AN ABSTRACT OF THE THESIS OF

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Title: Stability and Gel Strength of Meat Emulsions Made with Prerigor, Preblended Beef and Reduced Salt Levels.

Abstract approved: ______________________

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The purpose of this study was to investigate the use of preblended, prerigor beef in reduced salt meat batters. The functional properties of water-holding capacity, fat binding and gel strength were evaluated. Proximate analyses (protein, moisture and fat contents) of all cooked samples were performed, in duplicate.

The sternomandibularis muscle (SM) was removed from the right side of each of fifteen steers within 1 hr after death. The control samples remained on the left side of each carcass for 48 hr at 2°C before removal.

The muscles removed prerigor were preblended with four different levels of salt: 1.5, 2.25, 2.5, and 3.0%. The preblends and the postrigor SM were used to formulate

batters with 1.5 or 2.5% salt. During preparation, the batters were chopped until a temperature of 16.0 +/- 0.5°C was reached, and the batter pH was adjusted to 5.8 with NaOH.

Aliquots of batter were weighed into centrifuge tubes and cooked in a 70 - 75°C water bath for 30 min. Water-holding capacity was determined by weighing the amount of fluid lost during cooking. After the cooked batters had cooled, gel strength was evaluated with an Instron Universal Testing Machine using the penetration method with a cylindrical punch.

The mean pH of the prerigor muscles (6.70) was significantly higher ($p<0.01$) than that of the control muscles (5.66). The proximate analysis results indicated no significant differences between treatments for the moisture and fat contents. The mean protein content of the 2.5% salt batter control treatment was significantly lower ($p<0.05$) at 11.13%, than the four prerigor, preblended treatments which ranged from 11.88 to 12.21%.

The 1.5% salt batter control treatment had a mean cook loss of 9.75% and was significantly higher ($p<0.05$) than the other treatments which ranged from 4.55 to 6.93%. A red-colored cook loss fluid was observed in the prerigor, preblended 1.5% salt final batter treatments. This loss seemed to have no significant ($p<0.05$) effect on the functional properties of the batters studied. Fat

release was negligible amounting to only a few droplets per treatment.

The four preblended treatments had significantly stronger ($p<0.05$) gel strengths (0.88 - 0.97 lbs) than the two postrigor control treatments (0.67, 0.69 lbs). Gel strength seemed to be more dependent on the state of rigor when salt was added than on the amount of salt added. The evidence indicates that it is possible to make an acceptable reduced salt product using prerigor, preblended beef.

Stability and Gel Strength of Meat Emulsions Made With Prerigor, Preblended Beef and Reduced Salt Levels.

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STABILITY AND GEL STRENGTH OF MEAT EMULSIONS MADE WITH PRERIGOR, PREBLENDED BEEF AND REDUCED SALT LEVELS.

INTRODUCTION

High sodium intake has been identified as a possible contributor to essential hypertension. Essential hypertension, in which the actual cause cannot be determined, is estimated to afflict 10 - 20% of the U.S. population (IFT, 1980). It seems to be influenced by both genetic and environmental factors, and a relationship between obesity, hypertension, and salt intake is likely (Pearson and Wolzak, 1982).

The American public has become aware of the possible effects of salt on health, and as a result, is more cautious about the salt content in foods purchased. Processed meats contribute a significant amount of sodium to the diet. The average daily intake of NaCl is 10-12 g and approximately 3-4 g of this is added during food manufacturing, with about 1 g of this coming from meat products (Whiting, 1984).

In emulsion-type meat products salt serves as a preservative, controls moisture levels, and enhances both

product texture and flavor (Sofos, 1983). Salt extracts and solubilizes myofibrillar proteins in the batter system which during chopping, emulsify fat by forming a protein coat or deposits on the surface of fat globules. When heated, the proteins partially unfold and noncovalently bond to adjacent molecules, forming a gel. The protein-protein interactions that occur during heat gelation are mostly responsible for the fat and water stability in the finished product (Hamm, 1986).

Sausages are typically manufactured with 2.5% NaCl. A reduction in the amount of salt used in processing has resulted in less stability of fat and water and a softer texture (Sofos, 1983; Puolanne and Terrell, 1983b; Whiting, 1984). There are several technological alternatives that may allow for reduction of salt without a great deal of product change.

