogen); NPN (non-protein nitrogen); CN (collagen nitrogen).

[b] Sum of SPN, NPN, and CN greater than 100 g due to variation in soluble nitrogen and collagen nitrogen.

Table 10. Non-protein nitrogen in dark and light turkey meat cooked to different temperatures.

| Internal temperature | Non-protein nitrogen[a] Dark meat | Light meat |
|---|---|---|
| °C | g | g |
| 60 | 1.11 | 1.25 |
| 66 | 1.06 | 1.41 |
| 71 | 0.93 | 1.21 |
| 77 | 1.40 | 1.39 |
| 82 | 1.01 | 1.13 |
| 88 | 1.40 | 1.28 |

[a] All values reported as g non-protein nitrogen per 100 g sample.

Table 11. Analysis of variance and Duncan's Multiple-range test for non-protein nitrogen in dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Light meat |
|---|---|---|---|
| Internal temperature | 5 | 0.12* | 0.03 |
| Non-protein nitrogen (NPN) | 12 | 0.03 | 0.11 |
| Total | 17 | | |

Duncan's Multiple range test

Dark meat

| Internal temp. (°C) | 88 | 77 | 60 | 66 | 82 | 71 |
|---|---|---|---|---|---|---|
| NPN (g N/100 g sample) | 1.40[a] | 1.40 | 1.11 | 1.06 | 1.01 | 0.93 |

Light meat

| Internal temp. (°C) | 66 | 77 | 88 | 60 | 71 | 82 |
|---|---|---|---|---|---|---|
| NPN (g N/100 g sample) | 1.41[a] | 1.39 | 1.28 | 1.25 | 1.21 | 1.13 |

* Significant five percent level.

[a] Values arranged in decreasing order for statistical clarity. Any two values underscored by the same line are not significantly different at the five percent level.

dependent on the temperatures of cooked rolls within the range used.

Soluble Protein Nitrogen:

Soluble protein nitrogen (alkali soluble nitrogen minus non-protein nitrogen) per 100 g sample are shown in Figure 9. Values from both dark and light meat increased as temperature of cooked rolls increased.

Highly significant differences in soluble protein nitrogen from both dark and light meat cooked to various temperatures are shown in Table 12. The increase in soluble protein nitrogen, as meat temperatures increased, was similar in both dark and light meat. Soluble protein nitrogen increased from 5.22 to 6.49 g as dark meat temperature increased from 60 to 88°C, and from 5.00 to 6.49 g as light meat temperature increased.

Grams of soluble protein nitrogen in 100 g of total nitrogen are shown in Table 9. Soluble protein nitrogen in dark meat increased from 76.8 to 80.7 g when meat temperature increased from 60 to 88°C. In light meat, values increased from 78.4 to 81.1 g from respective samples.

The increase in soluble protein nitrogen from dark and light meat with extended cooking indicates that protein denaturation and proteolysis occurred during cooking. Bendall (1964) reported that when meat reached 62°C, denaturation occurred in the soluble proteins of the sarcoplasm and the actomyosin system of the fibrils. Hepburn (1950) reported that increased aqueous extracts from chicken meat was due to accumulation of free amino acids resulting from degradation of small, simple proteins.

Collagen Nitrogen:

The effects of cooking time on the liberation of collagen nitrogen from dark and light turkey meat cooked to 77°C are shown in Figure 10.

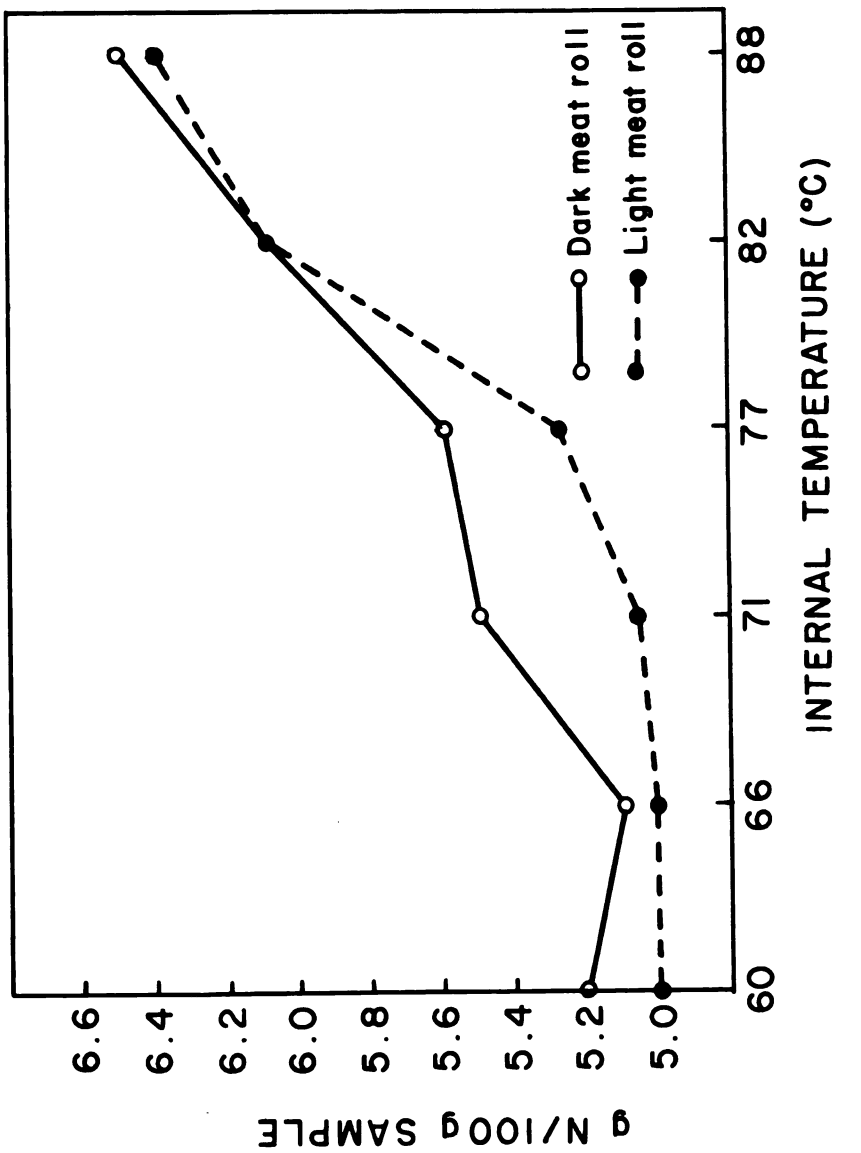



Figure 9. Soluble protein nitrogen in dark and light turkey meat cooked to different temperatures.

Table 12. Analysis of variance and Duncan's Multiple-range test for soluble protein nitrogen in dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Mean square Light meat |
|---|---|---|---|
| Internal temperature | 5 | 0.87** | 1.21** |
| Soluble protein nitrogen | 12 | 0.12 | 0.15 |
| Total | 17 | | |

Duncan's Multiple-range test

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| Dark meat soluble protein nitrogen (g) | 5.22[a] | 5.10 | 5.49 | 5.58 | 6.13 | 6.49 |
| Light meat soluble protein nitrogen (g) | 5.00[a] | 4.91 | 5.05 | 5.29 | 6.06 | 6.45 |

** Significant one percent level.

[a] All values reported as g soluble protein nitrogen per 100 g sample. Any two means underscored by the same line are not significantly different at the five percent level.

