

**PSE Poultry Breast Enhancement through the Utilization of Poultry Collagen,  
Soy Protein, and Carrageenan in a Chunked and Formed Deli Roll**

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# **PSE Poultry Breast Enhancement through the Utilization of Poultry Collagen, Soy Protein, and Carrageenan in a Chunked and Formed Deli Roll**

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(ABSTRACT)

Pale, soft, and exudative (PSE) poultry originates during rigor mortis when the muscle pH drops rapidly in high temperature carcasses. This condition results from antemortem stress and/or genetic material in the live animal. PSE poultry is pale in color, has low water-holding capacity, and forms products that are unappealing, dry, and unacceptable to consumers. Since value added products processed with PSE turkey meat display poor protein bind, color, and water retention, enhanced usability could add value to this low value raw material through locating a niche for PSE meat currently utilized in further processed products.

Experiment 1 consisted of four broiler breast treatments: 100% PSE, 100% PSE + 1.5% chicken collagen, 100% normal, and 100% normal + 1.5% chicken collagen to test the effects of raw material and chicken collagen. Incorporation of collagen improved ( $p < 0.05$ ) protein bind and CIE L\* values in both PSE and normal broiler breast treatments, while decreasing ( $p < 0.05$ ) the cooking and chilling loss of PSE broiler breast treatments.

Experiment 2 consisted of four turkey breast treatments: 100% PSE, 100% PSE + 1.5% turkey collagen, 100% normal, and 100% normal + 1.5% turkey collagen to test the effects of raw material and turkey collagen. Addition of turkey collagen improved ( $p < 0.05$ ) the protein bind and CIE L\* values in both PSE and normal broiler breast treatments, while decreasing ( $p < 0.05$ ) the cooking and chilling loss of PSE turkey breast treatments.

Experiment 3 consisted of five turkey breast treatments: 100% PSE, 100% PSE + 1.5% collagen, 100% PSE + 0.30% kappa/iota carrageenan, 100% PSE + 1.5% soy protein concentrate, and 100% normal to test the effects of raw material, turkey collagen, soy protein concentrate, and carrageenan. Addition of soy protein and turkey collagen both decreased ( $p < 0.05$ ) cooking and chilling loss and increased ( $p < 0.005$ ) the protein bind of 100% PSE. Purge loss was decreased ( $p < 0.05$ ) in PSE raw material when turkey collagen, soy protein concentrate, and kappa/iota carrageenan were utilized. Treatments with collagen displayed similar ( $p > 0.05$ ) CIE L\* and CIE a\* values to that of normal treatments. No differences ( $p > 0.05$ ) in consumer acceptability existed among the treatments.

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# CHAPTER 1

## 1.1 INTRODUCTION

Poultry meat production and consumption has dramatically increased over the last few decades (American Meat Institute, 2004). This increase can be attributed to poultry having low production costs, rapid growth rates, high nutritional values, and the increased production of further processed products (Barbut, 2002). During the early 1900s, the majority of poultry was raised in small flocks to supply eggs and meat for family consumption, and additional birds and eggs were sold in local markets for profit. Currently, in the poultry industry, hatcheries, growers, and processing plants are normally owned and operated by a number of large corporations. Since populations are increasing and people are becoming more health conscious, poultry is being marketed to all age groups. Per capita consumption of poultry has increased from 11.8 kgs in 1975 to approximately 44.9 kgs in 2004 (Sams, 2001; American Meat Institute, 2004). Furthermore, traditional red meat products such as bacon, ham, frankfurters, and delicatessen meats are frequently formulated with poultry.

Success of these processed products has been enhanced by the ability to economically produce acceptable products. However, harvesting larger birds at a younger age, coupled with inadequate chilling practices has led to the production of pale, soft, and exudative (PSE) meat. Selection for increased growth has resulted in rapid growing muscle fibers with less developed connective tissue (Swatland, 1989). It has been postulated that a mutation developed in the genetic material during this selection process initiating a reduction in poultry quality, texture, and flavor (Anthony, 1998). The combinations of these changes strongly influence biochemical alterations occurring in the muscle during rigor mortis, which is directly responsible for the production of PSE meat (Alvarado and Sams, 2002).

PSE broiler and turkey meat is produced when the combination of rapid pH decline in postmortem muscle and high carcass temperature leads to pale color, poor water-holding capacity, and a soft, dry texture (Barbut, 1993; Allen et al., 1998; Sams, 1999). PSE meat causes undesirable characteristics in processed products. Following heat processing, PSE pork and poultry both exhibit cracking, pale color, and dryness due to protein denaturation. PSE has been evident in pork for decades, but is a newly recognized phenomenon in the poultry industry. It is estimated that PSE poultry can cost a single plant 4.4 million dollars a years in lost meat product without including packaging and labor (Sams, 2002).

To enhance the value of this low quality meat, protein functionality must be increased in order to improve texture, color, and water retention. Marination of broiler breast fillets has been utilized as a means to improve moisture, flavor, and functionality (Smith and Acton, 2001). Previous research has demonstrated that the incorporation of collagen, soy protein concentrate, and carrageenan improve the protein functionality of processed meat products (Schilling et al., 2003, 2004; Prabhu et al., 2000, 2002; BeMiller and Whistler, 1996; Motzer, 1998; Pearson and Gillett, 1996). Pork collagen has been found to improve the water-holding capacity and texture of PSE pork in restructured boneless deli rolls through increasing protein functionality (Schilling et al., 2003). Soy protein concentrates are effective in improving the cooking yield, protein content, water binding, and flavor of meat products (Pearson and Gillett, 1996). Kappa and iota carrageenan, products of red sea weed, have been found to increase the yield of poultry rolls by 20-80% as well as improve the adhesion of PSE pork in restructured hams (BeMiller and Whistler, 1996; Motzer, 1998).