To compensate for salt reduction, phosphates, preblends, and preemulsified fats have been advocated (Sebranek et al., 1983). Preblending meat for sausage production has been used extensively in the United States. The term prerigor preblending describes meat that is removed from the carcass immediately postmortem, ground to appropriate particle size, and mixed with salt, water, and often cure (Puolanne and Terrell, 1983b). This mixture may be held at refrigeration temperatures for 24 hours or

more.

Prerigor meat has a higher water-holding capacity (WHC) and better fat binding properties than meat in the rigor or post-rigor state. This high WHC can be maintained by mincing and salting the prerigor meat while it still has a high adenosine triphosphate (ATP) concentration and high tissue pH (Hamm, 1982). The combined effect of ATP, high pH and high ionic strength results in a strong repulsion between adjacent protein molecules that leads to an expanded structure which will immobilize more fat and water after heat coagulation (Hamm, 1977).

The use of prerigor, preblended beef in reduced salt batters was investigated in this study. The objective was to determine the effects of prerigor, preblended beef and reduced salt levels on the stability and gel strength of meat emulsions. The effects of preblending with several salt levels were studied. The goal was to prepare batters with prerigor, preblended beef and reduced salt levels that when heated, formed gels with acceptable functional properties.

LITERATURE REVIEW

DIETARY SALT

Sodium chloride consumption in the United States has become a major issue in the food processing industry. The primary reason is that sodium ions seem to be closely linked to hypertension in humans. Since the public has become aware of this relationship, consumers are becoming increasingly concerned about the salt content in the foods they buy.

Sodium and chloride together make up salt and each is a dietary essential (Pearson and Wolzak, 1982). Sodium chloride is not stored in the body and so a certain amount is required daily. Although the exact amount has been difficult to determine, the most frequent estimate for an adult is a minimum daily requirement of 200 mg sodium, or 0.5 g NaCl. Most Americans exceed this level by consuming 10-12 g of NaCl per day or 3900-4700 mg sodium (Sebranek et al., 1983).

Salt intake by humans comes from three major sources: 1) salt naturally present in food and water, 2) salt added during processing, and 3) salt added during cooking or at the table (Pearson and Wolzak, 1982). Since the American

diet is consistently high in sodium, the body has to adjust to the extra sodium. About 10 - 20% of the U.S. population is genetically susceptible to essential hypertension. This term is used to describe 90% of the hypertension cases where the cause is not known (Sebranek et al., 1983).

Compared to fruits and vegetables, meat is a significant source of sodium, containing about 70 mg sodium per 100 grams meat (IFT, 1980). The use of salt during processing increases sodium to relatively high levels.

The meat industry is currently the largest user of salt in the food processing industry (Andres, 1982). Meat processing involves several sodium-containing additives other than salt; however, only salt is present in large enough amounts wherein a reduction would make a difference (Terrell, 1983). Since most of the sodium in meat products is deliberately added in the form of salt, a decrease in sodium content might be accomplished by reducing the amount of salt added during processing.

Decreasing salt has many implications on the finished meat product. Properties that may be adversely affected are texture, flavor, moisture retention, appearance and microbial stability or shelf life (Sebranek et al., 1983). Substituting up to one-half of the sodium chloride with

potassium chloride has experienced some success in processed meats. Potassium chloride is functionally equivalent to NaCl in products at an equal ionic strength; however, a limiting factor to its use in meat products has been a bitter flavor (Seman et al., 1980).

MUSCLE STRUCTURE

Skeletal muscles are composed of long, narrow, multi-nucleated fibers that range from a few to several centimeters in length and from 10 - 100 μm in diameter. These fibers are arranged in a parallel manner to form bundles with groups of bundles making up a muscle. Each of the above units is surrounded by connective tissue (Hultin, 1985).

The myofibril is the basic structural unit of the muscle fiber. Myofibrils are long, thread-like rods. They are composed of light and dark bands and transverse Z-lines which divide myofibrils into regular, repeating units (sarcomeres) along the length of the myofibrils. The alternating light and dark bands result from the overlapping of the interdigitating thick or myosin protein filaments with the thin or actin protein filaments. Both the thick and thin filaments are oriented in parallel with the direction of the muscle fibers. The Z-lines which are

perpendicular to the fiber direction are composed mainly of alpha actinin and serve to hold the actin filaments in place. The distance between two Z-lines is one sarcomere which is the smallest functional unit of the myofibril capable of contraction. This arrangement is frequently referred to as the sliding filament structure of the myofibril (Bechtel, 1986).