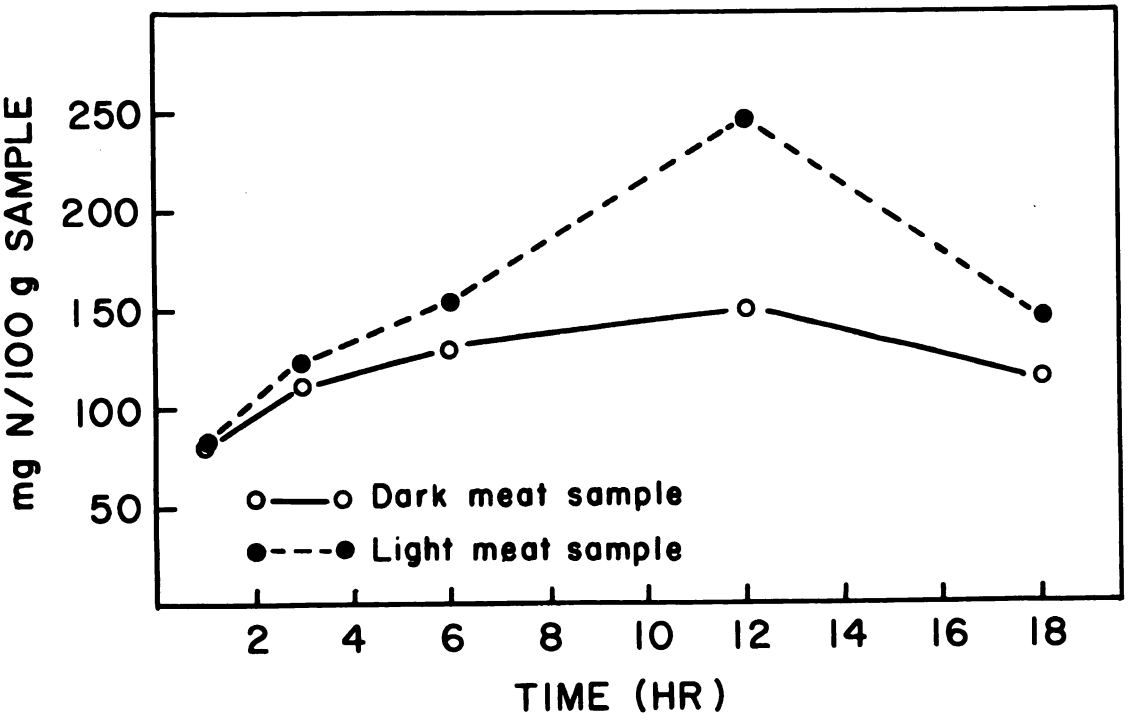



Figure 10. Hydrolysis time for collagen nitrogen in dark and light turkey meat cooked to 77°C.

All hydrolysates were determined as previously described using an autoclave at 15 psig. Maximum liberation of collagen nitrogen (with times used) occurred after 12 hr hydrolysis time for both dark and light meat. Collagen nitrogen was found to be higher in light meat samples than in dark meat samples. Miyada and Tappel (1956 b) used six hr hydrolysis in an autoclave at 15 psig for collagen nitrogen determinations but did not indicate the basis for this time. In this study, all collagen nitrogen determinations were based on a 12 hr hydrolysis time which was necessary for maximum liberation.

Collagen nitrogen values for light and dark meat cooked to temperatures ranging from 60 to 88°C are shown in Figure 11. Values from dark meat remained relatively constant in the meat cooked to 71°C, then decreased at a constant rate as temperature of cooked meat increased. Collagen nitrogen values from light meat were lower than from dark meat cooked to 71°C, but similar from samples cooked to the higher temperatures.

The g of collagen nitrogen per 100 g of total nitrogen are shown in Table 9. Collagen nitrogen in dark meat decreased from 3.5 g to 0.6 g as meat temperature increased from 60 to 88°C, and in light meat, decreased from 2.8 to 1.9 g for meat cooked to the same temperatures. Significant differences in collagen nitrogen between samples cooked to different temperatures were found in dark meat (1% level) and light meat (5% level) as shown in Table 13. In general, the meat cooked to lower temperatures contained more collagen than that cooked to higher temperatures. The loss of collagen nitrogen during cooking agrees with the results of Griswold (1955) and Cover *et al*. (1962 b). However, the loss from cooking was higher in dark meat than in light meat. This

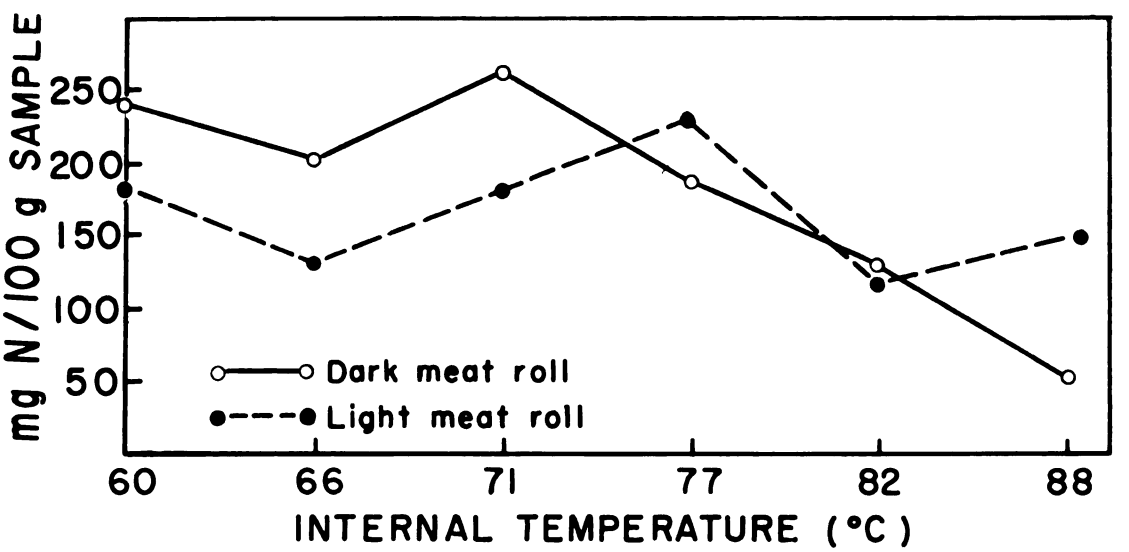



Figure 11. Collagen nitrogen in dark and light meat cooked to different temperatures.

Table 13. Analysis of variance and Duncan's Multiple-range test for collagen nitrogen in dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Mean square Light meat |
|---|---|---|---|
| Internal temperature | 5 | 0.02** | 0.004* |
| Collagen nitrogen | 12 | 0.002 | 0.0008 |
| Total | 17 | | |

Duncan's Multiple-range test

Dark meat

| Internal temp. (°C) | 71 | 60 | 66 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| Collagen nitrogen (mg N/100 g sample) | 260[a] | 240 | 200 | 190 | 130 | 53 |

Light meat

| Internal temp. (°C) | 77 | 71 | 60 | 88 | 66 | 82 |
|---|---|---|---|---|---|---|
| Collagen nitrogen (mg N/100 g sample) | 230[a] | 180 | 180 | 150 | 130 | 120 |

* Significant five percent level.

** Significant one percent level.

[a] Values arranged in decreasing order for statistical clarity. Any two values underscored by the same line are not significantly different at the five percent level.

apparent loss in collagen (and other cooking losses) could have also been related to the apparent increase in total nitrogen and alkali soluble nitrogen.