Since further processed products manufactured with PSE broiler or turkey meat display poor protein bind, color, and water retention (McKee and Sams, 1998), enhancement of PSE

meat can add value to this low value raw material as well as create a niche for PSE raw material currently sold only in the fresh state (McKee and Sams, 1998). Incorporating additional moisture into a product provides a higher yield for the processor and a more tender, juicier product for the consumer (Smith and Acton, 2001).

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## **CHAPTER 2**

### **Literature Review**

#### **2.1 PSE POULTRY**

##### ***2.1.1 History of PSE***

Pale, soft, and exudative (PSE) meat was first reported in swine. Briskey and Wismer-Pedersen (1961) concluded that PSE pork resulted from an extremely rapid postmortem glycolytic rate. Van Hoof (1979) first documented the occurrence of PSE turkey and suggested it had originated from similar postmortem events that lead to PSE pork. Since that time relatively little research was conducted on PSE poultry. Glycolysis rate and its effect on poultry meat quality did receive renewed interest in the early 1990's (Sante et al., 1991; Barbut, 1993; Sosnicki, 1993). This research demonstrated that the rate of early postmortem pH decline was 1.4 fold faster in a fast growing turkey compared to a slow growing breed. Furthermore, the onset of rigor mortis in the pectoralis major muscle was similar to events associated with PSE pork. As a result of increasing demands for value added poultry products, the PSE problem has become a major industry concern (Anthony, 1998). Increased yield losses, and a dry, soft texture make these products containing PSE unappealing to consumers and troublesome for processors (Owens et al., 2000). As research on PSE poultry has intensified, genetic lineages, preslaughter handling practices, stunning methods and chilling regimes have been identified as contributors to the incidence of PSE in poultry.

##### ***2.1.2 Implications and utilization of PSE***

PSE is a significant problem in the poultry industry with reports ranging from incidences between 5 and 50% and 5-30% for broiler and turkey meat, respectively (Owens et al., 2000; Woelfel et al., 2002; Woelfel and Sams, 2001; Barbut, 1996; 1997a; 1997b; McCurdy et al., 1996). PSE poultry can be characterized as pale in color, soft in texture, and low in water

retention (van Laack et al., 2000). The occurrence of PSE poultry is highly variable, but it has been estimated that this pervasive problem costs each plant approximately \$4.4 million per year (Sams, 2002).

In order to recover losses from the occurrence of PSE poultry the processor can either discount the price of the lower quality poultry, improve functionality in the fresh state, or utilize it in a further processed product. Currently, researchers have suggested that measuring the CIE L\* values of poultry meat would be sufficient to segregate PSE from normal so that PSE-type meat could be utilized in specialized formulations (Barbut, 1993; Owens et al., 2000).

Improving the functionality with adjuncts such as salt, phosphate, collagen, soy protein, and carrageenan would provide a more acceptable product to consumers while allowing the processor to improve yields, thus increasing profit.

### ***2.1.3 Environmental Factors***

Pre-slaughter condition affects poultry product properties (Kotula and Wang, 1994). Antemortem stress is attributable to many factors including the withdrawal of feed, severe environmental changes, overcrowded crates, handling practices and stressful transportation (Cassens et al., 1975; Offer and Trinick, 1983; Backstrom and Kauffman, 1995; D'Souza et al., 1998; Owens and Sams, 2000; McKee and Sams, 1998). This includes putting birds from different farms in the same truck. Stressors such as enduring long periods of heat, transportation, and feed withdrawal prior to slaughter can trigger the acceleration of postmortem glycolysis in turkeys, and cause the production of PSE meat (McCurdy et al., 1996; McKee and Sams, 1997). Researchers demonstrated that transportation is stressful on swine and poultry, causing elevated levels of  $\beta$ -endorphin, corticosterone, cortisol, and creatine phosphokinase (Szilagyi et al., 1981; Freeman et al., 1984; Brown et al., 1998). Typically, poultry undergo a feed withdrawal period

of 6 to 12 hours prior to slaughter. Sams and Mills (1993) indicated that withdrawal of feed from broilers prior to slaughter significantly lowered muscle energy stores that could be used during postmortem metabolism. Ngoka et al., (1982) reported that a feed withdrawal period of 15 hours in turkeys resulted in meat with significantly higher ultimate pH and normal color. McKee and Sams (1998) revealed that heat stressed turkeys exhibited lower initial and final postmortem pH with higher rates of postmortem pH decline when compared to non-stressed birds. Wood and Richards (1975) reported that birds exposed to heat and cold stress demonstrated longer and shorter postmortem glycolysis respectively. Birds that struggle prior to slaughter have an accelerated rate of postmortem glycolysis due to muscle temperature elevation, causing a higher consumption of glycogen, lower initial pH, and an earlier onset of rigor mortis (Dodge and Peters, 1960; Lawrie, 1985; Hedrick et al., 1994).

#### ***2.1.4 Genetic Causes***

Genetic factors are critical to a bird's stress susceptibility and its ability to adapt to stressors, thereby influencing the probability of developing PSE meat (Strasburg and Chiang, 2003). Genetic improvements in poultry have resulted in larger carcasses and more muscling which need more time postmortem to reduce the internal temperature (Rathgeber et al., 1999). A 12-week period was required to reach the slaughter weight for broilers at 1.8-2.0 kg in 1950, and now less than six weeks is required (Lilburn, 1994). Rapidly grown turkeys have a pH decline in early postmortem anywhere from 1 to 4 times faster than slower growing breeds (Sante et al., 1991; Barbut, 1997a). Sosnicki (1993) stated that rapid growing turkeys have enlarged muscle fibers that develop faster than the connective tissues and capillaries, resulting in fiber necrosis and/or loss of connective tissue integrity. Swatland (1990) demonstrated that the outgrowth of turkey breast muscle fibers over the supportive connective tissue may predispose products to

fragmentation and poor cohesion. The role of genetics in development of PSE in poultry is not completely known, but animals exhibiting the halothane gene are prone to this condition (Owens et al., 2000). Screening pigs for the halothane gene has been an effective method for identifying PSE pork (Monin et al., 1981). A study completed by Owens et al. (2000) demonstrated that there were no statistical differences between halothane positive and negative turkeys when moisture retention, pH level, and CIE L\* value were measured. Halothane positive turkeys did however display a greater percentage of pale meat compared to halothane negative turkeys. It was concluded from the research that halothane screening could be a limited predictor for PSE meat in turkeys (Owens, et al., 2000).