MUSCLE PROTEINS

Muscle is made up of approximately 75% water, 20% protein, 3% fat and 2% ash (Fennema, 1977). The proteins are classified as sarcoplasmic, myofibrillar and stromal, based on their solubility in aqueous salt solutions.

Sarcoplasmic Proteins

Sarcoplasmic proteins make up 30-35% of the total protein. Myoglobin, myogens (most of the enzymes in the glycolytic pathway), and some albumins are water soluble. The rest of the sarcoplasmic proteins are soluble in solutions of low salt concentrations with an ionic strength of less than 0.1 (Asghar et al., 1985). There are 50 to 100 different sarcoplasmic proteins and they are very diverse. They do have many common characteristics

that include: a relatively low molecular weight of 20,000 to 100,000 daltons, a globular or rod shaped conformation, low viscosity and an isoelectric point between pH 6.0 and 7.0 (Morrissey et al., 1987).

Myofibrillar Proteins

The myofibrillar proteins are those that are directly involved in contraction. This fraction makes up about 55% of the muscle proteins and is soluble in salt solutions having an ionic strength greater than 0.5 at neutral pH. Myofibrillar proteins can be divided into two groups: the contractile proteins and the regulatory proteins (Asghar et al., 1985).

Myosin is the major contractile protein, accounting for 45% of the total myofibrillar proteins (Yates and Greaser, 1983). It makes up the major portion of the thick filament, with 200-400 molecules of myosin per thick filament.

Myosin is made up of six chains. Two are identical large polypeptide chains called heavy chains. They have a mostly alpha-helical structure, are supercoiled around each other, and make up the rod section of the molecule. At one end there are two globular heads that maintain the ATPase activity so the myosin can interact with actin

(Hultin, 1985). The heavy chains are noncovalently associated with four moles of "light chains". Two are termed DNTB light chains because they can be dissociated by the thiol reagent DNTB [(5,5'-dithiobis)-2-(nitrobenzoic acid)] and affect the calcium binding ability of myosin. The remaining two are the alkali light chains, so termed because they are released under alkaline conditions. These two chains are essential for ATPase activity (Morrissey et al., 1987). Each globular head has one alkali light chain and one DNTB light chain. In the intact myosin molecule this globular head can bend as if hinged to grab actin and pull it in, shortening the sarcomere and contracting the muscle (Elliot and Offer, 1978).

Actin is the major component of the thin filament and makes up 22% of the myofibrillar protein. It can exist in two forms: a globular (G-actin) and a fibrous (F-actin) form, depending on the ionic strength of the environment (Asghar et al., 1985). It is in the globular form in low ionic strength solutions under laboratory conditions, but in natural muscle under the influence of salts, G-actin monomers polymerize to form F-actin or thin filaments. These filaments are double stranded with a right-handed helical structure in muscle (Morrissey et al., 1987).

Tropomyosin and troponin are also present in the thin

filaments but in low amounts. They are regulatory proteins that impart calcium ion sensitivity to the contractile proteins. A number of other minor myofibrillar proteins with unspecified functions have been discovered recently. These proteins, however, along with tropomyosin and troponin seem to have little effect on the functionality of muscle proteins in meat processing (King and Macfarlane, 1987).

Stromal Proteins

The third type of protein in muscle is the stroma proteins. They consist of collagen, reticulin and elastin and are commonly known as connective tissue proteins. Collagen is the most abundant in muscle tissue, and is present as a sheath surrounding muscle bundles. Collagen is a long cylindrical protein that is approximately 300 nm long and 1.5 nm in diameter (Bechtel, 1986). It is formed from three tropocollagen subunits that are coiled together to form a superhelix. These collagen fibers form intra- and intermolecular covalent crosslinks as an animal matures (Gillett, 1987). The enzyme lysyl oxidase initiates these crosslinks by converting lysine to allysine and hydroxyallysine (Bechtel, 1986). These products then form stable Shiff-base and aldol cross-links

that are partially responsible for the decreased solubility and increased toughness of meat.

When heated to 65 - 70°C, the triple helical chain structure of collagen collapses and the fiber shrinks to about one-third of its original length (King and Macfarlane, 1987). In comminuted products, high collagen levels or insufficiently comminuted collagen fibers will cause problems in meat products when cooked. As collagen is heated and shrinks, fat and water are exuded (Mawson and Hutton, 1987). However, small filament particles of connective tissue seem to contribute to the texture and bite in the finished sausage product (Hoogenkamp, 1986).