Free Water and Bound Water:

The amount of free water (expressed juice) after cooking was determined by centrifugation and was used to calculate water holding capacity (WHC) of meat by relating the amount of free water plus water lost during cooking to the total water before cooking. Wierbicki et al. (1957 b) determined WHC of beef samples in the same centrifuge tubes in which the meat was heated in a water bath. However, in this study, samples were cooked first and then centrifuged to avoid two separate cooking methods (oven and centrifuge tube). Cooked meat samples used in this study, therefore, were similar to the samples used for other chemical analyses.

In order to determine a centrifugation time necessary to give reproducible values for expressed juice, triplicate pre-cooked turkey meat samples were centrifuged at 1,000 rpm (170 X g) for ten or 20 min. The effects of centrifugation time on amount of expressed juice from pre-cooked samples are presented in Table 14. Variability in results from triplicate samples was greater after ten min than after 20 min of centrifuging. In all but two samples (dark meat at 60 and 88°C) expressed juice was higher after centrifuging for 20 min. Wierbicki et al. (1957 b) used centrifugation at 1,000 rpm (170 X g) for ten min to determine shrinkage of beef samples during heating. They suggested that the primary error appears to be the centrifugal force applied rather than the time of centrifugation for reproductibility of duplicate

Table 14. Expressed juice related to centrifugation time for dark and light turkey meat cooked to different temperatures.

| Internal temp. | Dark meat Time (min) in centrifuge[a] 10 | 20 | Light meat Time (min) in centrifuge[a] 10 | 20 |
|---|---|---|---|---|
| °C | ml | ml | ml | ml |
| 38 | 5.6[b] | 7.3[b] | 5.9[b] | 7.5[b] |
| | 5.5 | 7.0 | 5.8 | 7.3 |
| | 5.6 | 7.0 | 6.0 | 7.3 |
| 60 | 4.1 | 4.0 | 3.6 | 3.8 |
| | 4.0 | 4.0 | 3.8 | 3.8 |
| | 4.1 | 3.9 | 3.7 | 4.0 |
| 66 | 1.9 | 1.9 | 3.0 | 3.2 |
| | 1.5 | 2.1 | 2.7 | 3.5 |
| | 1.5 | 2.0 | 2.8 | 3.5 |
| 88 | 1.2 | 1.2 | 2.0 | 2.2 |
| | 1.7 | 1.2 | 2.1 | 2.2 |
| | 1.4 | 1.2 | 2.1 | 1.9 |

[a] All centrifugations determined at 1,000 rpm (170 X g).

[b] All values reported as ml juice expressed from 25.0 g sample.

samples. WHC, as described in this study, was determined by centrifuging samples at 1,000 rpm (170 X g) for 20 min. Determinations were made on triplicate turkey meat samples.

Moisture after cooking, WHC, and bound water were determined for dark and light meat rolls cooked to various temperatures. Results are presented in Table 15.

Total moisture in samples before cooking are presented in Table 15. Moisture of fresh samples (expressed as g moisture per 100 g sample) varied only from 73.6 g to 71.2 g for dark meat and 77.6 g to 76.6 g for light meat.

Moisture content of dark and light meat samples cooked to temperatures ranging from 60 to 88°C are shown in Figure 12. Moisture in both dark and light meat decreased as temperature of cooked meat increased. Highly significant differences between moisture content of both dark and light meat cooked to different temperatures were found and are presented in Table 16. A significant decrease in moisture was noted when temperature of dark meat increased from 71 to 77°C. Similar moisture losses from cooking were reported by Cover et al. (1962 b).

Water holding capacity (WHC) values from dark and light meat samples cooked to different temperatures are presented in Table 15. No significant differences in WHC among cooked samples were found (Table 17). WHC (expressed as g moisture per 100 g sample) was higher in light meat samples than in dark meat samples at all temperatures.

The term "bound water", as used in this study, was the amount of water remaining after free water was removed, or the difference between WHC and moisture remaining after cooking. Ritchey and Hostetler (1964), stated that the term bound water was the water not pressed from the meat

Table 15. Moisture before cooking and moisture, WHC, bound water and bound water/moisture (cooked) in dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | grams | | | | | |
| Dark meat | | | | | | |
| Moisture (fresh) | 73.6[a] | 71.4 | 71.2 | 71.5 | 72.2 | 71.5 |
| Moisture (cooked) | 68.2[b] | 67.4 | 66.2 | 62.3 | 63.5 | 62.9 |
| WHC | 27.8[b] | 31.3 | 27.4 | 31.3 | 29.9 | 29.2 |
| Bound water | 40.4[b] | 36.1 | 38.8 | 31.0 | 33.6 | 33.7 |
| Bound water/ moisture (cooked) | 59.2[c] | 53.6 | 58.6 | 49.7 | 52.9 | 53.6 |
| Light meat | | | | | | |
| Moisture (fresh) | 77.0[a] | 77.1 | 76.9 | 77.6 | 76.6 | 76.8 |
| Moisture (cooked) | 69.6[b] | 69.8 | 68.4 | 67.9 | 66.9 | 64.5 |
| WHC | 36.2[b] | 35.5 | 34.3 | 34.3 | 35.3 | 33.8 |
| Bound water | 33.3[b] | 34.3 | 34.1 | 33.6 | 31.6 | 30.7 |
| Bound water/ moisture (cooked) | 47.8[c] | 49.1 | 49.8 | 49.5 | 47.2 | 47.6 |

[a] All values reported as g moisture per 100 g fresh sample.

[b] All values reported as g moisture per 100 g cooked sample.

[c] All fractions multiplied by 100.

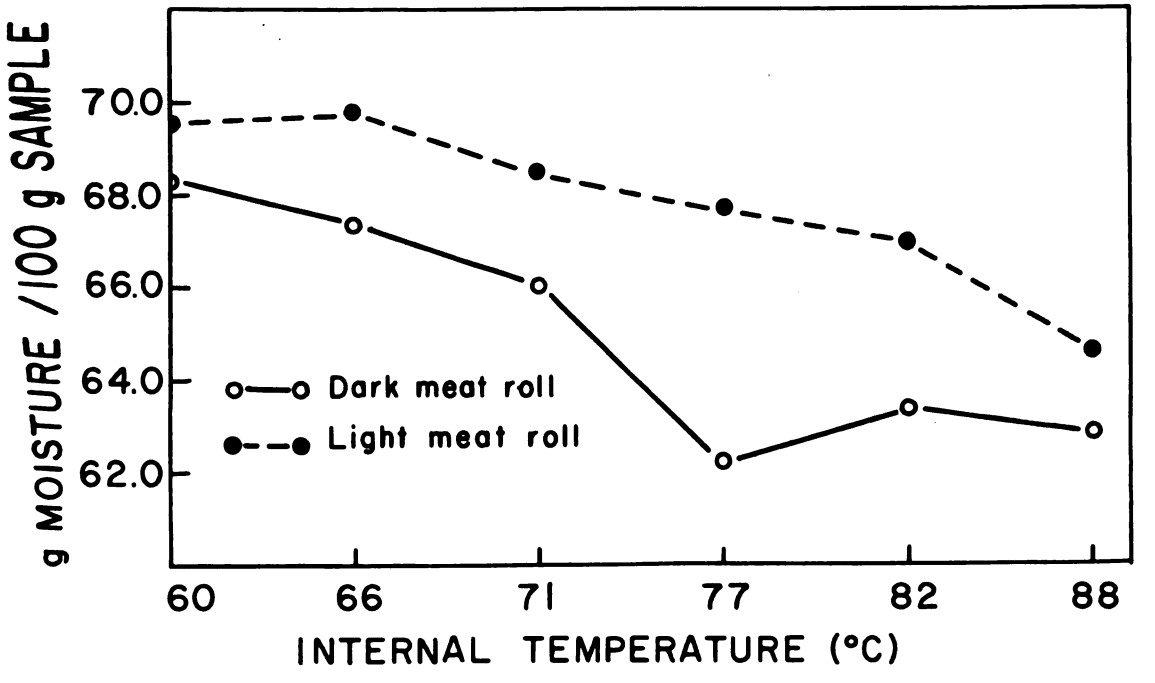



Figure 12. Moisture in dark and light turkey meat cooked to different temperatures.