Wang et al., (1999) hypothesized that a certain population of commercial turkeys may have an altered sarcoplasmic reticulum  $Ca^{++}$  channel protein resulting in abnormal activity and leading to the development of PSE meat. In all muscle cells, the cytosolic free calcium concentration exerts primary control over the initiation, time course, and force of contraction. The process of coupling chemical and electrical signals at the cell surface to the intracellular release of  $Ca^{2+}$  and ultimate contraction of muscle fibers is termed excitation-contraction coupling (Strasburg and Chiang, 2003). Initially this calcium release channel was identified in sarcoplasmic reticulum vesicles of rabbit skeletal muscle as ryanodine binding protein (RYR1) because of its high affinity for ryanodine, a neutral plant alkaloid (Jenden and Fairhurst, 1969). Ryanodine receptor activity and variation suggest one or more mutations in turkey skeletal muscle RYR predispose birds to the development of PSE (Strasburg and Chiang, 2003). Poultry have two RYR isoforms in skeletal muscle and each isoform has two copies that can be independently normal or defective, which increases the number of potential combinations of normal and defective proteins (Sams, 1999).

### ***2.1.5 Postmortem Glycolysis***

Understanding the processes that occur during the conversion of muscle to meat is essential when assessing quality in muscle-based foods (Faustman, 1994). In the living animal, the circulatory system cools the animal's body by carrying heat from metabolic reactions in the muscles to the lungs (Hedrick et al., 1994). Regardless of the species harvested, exsanguination initiates the animal's muscles to maintain homeostasis, providing significant biochemical reactions to take place. Following exsanguination, the circulatory and oxygen supply to muscles are interrupted. Depletion of the oxygen supply to the animal's tissues causes cellular metabolism to shift from the aerobic to the anaerobic pathway, resulting in rapid utilization of glycogen (Lyon and Buhr, 1999). Glycogen acts as the primary storage of the carbohydrate in the muscle. It is formed from glucose units and is a rapidly available energy source for muscle activity.

Contraction and relaxation of living muscle requires energy in the form of adenosine triphosphate (ATP) (Lawrie, 1985; Hedrick et al., 1994). As more glycogen is utilized in anaerobic metabolism, lactic acid is generated preventing the products of anaerobic metabolism to be transported to the liver and re-synthesized into glucose and glycogen (Hedrick et al., 1994). The quantity of glycogen in muscle tissue at the time of death also determines the magnitude of lactic acid accumulation and pH decline (Lyon and Buhr, 1999). As lactic acid builds up in the muscles, the pH of the carcass is lowered from approximately 7.1 to 5.87, inhibiting glycolysis (McGinnis et al., 1989). The quantity of glycogen in muscle tissue at the time of death also determines the magnitude of lactic acid accumulation and pH decline (Lyon and Buhr, 1999). While metabolic reactions continue to occur, the carcass can experience a rapid rate of glycolysis and an increase in body temperature (Alvarado and Sams, 2002). Rapid glycolysis, responsible

for rapid pH decline is capable of denaturing the muscle proteins related to color, texture, and water-holding capacity.

Lee et al. (1979) revealed that postmortem carcass temperature was the most important factor influencing rigor mortis and overall meat quality. Carcass cooling can only be accomplished with a cool environmental temperature in the form of a chill tank or cooler. Delayed postmortem chilling prevents the hot carcass from cooling before lactic acid accumulates in the muscles, which results in PSE characteristics. Temperatures as high as 55° C are common when broilers are slaughtered and scalded. This increases carcass temperature early on during rigor mortis when pH values range from 6.90 to 5.90 (Wakefield et al., 1989). Broiler carcasses exposed to temperatures between 37°C and 41°C during processing exhibit rapid rates of glycolysis and a premature onset of rigor mortis (de Femery and Pool, 1960). Dransfield and Sosnicki (1999) reported that an increase of 10°C resulted in a 20-fold increase in protein denaturation. Bendall et al. (1963) demonstrated that muscles exhibiting PSE had a postmortem pH decline of 1.04-units/hour while normal muscles declined at 0.65 units/hour. More recently, Sosnicki et al. (1998) found that normal turkey breast muscle declined 0.03 units/min while the pH decreased 0.06 units/min in the PSE group.

### ***2.1.6 Muscle Fiber Type***

Muscle fibers are highly specialized cells acting as the structural units of skeletal muscle tissue (Hedrick et al., 1994). Muscles are classified as either red or white depending on the proportion of red and white fibers in an area. Red muscles are those with a higher proportion of red fibers than white fibers. Alternatively, white muscles have fewer red fibers than white fibers (Hedrick et al., 1994). Aside from the difference in color, red and white fibers have many structural and chemical differences. Red fibers have higher myoglobin and hemoglobin content,

lower glycolytic potential, higher oxidative metabolism, and have a tonic contractile action in comparison to white fibers (Hedrick et al., 1994). White fibers are more susceptible to PSE due to their greater dependence on anaerobic/glycolytic metabolism and phasic contractile action (Solomon et al., 1998). A phasic mode of contraction allows white fibers to contract faster than red muscles but also causes muscles to become easily fatigued. Red muscle fibers exhibit a tonic mode of action, which is slower, but can contract for longer periods before fatigue sets in (Hedrick et al., 1994). These differences can lead to PSE in animals that have a high amount of white muscle fibers. In the antemortem phase animals with abundant white fibers can be easily fatigued resulting in a higher lactic acid concentration within the muscles.