POSTMORTEM CHANGES

Rigor Mortis

In a live animal, muscle is maintained in a narrow pH range of 6.9 to 7.2. After death, the muscle is deprived of its oxygen supply and becomes anaerobic. The adenosine triphosphate (ATP) levels can no longer be maintained by oxidative phosphorylation, although creatine phosphate (CP) helps to maintain ATP by providing phosphate (Bendall, 1973). When CP becomes exhausted, ATP levels fall and the muscle begins anaerobic conversion of

glycogen to lactate. As lactate accumulates in the cells, a drop in pH is observed (Bechtel, 1986). At a pH of about 5.5, ATP is depleted, and certain critical enzymes, like phosphofructokinase, are inhibited and glycolysis ceases (Hultin, 1985).

When the ATP level falls to about 1.0 μM/g and the pH to 5.9, muscle begins to lose its extensibility (Bendall, 1973). This begins to occur within the first hour postmortem in a beef carcass (Hamm, 1982). When the ATP levels fall below about 0.1 μM/g, muscle loses extensibility and becomes very rigid or stiff as it goes into rigor mortis. The development of rigor is accompanied by a sharp decrease in the functional properties of muscle, particularly in water-holding capacity (WHC) (Honikel et al., 1981).

Prerigor Meat

The meat industry consumes large amounts of energy. Any decrease in the energy used for processing benefits the industry economically and helps conserve national resources. The hot-boning of meat after slaughter helps to reduce the amount of energy used. It facilitates centralized processing, lowers cooling space requirements, shortens chill time, and decreases refrigeration costs

(Hultin, 1985).

Hot-boned meat has been found to experience less drip (moisture) loss and has a higher expressible moisture content (Kastner et al., 1973). Hot-boned, or prerigor, meat seems to improve the functional characteristics of sausage products. Acton and Saffle (1969) demonstrated that prerigor meat emulsified 22.4% more fat than postrigor meat. Prerigor processing produces products showing excellent water-holding and fat-emulsifying capabilities (Hamm, 1960).

Adding salt to prerigor tissue causes an irreversible increase in WHC although it accelerates the breakdown of ATP (Hamm, 1977). This can be explained by the exchange of calcium ions from the sarcoplasmic reticulum against sodium ions of the NaCl. Liberation of calcium ions activates ATPase in myosin and allows contraction to occur (Hultin, 1985). The combined effect of low pH and high ionic strength causes the inhibition of glycolytic enzymes at a higher pH (about 5.8) than in the absence of NaCl (pH 5.1 - 5.5) (Hamm, 1977).

Postrigor Meat

The development of rigor mortis at pH 5.9 in hot-boned

(Honikel et al., 1981). The cooking loss and expressible fluid decrease slightly and continuously with the postmortem pH drop from 7.0 to 5.9. As the myofibrillar proteins are approaching their isoelectric point of pH 5.0, there is an increase of oppositely charged groups leading to intermolecular ionic crosslinkages (Hamm, 1960). The myofibrillar structure tightens under these conditions and less water is immobilized. This pH dependent intermolecular crosslinking is so strong that the crosslinking between actin and myosin caused by rigor development does not exert an additional significant effect on WHC in the absence of salt (Hamm, 1982).

MEAT EMULSIONS

Salt-soluble proteins of meat emulsify fat by forming a protein coat or deposits on the surface of fat globules. Although comminuted meat systems do not have all of the properties of a true oil-in-water emulsion, they do have similarities. A true meat emulsion consists of two phases: an aqueous phase in which the lipid phase, or fat, is finely dispersed (Acton and Saffle, 1969). The term, "meat emulsion", is being replaced by "meat batter" to reflect the more complex nature of the system and to shift the emphasis to the thermal gelation behavior of

proteins (Whiting, 1988).

Chopping Operation

The temperature of the batter during the chopping operation is important. Since fat mobility is inversely related to hardness (Lee et al., 1981), fat cells rupture and tend to melt slightly as the chopping time and temperature increase (Rizvi, 1981). If the chopping temperature of the meat rises above 20°C, the fat may melt and coalesce to disrupt the protein matrix. This results in loss of fat and water during cooking. Too high a chop temperature may also destabilize the meat batter by causing denaturation of the proteins too early in the processing procedure.