Table 16. Analysis of variance and Duncan's Multiple-range test for moisture in dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Light meat |
|---|---|---|---|
| Internal temperature | 5 | 18.83** | 11.22** |
| Moisture | 12 | 1.75 | 0.56 |
| Total | 17 | | |

Duncan's Multiple-range test

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| Dark meat moisture (g) | 68.2[a] | 67.4 | 66.2 | 62.3 | 63.5 | 62.9 |
| Light meat moisture (g) | 69.6[a] | 69.8 | 68.4 | 67.9 | 66.9 | 64.5 |

** Significant one percent level.

[a] All values reported as g moisture per 100 g sample.
Any two values underscored by the same line are not significantly different at the five percent level.

Table 17. Analysis of variance and mean water holding capacity (WHC) of dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Light meat |
|---|---|---|---|
| Internal temperature | 5 | 8.53 | 2.47 |
| WHC | 12 | 4.27 | 2.44 |
| Total | 17 | | |

Mean WHC

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| Dark meat WHC (g) | 27.8[a] | 31.3 | 27.4 | 31.3 | 29.9 | 29.2 |
| Light meat WHC (g) | 36.2[a] | 35.5 | 34.3 | 34.3 | 35.3 | 33.8 |

[a] All values reported as g moisture per 100 g sample.

with a pressure of 12,500 lbs (Carver press), and free water referred to water expressed from the meat at this pressure. They reported bound water as that which remained after pressing and free water was the difference between total water and bound water. In this study, free water was the water expressed by centrifuging plus water lost during cooking, related to moisture before cooking, and bound water was determined by the difference between free water and water remaining after cooking.

Bound water from dark meat and light meat samples cooked to temperatures ranging from 60 to 88°C are reported in Table 15. Significant differences in bound water from samples cooked to various temperatures were found in dark meat but not in light meat (Table 18). Bound water in dark meat (expressed as g moisture per 100 g sample) decreased from 40.4 to 33.7 g and in light meat from 33.3 to 30.7 g as temperature of cooked meat increased from 60 to 88°C.

Bound water values, expressed as a fraction of the total water after cooking, are shown in Table 15. This fraction decreased from 59.2 to 53.6 in dark meat samples and from 47.8 to 47.6 in light meat as temperature of cooked meat increased. Bound water, as a fraction of total water after cooking, was higher in dark meat than in light meat.

These results have shown (Table 15) that although total moisture after cooking and bound water decreased during cooking, the amount of bound water, expressed as a fraction of total water, remained fairly constant. According to Ritchey (1965) bound water is released during heating and becomes free water. In this study when turkey meat was subjected to higher temperatures, the rate of loss of bound water

Table 18. Analysis of variance and Duncan's Multiple-range test for bound water in dark and light turkey meat cooked to different temperatures.

| Source of variation | Degrees of freedom | Mean square Dark meat | Light meat |
|---|---|---|---|
| Internal temperature | 5 | 37.03* | 6.47 |
| Bound water | 12 | 8.47 | 7.08 |
| Total | 17 | | |

Duncan's Multiple-range test

Dark meat

| Internal temp. (°C) | 60 | 71 | 66 | 88 | 82 | 77 |
|---|---|---|---|---|---|---|
| Bound water (g water/ 100 g sample) | 40.4[a] | 38.8 | 36.1 | 33.7 | 33.6 | 31.0 |

Light meat

| Internal temp. (°C) | 66 | 71 | 77 | 60 | 82 | 88 |
|---|---|---|---|---|---|---|
| Bound water (g water/ 100 g sample) | 34.2[a] | 34.1 | 33.6 | 33.3 | 31.6 | 30.7 |

* Significant five percent level.

[a] Values arranged in decreasing order for statistical clarity. Any two values underscored by the same line are not significantly different at the five percent level.

exceeded the release of free water and resulted in an increase in loss of total water.

pH of Meat and Drip:

The pH values of meat and drip from samples cooked to different temperatures are presented in Table 19. The pH of dark meat cooked to different temperatures varied from 6.4 to 6.6 and of light meat from 5.9 to 6.5. The pH of drip from rolls cooked to different temperatures was approximately the same. Slight differences in pH of meat and drip were found, but a relationship with cooking temperature was not apparent.

Part III: Correlation Coefficients

Relationships between tenderness (panel and shear force) and chemical, physical, and other sensory data were calculated and are presented in Table 20. The panel evaluated turkey meat cooked to internal temperatures from 71 to 88°C, and their mean scores were related to other factors only for these temperatures.

A significant correlation coefficient (5% level) was found between tenderness scores and shear force values from light meat ($r = 0.64$) but not from dark meat ($r = 0.25$). A significant negative correlation coefficient was found between tenderness scores and alkali soluble nitrogen ($r = -0.63$) from dark meat but not from light meat ($r = -0.13$). Other correlation coefficients were not significant.

Highly significant correlations (1% level) were found between shear force values of dark meat and total nitrogen ($r = -0.91$), alkali soluble nitrogen ($r = -0.78$), soluble protein nitrogen ($r = -0.64$), collagen nitrogen ($r = 0.68$), total moisture of cooked meat ($r = 0.84$), and bound water ($r = 0.75$). Other correlation coefficients were not

Table 19. pH values[a] for meat and drip from dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| pH meat | | | | | | |
| Dark meat | 6.4 | 6.4 | 6.6 | 6.6 | 6.4 | 6.6 |
| Light meat | 6.0 | 5.9 | 6.5 | 6.4 | 6.1 | 6.0 |
| pH drip | | | | | | |
| Dark meat | 6.2 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 |
| Light meat | 6.1 | 6.2 | 6.2 | 6.1 | 6.2 | 6.1 |

[a] Mean values of three samples each containing three replications.

Table 20. Correlation coefficients of various factors for dark and light turkey meat.

| Related factor | Correlation coefficient Dark meat | Light meat |
|---|---|---|
| Panel tenderness scores (df = 11) and: | | |
| Shear force | 0.25 | 0.64* |
| Total nitrogen | -0.36 | 0.38 |
| Alkali soluble nitrogen | -0.63* | -0.13 |
| Non-protein nitrogen | -0.44 | -0.20 |
| Soluble protein nitrogen | -0.39 | 0.04 |
| Collagen nitrogen | 0.04 | 0.20 |
| Juiciness scores | -0.32 | -0.05 |
| Moisture (cooked) | 0.36 | -0.32 |
| Bound water | 0.49 | 0.04 |
| Shear force (df = 17) and: | | |
| Total nitrogen | -0.91** | -0.02 |
| Alkali soluble nitrogen | -0.78** | -0.20 |
| Non-protein nitrogen | -0.42 | -0.07 |
| Soluble protein nitrogen | -0.64** | -0.13 |
| Collagen nitrogen | 0.68** | -0.01 |
| Moisture (cooked) | 0.84** | 0.24 |
| Bound water | 0.75** | 0.03 |
| Panel juiciness scores (df = 11) and: | | |
| Moisture (cooked) | -0.61* | -0.67* |
| Bound water | -0.67* | -0.54 |

* Significant five percent level.