### ***2.1.7 Quality Classifications***

Grading is the classifying and sorting of poultry and poultry products according to groups of conditions and quality characteristics. Appearance, texture, juiciness, exudation, firmness, tenderness, odor and flavor are among the most important characteristics that influence the initial and final quality judgment by consumers before and after purchasing a meat and poultry product (Cross et al., 1986). Although based on subjective criteria, grading poultry products allow consumers to anticipate a particular quality of poultry in relation to proper slaughtering and processing techniques, carcass conformation, and defects. Further processed poultry products require good protein functionality, which cannot necessarily be judged by aesthetic carcass characteristics (Barbut, 1996). If the poultry industry measured pH or CIE L\* of raw poultry meat during processing, each processor could shift a percentage of poor quality poultry meat to a further processed product to add functionality and value (Barbut, 1993).

### **2.1.8 Color**

Color is the single greatest factor that determines whether a meat cut will be purchased (Kropf, 1980). Poultry is the only species that has marked differences of color throughout its body. Thighs and legs tend to exhibit a dark red color that results from a higher concentration of myoglobin and typically is referred to as “dark meat” by the consumer. Market age poultry breasts typically display a pink color and the consumer usually refers to it as “white meat”. Hemoglobin and myoglobin are the two proteins in meat that impart muscle pigmentation. In a properly bled carcass, myoglobin accounts for 80 to 90 percent of the total pigment (Hedrick et al., 1994). Myoglobin concentration is species, age, sex, and muscle dependent with poultry having a low quantity in comparison to beef, lamb, and pork. In terms of retail marketing, poultry fillets and delicatessen luncheon rolls are placed adjacently to its respective product in the display case. Evidence of one delicatessen roll or fillet being considered too pale by a consumer could jeopardize the sale of that product. Boulianne and King (1995) suggested that the paleness of breast meat could be attributed to the leakage of heme pigments in water when meat is stored in ice slush. In a broiler study completed by Le Bihan-Duval et al. (1999), lightness of the meat was positively correlated to drip loss. Furthermore, Barbut (1993) reported that paleness of turkey muscle has an inverse relationship with ultimate pH and that muscles with a low pH were paler than those with a high pH.

### **2.1.9 Water-Holding Capacity**

Muscle is made up of 65-80% of water that exists in either the free, immobilized, or bound form (Hedrick et al., 1994). A product’s water-holding capacity is primarily determined through exposing the product to external forces such as cutting, heating, grinding, or pressing (Hedrick et al., 1994). Since water is a polar molecule, it can become associated with electrically

charged reactive groups on the muscle proteins, resulting in a strong attraction and immobilization known as bound water. Bound water will continually attract other water molecules, resulting in immobilized water. Immobilized water has less order and thus a lower attraction to the reactive groups. Free water is held only by surface tension and can be easily removed with little physical force such as the shrinking of myofibrils during the development of rigor mortis. Rapid pH decline in a high temperature carcass results in denaturation and shrinking of myosin, causing a reduction of filament spacing (Offer, 1991). Consequently, water is expelled from the cells and lost in the form of purge or drip loss. Products processed from PSE meat not only have lower water binding capacity (lower yields), but also exhibit a reduced cohesiveness (Solomon et al, 1998). McCurdy et al. (1996), observed poor water holding capacity (WHC) in turkey breast samples having CIE L values  $\geq 50$ . Sosnicki et al., (1998) demonstrated that water binding-capacity and cooking yield were significantly higher in the normal turkey breast compared to the PSE turkey, while the Minolta CIE L\* values were significantly lower (darker color) in the normal group. Barbut, (1997a) also found that as the CIE L\* value increased, WHC decreased and the product exhibited a softer texture.

## **2.2 PROTEIN FUNCTIONALITY**

### ***2.2.1 Protein Properties in Fresh Poultry***

Poultry meat contains 20 to 23% protein, which can be divided into three categories based on solubility and function: myofibrillar, sarcoplasmic and stromal (Smith, 2001). Myofibrillar proteins (salt soluble proteins) comprise 50 to 56% of the total skeletal muscle with myosin responsible for 50 to 55% of the myofibrillar structure. Actin is the second most abundant myofibrillar protein comprising 20-25 % of the myofibrillar proteins (Smith, 2001). Located in the myofibril of an intact muscle, myofibrillar proteins extend the length of the

myofibril and are surrounded by the sarcoplasm (Smith, 2001). Divided by function, myofibrillar proteins can be categorized into contractile, regulatory, and cytoskeletal proteins (Smith, 2001). Contractile proteins are responsible for muscle contraction, regulatory proteins assist with the control of contraction, and cytoskeletal proteins support and maintain the structural integrity of the myofibril (Smith, 2001).

Muscle stiffening at rigor mortis is caused by the formation of permanent cross-bridges in the muscle between actin and myosin filaments, resulting in actomyosin (Hedrick et al., 1994). As myosin and actin join, the shorter myosin heads result in reduced filament spacing (Offer, 1991). In post-rigor muscle, actin is usually coupled with myosin, which modifies the functionality of myosin in formed poultry products while salts and phosphates dissociate actomyosin into actin and myosin, increasing the water holding capacity and improving the texture of the meat (Smith, 2001). Poultry possesses suitable characteristics for improving quality through tumbling since the undenatured myofibrillar proteins (actin, myosin, actomyosin) are able to be extracted and retain added water during marination (Whiting, 1988). Consequently, denatured myofibrillar proteins adversely affect water holding capacity, texture, and color.

Sarcoplasmic (or water-soluble) proteins constitute approximately 30-35% of the total muscle protein and are found in the sarcoplasm (Smith, 2001). Several prominent sarcoplasmic proteins that relate to meat quality consist of glycolytic enzymes, hemoglobin, and myoglobin (Miller, 1994). In the presence of a low ionic strength (0.06) salt solution, sarcoplasmic proteins can be extracted from meat and utilized as effective lipid emulsifiers in sausages (Pearson and Gillett, 1996). Gels manufactured with sarcoplasmic proteins are not as stable as those formulated with myofibrillar proteins, but do have greater stability than meats with a high content of collagen proteins (Pearson and Gillett, 1996). Connective tissue proteins are

composed primarily of collagen and elastin and serve to support the framework of the living body (Pearson and Gillett, 1996). Collagen is widely distributed throughout the body and is the primary protein in bone, tendon, and skin. Elastin is extremely unreactive and is present in the ligaments of vertebrae and the walls of large arteries (Hedrick et al, 1994).

### ***2.2.2 Myoglobin***

Myoglobin is the core pigment in meat and accounts for 80-90 % of the total pigment by providing red color when oxygen is bound to the muscle and serves as a storage site for oxygen in the muscles of live animals (Hedrick et al., 1994). Oxygen is transported from the lungs to the blood stream by hemoglobin and diffused into the muscle tissue. Once hemoglobin is in the muscle tissue, it is bound by myoglobin for subsequent use in aerobic metabolism (Bodwell and McClain, 1987). Myoglobin concentration is species and age dependent. The storage role of myoglobin is reflected in its varying concentrations in different tissues. In contrast to beef, lamb, and pork, poultry has the lowest amount of myoglobin hence the terms white and dark meat. Higher myoglobin content in beef muscle is the major factor that differentiates the bright, cherry red color of beef when compared to the lighter color of pork or poultry meat (Miller, 1994). The color differences between the turkey thigh and the turkey breast demonstrate that locomotive muscles that are composed predominately of red fibers have more myoglobin than support-type muscles that are composed of a larger quantity of white fibers (Faustman, 1994). High-use muscles, such as the leg muscle in chicken and other species, have higher myoglobin content due to the need for myoglobin to store and deliver oxygen to the muscle (Miller, 1994). Although not considered a functional protein, myoglobin plays a key factor in consumer preference when purchasing fresh meat since it is the key component of product color (Kropf, 1980).

### ***2.2.3 Protein Properties in Processed Meats***

Proteins are the principle functional and structural components of processed meats and are therefore responsible for the characteristic handling, texture, and appearance of these products (Hermansson et al., 1986). Proteins are good emulsifiers since they have a hydrophobic/hydrophilic nature. Factors that help determine the nature of the extracted proteins and how well they will act as binders in processed meats include the muscle's extent of rigor, pH, mechanical pre-treatment, presence of salts, and temperature (Bailey and Light, 1989; Smith, 2001). Restructured and comminuted poultry products can be formed into new shapes and sizes based on protein interactions with water, fat, and heat in the formulation. Three functional properties involving protein-water interactions are critical in poultry products: protein extraction and solubilization, water retention, and viscosity (Smith, 2001). Water retention describes the protein's ability to absorb and hold water in response to an external force such as cooking or pressing (Smith, 2001; Hedrick et al., 1994). Water may be chemically bound to the protein, held with capillary action, or physically entrapped within a protein structure (Smith, 2001). Viscosity is defined as the resistance of a material to flow, which is influential in the stability of the raw product prior to cooking.

Protein-protein interactions are responsible for a protein gel matrix and myofibrillar protein gelation is the most critical property to occur in processed poultry products during cooking (Smith, 2001). When heated to about 40°C, poultry myofibrillar proteins begin to unfold. The protein gel point is reached at approximately 55°C and a defined cross-linked network is formed in the product (Smith, 2001). Protein gels bind and hold large quantities of water within their network structure through chemical reactions and physical entrapment (Smith,

2001). Poultry products heated to above 70°C can experience syneresis due to extensive protein aggregation, two occurrences that are detrimental to product quality (Smith, 2001).

#### ***2.2.4 Restructured Meats***

Mandigo (1974) stated that the restructuring of beef, pork, and lamb into portion controlled meat products offers a large new area for merchandising meat. Poultry can also be utilized in this way, which allow consumers to purchase adequate portions with improved functionality. Restructuring meat items involves reducing the particle size of meat by grinding, flaking, dicing, chopping, slicing, or emulsifying and reforming it into an appealing form (Keeton, 2001). Restructured poultry products include batter-breaded patties and nuggets, sliced meats for delis, luncheon meats for sandwiches, turkey ham, and turkey bacon.

#### ***2.2.5 Sectioned and Formed Meats***

Sectioned and formed meats are primarily composed of intact muscles or sections of muscles that are bonded together to form a single piece (Pearson and Gillett, 1996). Advantages of formed products include being boneless, easier portioning into sizes and shapes, and allowing the processor to utilize whole muscle pieces with otherwise less utility (Keeton, 2001). For binding to occur between raw muscles, salt soluble proteins must be extracted to form a tacky surface for the adhesion of muscle pieces. Addition of phosphates and salt through injection or tumbling allows this process to take place.