** Significant one percent level.

significant.

Significant correlation coefficients were found between juiciness scores and total moisture (r = -0.61), and bound water (r = -0.67) from dark meat; total moisture (r = -0.67) from light meat.

Results obtained from panel scores (tenderness) did not agree with shear values of dark meat (r = 0.25) but they did agree significantly with shear values of light meat (r = 0.64). Marquess et al. (1963) reported that results obtained by a Warner-Bratzler shear press did not agree with panel evaluations for tenderness in light meat turkey rolls; however, they did not report on dark meat turkey rolls. A significant negative relationship (r = -0.63) between panel tenderness scores of dark meat and alkali soluble nitrogen was found. This relationship indicates that tenderness scores decreased (indicating more tender portions) as soluble nitrogen increased. Paul et al. (1958) found buffer extractable nitrogen of chicken meat increased with increased tenderness scores. They concluded that the correlation was high enough to be significant, but too low to indicate decided usefulness for measuring tenderness in chicken meat.

Shear values of turkey meat rolls (cooked to temperatures from 60 to 88°C) were negatively related (1% level) to total nitrogen of dark meat (r = -0.91), alkali soluble nitrogen (r = -0.78) and soluble protein nitrogen of dark meat (r = -0.64). These relationships indicate that tenderness of dark meat, as measured by shear force, increased as the nitrogen fractions increased. The same relationships were not found from light meat.

A highly significant correlation coefficient between shear values and collagen nitrogen content in dark meat was found (r = 0.68) but not

in light meat (r = -0.01). As collagen nitrogen in dark meat decreased, tenderness decreased, as measured by shear force. No significant relationship was found between panel tenderness scores and collagen content of dark meat or light meat.

Changes in tenderness of dark and light meat during cooking were apparent from these significant relationships. As total and extractable nitrogen increased (and collagen nitrogen decreased), tenderness of dark meat increased. Decreased amounts of collagen nitrogen with increased meat temperatures could have been related to the increase in total nitrogen and alkali soluble nitrogen in dark and light meat; however, only significant relationships with shear force values of dark meat were found (Table 20). Panel scores were significantly related to shear force for light meat only. These relationships may indicate that panel members were evaluating tenderness of light meat by a different set of factors. Husaini et al. (1950 a,b) reported that the amount of connective tissue, as represented by alkali insoluble protein and hemoglobin (myoglobin) was closely correlated with changes in tenderness of beef during aging. Myoglobin content, reported to be ten times higher in poultry leg meat than in breast meat (Lawrie, 1950), may be involved in changes in muscle tenderness.

Shear values and panel scores from light meat samples were significantly related (r = 0.64), but such a relationship was not found in dark meat samples (r = 0.25). The relationship between collagen content and shear values was highly significant in dark meat samples, but not in light meat samples. Cover et al. (1962 d) evaluated LD and BF beef muscles, and reported that when LD muscles were cooked to 80 and 100°C, neither shear force nor scores for the already tender connective tissue

changed greatly, although collagen content decreased. In the BF muscles cooked to 80 and 100°C shear force values did not change greatly although the connective tissue scores and collagen contents indicated marked "tendering". They concluded that shear values obtained across the grain of the meat were unreliable as a measure of the "tendering" of connective tissue by heat or as a means of relating heat changes in collagen to tenderness of connective tissue.

A highly significant correlation coefficient was found between both total moisture and bound water and shear values in dark meat but not light meat (Table 20). The amount of total moisture and bound water (moisture remaining after free water was removed) was an indication of tenderness in dark meat samples. The most notable relationships between shear values, total moisture, or bound water and temperature of cooked meat were found at internal temperatures of 71 and 77°C, in which all three values decreased. (See Figures 4, 12 and Table 15, respectively.) These relationships suggest that decreased tenderness occurred from loss of total and bound water in dark meat but did not significantly affect tenderness of light meat.

Results obtained when panel juiciness scores were related to total moisture and bound water are presented in Table 20. Panel scores agreed significantly with total moisture of dark meat ($r = -0.61$) and light meat ($r = -0.67$), indicating that as moisture decreased, samples were found to be less juicy. Bound water was significantly related to juiciness scores for dark meat ($r = -0.67$) but not for light meat ($r = -0.54$). This may reflect the higher amount of bound water in dark meat than in light meat resulting in increased juiciness (Table 15).

## SUMMARY

This study was conducted to evaluate the effects of different meat temperatures on tenderness of boneless dark and light turkey meat in the form of rolls, as measured by physical (shear) forces and sensory (panel) methods and to evaluate the effects of cooked meat temperature on some chemical changes in these same turkey rolls. The inter-relationship between these physical, sensory, and chemical values were also evaluated.

The mean temperature recorded in the convection oven during the period of cooking was relatively constant when the attached temperature regulator was set at 107°C. The mean temperature at the center of each roll remained constant for about one hr, then increased rapidly. The highest internal temperature (88°C) was obtained in 6.4 hr in dark meat and 5.5 hr in light meat.

Shear force of dark meat samples decreased as temperature of cooked rolls increased. The largest difference occurred between tenderness of rolls cooked to 71 and 77°C (12.3 lb to 10.7 lb). No significant differences were found in shear force of light meat cooked to different temperatures; however, the pounds of force for light meat approached that for dark meat when both were cooked to 60 and 88°C.

Dark meat became more tender (panel evaluation) as temperature of cooked rolls increased. Scores for light meat were more variable and tenderness increased until the temperature of cooked meat reached 82°C; however, light meat cooked to 88°C received higher mean scores (less tender) than all others evaluated. Panel scores for tenderness were higher for light meat samples than dark meat samples cooked to all

temperatures except 88°C. When the temperature of the roll reached 88°C, light meat samples were less tender than dark meat samples.

Panel juiciness scores were the same for dark and light meat rolls cooked to 71°C or higher. The greatest difference in panel juiciness scores was found between light meat and dark meat cooked to 88°C in which the light meat was less juicy.

When the turkey rolls were cooked to temperatures from 60°C to 88°C, total nitrogen (moisture free basis) increased. This apparent increase may be partially due to increased loss of fat during cooking.

Alkali soluble nitrogen (moisture free basis) values were similar for dark and light meat; however, the values per 100 g samples increased with an increase in cooked meat temperature. Grams of alkali soluble nitrogen in 100 g of total nitrogen increased in dark meat as temperature of cooked meat increased. Values obtained from light meat remained relatively constant, except for lower values obtained from light meat cooked to 71°C.

Soluble protein nitrogen (SPN) increased similarly in both dark and light meat as meat temperature increased. However, in light meat SPN remained constant while it increased in dark meat when the internal temperature increased from 60 to 77°C. Grams of SPN in 100 g of total nitrogen increased in both dark and light meat cooked to temperatures from 60 to 88°C. The increase in SPN from dark meat and light meat with extended cooking indicates that protein denaturation and proteolysis occurred during cooking.

Collagen nitrogen from dark meat remained relatively constant in the meat cooked to 71°C, then decreased at a constant rate with increased temperature. Collagen nitrogen values from light meat samples were lower

than from dark meat cooked to 71°C, but similar from samples cooked to the higher temperatures. The g of collagen nitrogen per 100 g total nitrogen decreased as dark and light meat temperature increased; however, the loss from cooking was higher in dark meat than in light meat.