#### ***2.2.6 Tumbling and Massaging***

Marination has been utilized for centuries and originally served to increase flavor and preservation characteristics of fresh poultry. Currently, marination is being investigated for utilizing different systems and ingredients in an effort to improve the moisture, bind, and texture of less tender poultry. Injection, static soaking, blending, massaging and tumbling are all

processes that are applied to meat marination (Addis and Schanus, 1974). A tumbler consists of a stainless steel tank that is mounted on a set of rotating wheels to agitate the contents while spinning (Pearson and Gillett, 1996). The raw material and adjuncts are placed inside the tumbler. Currently, most tumblers are equipped with a vacuum that pulls the air out of the unit with a compressor. Tumbling under vacuum prevents air from entering the product and extracts the meat proteins to the surface (Pearson and Gillett, 1996). During tumbling the meat is agitated. This allows the extraction of myofibrillar proteins to the surface of the meat to enhance salt and adjunct absorption (Addis and Schanus, 1979). This extraction increases marinade pickup in comparison to still marination (Pearson and Gillett, 1996). A tumbling cycle rest period for several minutes after each agitation permits greater brine penetration through the meat surface, causing enhanced tenderness and protein functionality.

## **2.3 OTHER FACTORS AFFECTING PROTEIN FUNCTIONALITY**

### **2.3.1 Salt**

Salt and phosphate are ingredients that promote a functional marinating system (Smith and Acton, 2001). Salt contributes to flavor preservation, increases moisture retention and ionic strength, and solubilizes myofibrillar proteins, thus enhancing protein binding (Whiting, 1988; Pearson and Gillett, 1996). In post-rigor muscle, salts dissociate actomyosin into actin and myosin, increasing the water holding capacity and improving the texture of the meat (Smith, 2001). This absorption decreases internal forces of attraction between oppositely charged groups within the protein molecules (Smith, 2001). Hamm (1960) and Schut (1975) reported that this effect is primarily due to chloride ions being bound to the protein much more strongly than the sodium ions. When the pH is above the isoelectric point (pI), chloride ion binding breaks the salt bridges and results in an increased negative charge and improved water holding capacity.

Woelfel and Sams (2001) reported that salt and phosphates have a synergistic effect in increasing water-holding capacity. Salt solubilizes myofibrillar proteins by increasing the electrostatic repulsion between the filaments, thus alleviating some of the structural constraints and improving the binding properties of poultry meat (Babdji et al., 1982). Offer and Trinick (1983) found that 0.8-1.0M, 4.6-5.8% salt is needed to achieve maximum water-holding capacity, but good functionality can be achieved at 0.4-0.6M (Trout, 1983). When utilized in restructured products, salt soluble proteins undergo coagulation, binding the product together into a cohesive mass similar to whole muscle products (Smith, 2001).

### **2.3.2 Phosphates**

Phosphates can be broken into three classes: acidic, neutral, and basic (Sylvia et al., 1994). Schmidt (1987) reported that only alkaline phosphates are effective in improving binding because acid phosphates may cause filament shrinkage and lower the pH. Similarly to salt, alkaline phosphates (sodium or potassium tripolyphosphates) aid in the enhancement and retention of protein functionality (Whiting, 1988). As mentioned previously, salt and phosphates have a synergistic effect on altering meat properties. The addition of phosphates reduces the sodium chloride concentration required for maximum myofibrillar swelling (Bendall, 1954; Offer and Trinick, 1983; Trout, 1983) and water binding (Seman et al., 1980; Trout, 1983; Girard et al., 1990).

Alkaline polyphosphates increase the water binding and fat emulsifying capacity of the myofibrillar proteins by increasing the pH level (Pearson and Gillett, 1996). When the pH is increased away from the isoelectric point of the myofibrillar proteins, protein solubility is enhanced through increasing the electrostatic repulsion between protein molecules. This is the result of an increased net negative charge associated with a higher pH (Smith, 2001). Addition

of phosphate increases water-holding capacity by strengthening the water binding when polyphosphates act as polyelectrolytes and increasing ionic strength, thus increasing the pH level about 0.2 units (Pearson and Gillett, 1996). Increasing ionic strength improves the water holding capacity, texture, binding, and stability of the raw material (Whiting, 1988). Sodium acid pyrophosphate (SAPP), tetra sodium pyrophosphate (TSPP), sodium tripolyphosphate (STPP), and sodium triphosphate (STP) are commonly used in formulations for this purpose (Xiong and Kupski, 1998). Diphosphate is the key component of phosphate functionality in processed meat systems.

Diphosphates facilitate water-holding capacity through effectively unfolding proteins. Sodium acid pyrophosphate reduces the pH of the meat product, while TSPP and STPP raise the pH about 0.2 units (Whiting, 1988). Trout (1983) and Whiting (1988) have both demonstrated that a pH of 6.0 and a total ionic strength of 0.6 are needed for satisfactory binding when manufacturing a restructured product. Furthermore, polyphosphates decrease purge in vacuum packaged products and improve yields as well as increase emulsifying capacity through the dissociation of actomyosin to actin and myosin (Pearson and Gillett, 1996).

### ***2.3.3 Structural Irregularities***

Selection for rapid growing poultry has resulted in faster growing muscle fibers with less developed connective tissue as well as an increase in the number of fast-twitch fibers with a reduction in slow-contracting oxidative fibers (Swatland, 1990). Rapid development of poultry can cause hypertrophy due to increased muscle fiber size and proportion of fast-twitch fibers (Solomon, 1998). Fast-twitch fibers characteristically have lower capillary density, limited blood supply, and decreased energy production which leads to slow removal of wastes such as lactate (Solomon, 1998). In stressful times, this buildup of lactate can result in acidosis. Several

studies have also revealed that rapid growth in turkey is associated with fiber necrosis and the loss of connective tissue integrity (Sosnicki and Wilson, 1991).