Water holding capacity (WHC) in this study was expressed as the amount of loose or free water after cooking (determined by centrifugal force) plus the amount of moisture lost during cooking related to moisture content of the muscle tissue before cooking. No significant differences in WHC among cooked dark or light meat samples were found; however, WHC was higher in light meat samples than in dark meat samples at all temperatures.

The term "bound water", as used in this study, was the amount of water remaining after free water was removed, or the difference between WHC and moisture after cooking. Bound water in dark meat decreased significantly (5% level) from 40.4 to 33.7 g per 100 g sample as temperature of cooked meat increased from 60 to 88°C, and decreased (but not significantly) from 33.3 to 30.7 g from light meat.

The results of this study have shown that although total moisture and bound water decreased during cooking, the amount of bound water, expressed as a fraction of total water, remained fairly constant. When turkey meat was subjected to higher temperatures, the rate of loss of bound water exceeded the release of free water and resulted in an increase in loss of total water.

Changes in tenderness of dark and light meat during cooking were apparent from the significant relationships found in this study. As total and extractable nitrogen increased (and collagen nitrogen decreased), tenderness of dark meat increased. Decreased amounts of collagen

nitrogen with increased meat temperatures was responsible for an increase in total nitrogen and alkali soluble nitrogen in dark and light meat; however, only significant relationships with shear force values of dark meat were found. Panel scores were only significantly related (5% level) to shear force for light meat. These relationships may indicate that panel members were evaluating tenderness of light meat by a different set of factors.

Shear values and panel scores of light meat samples were significantly related, but such a relationship was not found in dark meat samples. The relationship between collagen content and shear values was highly significant in dark meat samples, but not in light meat samples.

The amount of total moisture and bound water was related to tenderness in dark meat samples but not in light meat samples. These relationships suggest that decreased tenderness occurs from loss of total and bound water in dark meat but such losses do not significantly affect tenderness of light meat.

Panel juiciness scores agreed significantly with total moisture of cooked dark and light meat samples indicating that as moisture decreased, meat was less juicy. Bound water was related to juiciness scores for dark meat but not for light meat. This may reflect the higher amount of bound water in dark meat than in light meat resulting in increased juiciness.

The results obtained under the conditions of this study indicate that cooking temperatures affect tenderness measured by physical (shear force) and sensory (panel) methods differently in dark and light meat turkey rolls. Even though chemical changes during cooking were similar

in both dark and light turkey meat, the relationships with tenderness were different. The results also indicate that moisture losses during cooking were similar in both dark and light turkey meat and agreed significantly with juiciness evaluations.

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# APPENDIX

APPENDIX TABLE 1

Preference sheet for tenderness and juiciness evaluations.

Name: _____ Date: _____

| Code (% or #) | Code (Ⓐ or *) | Code (% or #) | Code (Ⓐ or *) |
|---|---|---|---|
| Extremely Tender | Extremely Tender | Very Juicy | Very Juicy |
| Very Tender | Very Tender | Juicy | Juicy |
| Tender | Tender | Slightly Juicy | Slightly Juicy |
| Slightly Tender | Slightly Tender | Neither dry Nor juicy | Neither dry Nor juicy |
| Slightly Tough | Slightly Tough | Slightly Dry | Slightly Dry |
| Tough | Tough | Dry | Dry |
| Very Tough | Very Tough | Very Dry | Very Dry |

APPENDIX TABLE 2

Oven temperature 15 min and three hr after loading.

| Time | Recorded oven temperature 15 min cycle | 3 hr cycle |
|---|---|---|
| min | °C | °C |
| 2 | 106 | 107 |
| 4 | 105 | 106 |
| 6 | 108 | 107 |
| 8 | 110 | 108 |
| 10 | 109 | 107 |
| 12 | 108 | 106 |
| 14 | 106 | 107 |
| 16 | 105 | 108 |
| 18 | 106 | 107 |
| 20 | 108 | 106 |
| 22 | 109 | 107 |
| 24 | 110 | 108 |
| 26 | 109 | 107 |
| 28 | 108 | 106 |
| 30 | 106 | 107 |
| 32 | 105 | 108 |
| 34 | 106 | 107 |

APPENDIX TABLE 3

Heat penetration of dark and light meat turkey rolls.

| Time | Recorded internal temperature | |
|---|---|---|
| | Dark meat rolls | Light meat rolls |
| hr | °C | °C |
| 0 | 2 | 2 |
| 0.5 | 2 | 2 |
| 1.0 | 3 | 3 |
| 1.5 | 6 | 10 |
| 2.0 | 28 | 32 |
| 2.5 | 42 | 47 |
| 3.0 | 52 | 58 |
| 3.5 | 61 | 65 |
| 4.0 | 68 | 72 |
| 4.5 | 73 | 78 |
| 5.0 | 78 | 82 |
| 5.5 | 81 | 88 |
| 6.0 | 84 | - |
| 6.5 | 88 | - |

APPENDIX TABLE 4

Shear force values of dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | lb | lb | lb | lb | lb | lb |
| Dark meat sample | | | | | | |
| 1 | 12.9[a] | 12.0 | 13.0 | 11.3 | 10.1 | 10.4 |
| 2 | 13.8 | 13.0 | 12.0 | 9.2 | 10.7 | 9.8 |
| 3 | 11.4 | 12.1 | 12.0 | 11.5 | 10.8 | 9.6 |
| Total | 38.1 | 37.1 | 37.0 | 32.0 | 31.6 | 29.8 |
| Mean | 12.7 | 12.3 | 12.3 | 10.7 | 10.5 | 9.9 |
| Light meat sample | | | | | | |
| 1 | 12.5[a] | 7.2 | 9.7 | 7.9 | 8.4 | 12.6 |
| 2 | 14.8 | 10.8 | 7.8 | 8.1 | 6.8 | 8.0 |
| 3 | 10.0 | 7.8 | 8.7 | 7.1 | 9.2 | 8.2 |
| Total | 37.2 | 25.8 | 26.2 | 23.1 | 24.4 | 28.8 |
| Mean | 12.4 | 8.6 | 8.7 | 7.7 | 8.1 | 9.6 |

[a] All values reported as lb of shear force per g sample.

APPENDIX TABLE 5

Sensory panel tenderness scores of dark and light turkey meat cooked to different temperatures.

| Turkey roll composition | Panel member | Internal temp. (°C) 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|
| | | Tenderness scores | | | |
| Dark meat | 1 | 5.8 | 4.2 | 5.2 | 3.8 |
| | 2 | 4.2 | 4.1 | 3.7 | 3.8 |
| | 3 | 4.5 | 3.7 | 4.6 | 4.1 |
| | 4 | 5.2 | 4.9 | 4.6 | 4.4 |
| | 5 | 5.4 | 2.8 | 4.8 | 3.3 |
| | 6 | 4.4 | 3.7 | 3.2 | 2.5 |
| | Total | 29.5 | 23.4 | 26.1 | 21.9 |
| | Mean | 4.9 | 3.9 | 4.4 | 3.6 |
| Light meat | 1 | 4.4 | 4.2 | 3.3 | 4.6 |
| | 2 | 3.1 | 2.6 | 2.3 | 4.3 |
| | 3 | 4.1 | 3.4 | 2.4 | 3.7 |
| | 4 | 3.9 | 3.5 | 3.0 | 3.2 |
| | 5 | 4.4 | 3.0 | 3.7 | 4.4 |
| | 6 | 3.2 | 2.4 | 2.7 | 3.6 |
| | Total | 23.1 | 19.1 | 17.4 | 23.8 |
| | Mean | 3.8 | 3.2 | 2.9 | 4.0 |