### ***2.3.4 pH***

Meat color and texture are directly related to the pH of the carcass during rigor mortis. In the live state, an animal that is not stressed will have a pH level of approximately 7.0. Following exsanguination, the carcass pH declines as the amount of lactic acid builds up from the utilization of glycogen during postmortem glycolysis. When glycogen is depleted from the muscles the ultimate pH is reached, which is critical to fresh meat properties. The expected pH of normal poultry meat is approximately 6.0 with protein extractability being augmented as the pH rises towards this point (Keeton, 2001). An increase in the pH level of meat causes myofibrillar proteins to become more soluble and readily extractable (Hedrick et al., 1994). Poultry is generally classified as PSE when the pH decreases less than 5.8 while the carcass temperature is still high (Sosnicki and Wilson, 1992). When the pH drops too quickly while the carcass is still warm, the proteins can denature, decreasing moisture, texture, and color (Smith et al., 2001). The addition of 2.5% salt has also been found to decrease pH levels by 0.1 to 0.2 units, yet when used in conjunction with phosphates this decline is offset as phosphates increase the pH level to enhance protein extractability (Schmidt, 1987).

## **2.4 BINDERS AND EXTENDERS**

### ***2.4.1 Collagen***

Collagen is the predominant connective tissue protein in muscle and comprises 3-6% of the total protein in poultry muscle tissue (Smith, 2001). Collagen is found within tendons, skin, bone, the vascular system of animals, and the connective tissue sheaths surrounding muscle (Fennema, 1996). Collagen is very abundant in poultry skin. Poultry collagen is currently used

to increase fat percentages in comminuted products. Due to collagen's poor salt and water solubility, previous research has shown it to be a poor binder in its native form (Smith, 2001). If too much collagen is added to a formulation though, an undesirable accumulation of fat may result during emulsification since collagen does not exhibit a high emulsifying capacity (Bailey and Light, 1989). To make poultry collagen soluble, the skins are ground and undergo a low temperature rendering process (Prabhu, 2002). Once the colloidal collagen is swollen, it endures a milling and dehydration process with the resultant product containing more than 70% protein and less than 28 % fat (Prabhu, 2002). Hydration of collagen is minimal in the pH range of 6-8 and increases at extreme values of the pH scale (Bailey and Light, 1989). Following heat denaturation at 70°C, the water-holding capacity of collagen increases two-fold, thus allowing more moisture to be retained (Bailey and Light, 1989). Collagen can be converted to gelatin by heating with added water. This causes formation of a gel, and improves product yield, texture, and palatability (Osburn and Mandigo, 1998). Collagen is 60 % hydrophobic which aids in binding and when processed has the ability to encapsulate fat (Pearson and Gillett, 1996). Schilling et al. (2003) concluded that the utilization of pork collagen could increase functionality in both PSE and normal meat as well as increase water-binding capacity, which would potentially decrease costs.

When added to meat and poultry products, collagen can increase fat, water, and protein binding by immobilizing free water and preventing moisture loss during heat processing and storage (Prabhu et al., 2002). Meullenet et al. (1994) found that collagen in combination with water was successfully incorporated into frankfurters made from mechanically boned chicken, while Ladwig et al. (1989) reported that meat high in collagen combined with phosphates produces a successful 28% fat frankfurter.

#### ***2.4.2 Soy protein concentrate***

Soy protein concentrates contain at least 70% protein, are inexpensive due to their large production volume, and impart a desirable texture (Asbridge, 1995). Although limited in sulfur-containing amino acids for humans, soy proteins contain the essential amino acids isoleucine, leucine, lysine, and valine (Snyder and Kwon, 1987). Soy protein concentrates are prepared from soy flour or grits by removing the soluble carbohydrates, which are responsible for the beany flavor and flatulence (Pearson and Gillett, 1996). Rakowsky (1974) found that soy protein is able to improve functionality by binding fat and water as well as through gelation upon heating. When incorporated into processed meats, soy protein also provides increased water absorption, binding, gelation, cohesion-adhesion, emulsification, and fat absorption (Fulmer, 1995). Soy proteins function much like meat proteins in sausage batters (Zayas, 1997). Soy protein gelation occurs during heating as molecules form into strands in an ordered arrangement that provides increased protein and fat interaction. These gelling properties aid in the binding of meat chunks as well as enhancing fat and water binding (Hermansson, 1986; Pearson and Gillett, 1996). Simultaneously, soy proteins can increase viscosity, gel forming, and water holding capacity in comminuted meat products (Lauck, 1975), which in turn contributes to the formation of stable meat emulsions and improves moisture retention (Bowers and Engler, 1975), and appearance of the final product (Schweiger, 1974). Soy protein concentrate is an effective meat binder and extender since it improves cooking yield, protein content, water binding, and flavor (Pearson, and Gillett, 1996). Pearson and Gillett (1996) noted that sectioned and formed meat products also have increased fat and water binding properties when soy protein concentrate is added. In accordance with federal meat inspection regulations, soy protein concentrate cannot exceed 3.5% in the finished product (Pearson and Gillett, 1996).

### **2.4.3 Carrageenan**

Carrageenan belongs to the family of sulfated galactans and are extracted from red seaweed. The three main types of carrageenan are kappa (gelling), iota (gelling), and lambda (nongelling) (BeMiller and Whistler, 1996). The most important characteristic of carrageenan is the ability to react with proteins to improve yield, texture, and sliceability in processed meat products (BeMiller and Whistler, 1996). When raw material is heated, carrageenan solubilizes forming a gel at 50 to 60°C (Pearson and Gillett, 1996). Carrageenan forms highly viscous solutions with good stability over a broad range of pH levels (BeMiller and Whistler, 1996). Although more reactive with milk proteins, 1-2% kappa-type carrageenan improves the yield of poultry rolls by 20-80% (BeMiller and Whistler, 1996). Mills (1995) and Motzer et al. (1998) both improved the functionality and adhesion of PSE pork by utilizing kappa carrageenan. A study done by DeFreitas et al. (1997) demonstrated that the addition of kappa-carrageenan to salt-soluble meat proteins increased gel strength and water retention of salt-soluble meat protein gels. In a study to assess the quality characteristics of hydrocolloid oven roasted turkey breasts, incorporation of 0.5 % kappa-carrageenan improved visual appearance, sliceability, and rigidity in comparison to the control (Bater et al. 1992). To maximize functionality, kappa-type carrageenan should be mixed with iota carrageenan to avoid syneresis.

Kappa and iota type carrageenan exist as double helices of parallel chains. Forming firm gels and weak gels, respectively. A combination of both can improve the sensory characteristics without syneresis (Pearson and Gillett, 1996). This structure allows thermoreversible gels to form upon cooling (Shand et al. 1994). Iota carrageenan is currently utilized in low fat processed meats and poultry products because of its excellent gelling and water binding properties and the need for a binding agent to offset the low salt levels common in turkey breasts and restructured

rolls (Pearson and Gillett, 1996). Iota carrageenan is soluble at cold temperatures and has freeze-thaw stability. A combination of these two carrageenans improves water holding capacity and texture.

#### ***2.4.4 Miscellaneous Binders and Extenders***

Soy protein isolates and flour are effective protein extenders, increasing water and fat binding (Pearson and Gillett, 1996). Isolates contribute a minimum of 90 % protein and are prepared from soy flour or grits by removing the carbohydrates (Pearson and Gillett, 1996). Isolates can be utilized in either an acid form or as a sodium proteinate, since they are very soluble at the pH level 6.9-7.2 (Snyder and Kwon, 1987). Advantages of using isolates are that they can be included in formulations for emulsifications or binding (Snyder and Kwon, 1987). Isolates can be produced by extracting the soy protein from ground, defatted flakes and decreasing the pH to 4.5 (Snyder and Kwon, 1987). For neutralization, isolates are spray dried to ensure good solubility. Following the isolation process, the soy protein contains less lysine and sulfur than its original form, yet provides more protein solubility than all other soy proteins (Snyder and Kwon, 1987). Soy flour is the least refined of the soy proteins and is produced before or after the oil is removed and the soybean flakes are ground and screened (Rhee, 1994). Soy flour provides the least amount of protein and is inexpensive compared to isolates and concentrates (Pearson and Gillett, 1996). It is typically used in sausages and has been utilized by the school lunch program and the United States armed forces. Soy flour has also been added to fresh ground beef to improve nutritional content and texture (Pearson and Gillett, 1996).

Milk proteins utilized in processed meat products include whey protein and caseinates. Addition of milk protein additives produce smooth textures and flavors while improving fat and water binding (Keeton, 2001). Casein comprises 80% of the bovine milk proteins, while the

other proteins pass into whey protein (Swaisgood, 1996). Following pasteurization of skim milk, rennet, acidification, or a lactic acid culture can cause casein to be precipitated at pH 4.3-4.5. The casein curd is neutralized with sodium, potassium, or calcium bases at pH 6.8-7.5 to produce caseinates (Pearson and Gillett, 1996). Having a monovalent cation, sodium and potassium caseinates are more soluble than calcium caseinates. Sodium and potassium caseinates improve water and fat binding properties, but do not increase fat emulsification properties at the normal pH of meat (Pearson and Gillett, 1996). Sodium caseinates improve the viscosity of solutions, but do not gel as well as soy proteins, yet contribute to a product's ability to retain added water (Keeton, 2001). Nonfat dry milk (NFDM) can be produced by heating centrifugally separated skim milk to concentrate it to 45-50 % solids. NFDM is widely used in sausages for its ability to improve water and fat binding (Pearson and Gillett, 1996).

Whey protein can improve protein content and functionality of processed meats. Cheese manufacturing utilizes casein but leaves  $\beta$ -lactoglobulin and  $\alpha$ -lactalbumin whey proteins as waste from the process (Kilara, 1994). Whey proteins are not considered effective emulsifiers due to a lack of hydrophobic and hydrophilic groups, but do serve as binders and thickeners in various processed meats (Zayas, 1997). Whey proteins must be soluble in order to bind water, which is accomplished through protein denaturation. Lactalbumin is also capable of absorbing more water than undenatured whey protein (Kilara, 1994). An essential property of whey proteins is their abundance of sulfhydryl amino residues that allows them to form intermolecular covalent bonds during heating (Zayas, 1997). Whey is usually added to processed meats between 0.5 and 2 % on a dry weight basis (Keeton, 2001).

Modified food starch is widely utilized in processed meats since it is low in cost, is accessible, and has the ability to improve bind and texture (Keeton, 2001). Starch is a

carbohydrate polymer made up of anhydroglucose units linked primarily through alpha-1,4 glucosidic bonds (BeMiller and Whistler, 1996). The most common food starches originate from potato, corn, wheat, tapioca, and rice (Keeton, 2001). Native starches are weak-bodied, rubbery when cooked, and form undesirable pastes when cooled (BeMiller and Whistler, 1996). Modifications are needed to crosslink polymer chains, which allow pregelatinization to occur as well as non-crosslinking derivatization and depolymerization (BeMiller and Whistler, 1996). Following these modifications, modified food starch can bind two to four times its weight in moisture, provide freeze/thaw stability, serve as a fat replacer, and impart a firmer product texture (Keeton, 2001). Starch consists of a heterogeneous mix of amylose and amylopectin polymers both of which play a central role in the versatility of starch in foods. Amylose and amylopectin contain an abundance of hydroxyl groups, creating a highly hydrophilic polymer that readily absorbs moisture and disperses well in water (BeMiller and Whistler, 1996).

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