APPENDIX TABLE 6

Sensory panel juiciness scores of dark and light turkey meat cooked to different temperatures.

| Turkey roll composition | Panel member | Internal temp. (°C) 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|
| | | Juiciness scores | | | |
| Dark meat | 1 | 3.8 | 4.1 | 4.1 | 4.0 |
| | 2 | 2.2 | 3.0 | 3.6 | 2.8 |
| | 3 | 3.5 | 3.5 | 3.9 | 4.0 |
| | 4 | 3.1 | 4.3 | 4.3 | 4.5 |
| | 5 | 3.0 | 4.4 | 4.5 | 4.3 |
| | 6 | 2.9 | 4.3 | 3.3 | 3.3 |
| | Total | 18.5 | 23.6 | 23.7 | 22.9 |
| | Mean | 3.1 | 3.9 | 4.0 | 3.8 |
| Light meat | 1 | 3.2 | 4.7 | 4.1 | 5.2 |
| | 2 | 2.9 | 4.3 | 4.0 | 4.8 |
| | 3 | 4.3 | 4.6 | 4.9 | 4.1 |
| | 4 | 3.0 | 4.1 | 3.8 | 5.0 |
| | 5 | 2.7 | 4.3 | 4.6 | 4.6 |
| | 6 | 2.7 | 3.3 | 3.0 | 4.0 |
| | Total | 18.8 | 25.3 | 24.4 | 27.7 |
| | Mean | 3.1 | 4.2 | 4.1 | 4.6 |

APPENDIX TABLE 7

Total nitrogen (moisture free basis) in dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | g | g | g | g | g | g |
| Dark meat sample | | | | | | |
| 1 | 6.97[a] | 6.74 | 6.56 | 6.58 | 7.48 | 8.02 |
| 2 | 6.68 | 6.68 | 7.13 | 7.07 | 7.46 | 8.13 |
| 3 | 6.75 | 6.54 | 6.74 | 7.78 | 7.58 | 7.98 |
| Total | 20.40 | 20.01 | 20.43 | 21.43 | 22.52 | 24.13 |
| Mean | 6.80 | 6.67 | 6.81 | 7.14 | 7.51 | 8.04 |
| Light meat sample | | | | | | |
| 1 | 6.25[a] | 6.65 | 6.77 | 6.85 | 7.26 | 8.34 |
| 2 | 6.55 | 6.48 | 6.67 | 6.74 | 7.34 | 8.52 |
| 3 | 6.35 | 6.35 | 6.90 | 6.73 | 7.01 | 7.15 |
| Total | 19.15 | 19.48 | 20.34 | 20.32 | 21.61 | 24.01 |
| Mean | 6.38 | 6.49 | 6.78 | 6.77 | 7.20 | 8.00 |

[a] All values reported as g total nitrogen per 100 g sample.

APPENDIX TABLE 8

Alkali soluble nitrogen (moisture free basis) in dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | g | g | g | g | g | g |
| Dark meat sample | | | | | | |
| 1 | 6.26[a] | 6.29 | 6.35 | 6.56 | 7.10 | 7.84 |
| 2 | 6.44 | 5.94 | 6.67 | 6.76 | 7.26 | 7.83 |
| 3 | 6.29 | 6.27 | 6.24 | 7.60 | 7.05 | 8.02 |
| Total | 18.99 | 18.50 | 19.26 | 20.92 | 21.41 | 23.96 |
| Mean | 6.33 | 6.17 | 6.42 | 6.97 | 7.14 | 7.90 |
| Light meat sample | | | | | | |
| 1 | 6.06[a] | 6.40 | 6.53 | 6.69 | 7.08 | 7.78 |
| 2 | 6.25 | 6.13 | 5.92 | 6.78 | 7.62 | 7.77 |
| 3 | 6.44 | 6.44 | 6.33 | 6.56 | 6.87 | 7.65 |
| Total | 18.75 | 18.97 | 18.78 | 20.03 | 21.57 | 23.20 |
| Mean | 6.26 | 6.32 | 6.26 | 6.68 | 7.19 | 7.73 |

[a] All values reported as g alkali soluble nitrogen per 100 g sample.

APPENDIX TABLE 9

Non-protein nitrogen (TCA soluble) in dark and light turkey meat cooked to different temperatures

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | g | g | g | g | g | g |
| Dark meat sample | | | | | | |
| 1 | 1.32[a] | 1.02 | 1.21 | 1.44 | 1.03 | 1.30 |
| 2 | 0.91 | 1.17 | 1.06 | 1.37 | 0.78 | 1.68 |
| 3 | 1.09 | 1.00 | 0.83 | 1.38 | 1.22 | 1.23 |
| Total | 3.32 | 3.19 | 2.79 | 4.19 | 3.03 | 4.21 |
| Mean | 1.11 | 1.06 | 1.03 | 1.40 | 1.01 | 1.40 |
| Light meat sample | | | | | | |
| 1 | 1.38[a] | 2.28 | 1.29 | 1.47 | 1.18 | 1.38 |
| 2 | 1.26 | 1.11 | 1.20 | 1.43 | 1.24 | 1.17 |
| 3 | 1.11 | 0.85 | 1.14 | 1.26 | 0.98 | 1.30 |
| Total | 3.75 | 4.24 | 3.63 | 4.16 | 3.40 | 3.85 |
| Mean | 1.25 | 1.41 | 1.21 | 1.39 | 1.13 | 1.28 |

[a] All values reported as g non-protein nitrogen (TCA soluble) per 100 g sample.

APPENDIX TABLE 10

Soluble protein nitrogen in dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | g | g | g | g | g | g |
| Dark meat sample | | | | | | |
| 1 | 4.94[a] | 5.27 | 5.35 | 5.12 | 6.07 | 6.54 |
| 2 | 5.53 | 4.77 | 5.71 | 5.39 | 6.48 | 6.15 |
| 3 | 5.20 | 5.27 | 5.41 | 6.22 | 5.83 | 6.79 |
| Total | 15.67 | 15.31 | 16.47 | 16.73 | 18.38 | 19.48 |
| Mean | 5.22 | 5.10 | 5.49 | 5.58 | 6.13 | 6.40 |
| Light meat sample | | | | | | |
| 1 | 4.68[a] | 4.12 | 5.24 | 5.22 | 5.90 | 6.40 |
| 2 | 4.99 | 5.02 | 4.72 | 5.35 | 6.38 | 6.60 |
| 3 | 5.33 | 5.59 | 5.19 | 5.30 | 5.89 | 6.35 |
| Total | 15.00 | 14.73 | 15.15 | 15.87 | 18.17 | 19.35 |
| Mean | 5.00 | 4.91 | 5.05 | 5.29 | 6.06 | 6.45 |

[a] All values reported as g soluble protein nitrogen per 100 g sample.

APPENDIX TABLE 11

Collagen nitrogen and hydrolysis time for dark and light turkey meat samples cooked to 77°C.

| Hydrolysis time | Collagen nitrogen[a] | |
|---|---|---|
| | Dark meat | Light meat |
| hr | mg | mg |
| 1 | 83.0 | 83.0 |
| 3 | 116.0 | 121.0 |
| 6 | 133.0 | 150.0 |
| 12 | 149.0 | 249.0 |
| 18 | 116.0 | 138.0 |

[a] All values reported as mg collagen nitrogen per 100 g sample.

APPENDIX TABLE 12

Collagen nitrogen in dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | mg | mg | mg | mg | mg | mg |
| Dark meat sample | | | | | | |
| 1 | 280[a] | 190 | 230 | 170 | 140 | 50 |
| 2 | 230 | 220 | 340 | 190 | 160 | 50 |
| 3 | 220 | 200 | 210 | 210 | 100 | 60 |
| Total | 730 | 610 | 780 | 570 | 400 | 160 |
| Mean | 240 | 200 | 260 | 190 | 130 | 53 |
| Light meat sample | | | | | | |
| 1 | 190[a] | 150 | 140 | 280 | 90 | 180 |
| 2 | 160 | 120 | 180 | 190 | 130 | 150 |
| 3 | 180 | 110 | 220 | 220 | 150 | 120 |
| Total | 530 | 380 | 540 | 690 | 370 | 450 |
| Mean | 180 | 130 | 180 | 230 | 120 | 150 |

[a] All values reported as mg collagen nitrogen per 100 g sample.

APPENDIX TABLE 13

Moisture of dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | g | g | g | g | g | g |
| Dark meat sample | | | | | | |
| 1 | 67.4[a] | 68.5 | 67.9 | 62.6 | 62.8 | 63.4 |
| 2 | 70.6 | 67.8 | 64.8 | 62.8 | 63.4 | 63.2 |
| 3 | 66.5 | 66.0 | 65.8 | 61.6 | 64.4 | 62.0 |
| Total | 204.5 | 202.3 | 198.5 | 187.0 | 190.6 | 188.6 |
| Mean | 68.2 | 67.4 | 66.2 | 62.3 | 63.5 | 62.9 |
| Light meat sample | | | | | | |
| 1 | 70.3[a] | 68.4 | 68.1 | 67.6 | 67.5 | 65.0 |
| 2 | 69.4 | 70.2 | 68.1 | 68.3 | 66.2 | 63.9 |
| 3 | 69.0 | 70.8 | 69.1 | 67.8 | 66.9 | 64.7 |
| Total | 208.7 | 209.4 | 205.3 | 203.7 | 200.6 | 193.6 |
| Mean | 69.6 | 69.8 | 68.4 | 67.9 | 66.9 | 64.5 |

[a] All values reported as g moisture per 100 g sample.

APPENDIX TABLE 14

Moisture of fresh dark and light turkey meat.

| Sample number | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | g | g | g | g | g | g |
| Dark meat sample | | | | | | |
| 1 | 73.7[a] | 72.4 | 71.2 | 70.4 | 72.8 | 70.3 |
| 2 | 74.4 | 70.8 | 71.2 | 72.6 | 72.3 | 72.0 |
| 3 | 72.6 | 71.0 | 71.1 | 71.5 | 71.6 | 72.2 |
| Total | 220.7 | 214.2 | 213.5 | 214.5 | 216.7 | 214.5 |
| Mean | 73.6 | 71.4 | 71.2 | 71.5 | 72.2 | 71.5 |
| Light meat sample | | | | | | |
| 1 | 76.7[a] | 76.7 | 77.1 | 77.8 | 76.2 | 75.9 |
| 2 | 76.7 | 77.2 | 77.4 | 78.0 | 76.8 | 77.1 |
| 3 | 77.6 | 77.3 | 76.2 | 76.9 | 76.8 | 77.4 |
| Total | 231.0 | 231.2 | 230.7 | 232.7 | 229.8 | 230.4 |
| Mean | 77.0 | 77.1 | 76.9 | 77.6 | 76.6 | 76.8 |

[a] All values reported as g moisture per 100 g sample.

APPENDIX TABLE 15

Water holding capacity for dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | g | g | g | g | g | g |
| Dark meat sample | | | | | | |
| 1 | 28.0[a] | 32.4 | 28.1 | 28.9 | 31.5 | 26.9 |
| 2 | 25.0 | 30.9 | 27.3 | 31.3 | 29.5 | 28.0 |
| 3 | 30.4 | 30.6 | 26.7 | 33.7 | 28.8 | 32.6 |
| Total | 83.4 | 93.9 | 82.1 | 93.9 | 89.8 | 87.5 |
| Mean | 27.8 | 31.3 | 27.4 | 31.3 | 29.9 | 29.2 |
| Light meat sample | | | | | | |
| 1 | 33.1[a] | 36.4 | 33.3 | 33.6 | 33.9 | 33.8 |
| 2 | 37.1 | 36.6 | 35.1 | 34.2 | 36.3 | 34.7 |
| 3 | 38.5 | 33.5 | 34.4 | 35.2 | 35.7 | 33.0 |
| Total | 108.7 | 106.5 | 102.9 | 104.0 | 105.9 | 101.5 |
| Mean | 36.2 | 35.5 | 34.3 | 34.3 | 35.3 | 33.8 |

[a] All values reported as g moisture per 100 g sample.

APPENDIX TABLE 16

pH values[a] of dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | pH | pH | pH | pH | pH | pH |
| Dark meat sample | | | | | | |
| 1 | 6.4 | 6.4 | 6.6 | 6.6 | 6.4 | 6.8 |
| 2 | 6.4 | 6.3 | 6.6 | 6.6 | 6.4 | 6.5 |
| 3 | 6.4 | 6.4 | 6.7 | 6.7 | 6.3 | 6.4 |
| Total | 19.2 | 19.1 | 19.9 | 19.9 | 19.1 | 19.7 |
| Mean | 6.4 | 6.4 | 6.6 | 6.6 | 6.4 | 6.6 |
| Light meat sample | | | | | | |
| 1 | 6.0 | 5.9 | 6.5 | 6.4 | 6.0 | 6.0 |
| 2 | 6.0 | 5.9 | 6.4 | 6.4 | 6.0 | 6.0 |
| 3 | 6.0 | 5.9 | 6.5 | 6.4 | 6.2 | 5.9 |
| Total | 18.0 | 17.7 | 19.4 | 19.2 | 18.2 | 18.0 |
| Mean | 6.0 | 5.9 | 6.5 | 6.4 | 6.1 | 6.0 |

[a] Mean values from three replications.

APPENDIX TABLE 17

pH values[a] of drip from dark and light turkey meat cooked to different temperatures.

| Internal temp. (°C) | 60 | 66 | 71 | 77 | 82 | 88 |
|---|---|---|---|---|---|---|
| | pH | pH | pH | pH | pH | pH |
| Dark meat sample | | | | | | |
| 1 | 6.3 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 |
| 2 | 6.2 | 6.2 | 6.2 | 6.3 | 6.2 | 6.3 |
| 3 | 6.2 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 |
| Total | 18.7 | 18.6 | 18.6 | 18.9 | 18.8 | 18.9 |
| Mean | 6.2 | 6.2 | 6.2 | 6.3 | 6.3 | 6.3 |
| Light meat sample | | | | | | |
| 1 | 6.1 | 6.2 | 6.2 | 6.1 | 6.2 | 6.1 |
| 2 | 6.0 | 6.2 | 6.2 | 6.1 | 6.2 | 6.1 |
| 3 | 6.1 | 6.2 | 6.2 | 6.1 | 6.1 | 6.1 |
| Total | 18.2 | 18.6 | 18.6 | 18.3 | 18.5 | 18.3 |
| Mean | 6.1 | 6.2 | 6.2 | 6.1 | 6.2 | 6.1 |

[a] Mean values from three replications.