Effect of Salt

Salt enhances protein hydration. Thus muscle hydration increases with increasing salt concentration. It will reach a maximum, and then with continued increasing NaCl, fall to a level below the original WHC of unsalted meat (Hultin, 1985). Since the salt competes with proteins for available water, proteins may become dehydrated and partially denatured by excessive NaCl

levels (Hamm, 1960).

Myofibrils will adsorb the most water at an ionic strength of 0.8 - 1.0 which is equivalent to about 5% NaCl (Hamm, 1960). The site of water uptake is in the myofibrils themselves. The filament lattice network expands because of increased electrostatic repulsive forces due to the binding of added chlorine ions.

During water uptake the Z- and M-lines are reported to limit the swelling of myofibrils (Offer and Trinick, 1983). These transverse structural constraints may be removed as the salt concentration is increased to 0.8 to 1.0 ionic strength. High salt concentrations also tend to weaken the actomyosin complex. Thus myosin bonds are weakened at both the head and tail regions which results in dissociation of actomyosin to release myosin molecules (Smith, 1988).

The effect of salt on WHC depends on the pH of the system (Hamm, 1986). WHC decreases when NaCl is added at a pH lower than the isoelectric point of meat which is about pH 5.0. This effect of salt may be due to chloride ions binding to positively charged sites on the myofilaments. This decreases the intermolecular repulsion between like charges and the filaments assume a more closed structure to lower the WHC. When salt is added above the pI, where there are more negative charges, the

sodium ions are adsorbed poorly while chloride ions will neutralize the positive charges that still exist (Fennema, 1977). This will increase the net negative charge and lower the isoelectric point. The WHC will be enhanced due to increased intermolecular repulsion between the negatively charged groups (Asghar et al., 1985).

Salt also helps to bring proteins into solution (Acton et al., 1983). Comminution of salted muscle causes swelling of muscle fibers, depolymerization of myosin, solubilization of myosin and extraction of myofibrils from the muscle fibers (Smith, 1988). The higher the degree of comminution, the more surface area becomes available for greater protein extractability. These salted proteins will have a greater WHC because the hydrophilic sites on proteins are exposed to solvent instead of being involved in protein-protein interactions (Smith, 1988).

Frankfurters are typically manufactured with 2.5% NaCl. Sofos (1983) found that in lowering salt concentrations below 2.0% in frankfurters, water losses increased, and a softer, mealy texture resulted. This has been substantiated by others (Puolanne et al., 1983b; Whiting, 1984). Results also are partially dependent on fat content because salt is insoluble in nonpolar lipids and is thus concentrated in the aqueous phase.

Preblending

The high WHC of meat salted while it is still in the prerigor state is due to a strong electrostatic repulsion between dissociated actin and myosin. When salt is added to meat that has a pH higher than the isoelectric point of the myofibrillar proteins, the increase in WHC is caused by a lowering of the isoelectric point by the binding of chloride ions (Pearson, 1986).

The idea that the increase in WHC from preblending prerigor meat is caused by an irreversible solubilization of myofibrillar proteins is probably not correct (Morrissey et al., 1987). The solubility of myofibrillar proteins in prerigor salted comminuted beef decreases postmortem similar to unsalted beef, although the high WHC of salted beef persists (Hamm, 1986). The irreversible effect of salt on the WHC of prerigor beef is caused by the prevention of rigor mortis in the fibers. This is probably due to a strong repulsion between adjacent protein molecules resulting from the combined effects of ATP, high tissue pH, and high ionic strength. These conditions cause irreversible changes in the conformation of myofibrillar proteins (Honikel et al., 1981).

The formation of interfilamental crosslinks during rigor mortis depresses the swelling effect of salt.

Honikel et al. (1981) found that the relatively low WHC of unsalted muscle homogenates decreased slowly and linearly with decreasing pH until a final pH of 5.4 was reached. Homogenates with salt added at increasing times postmortem demonstrated a slow decrease in WHC which parallelled that of unsalted meat down to about pH 5.9 where rigor began. There, the salted homogenate underwent a strong linear decrease in WHC so that by pH 5.4 the WHC of the salted homogenate was indistinguishable from the unsalted. The parallel loss in WHC between pH 7.0 and 5.9 indicated a similar pH dependence of WHC.

High quality sausage products with optimum WHC and functional properties can be made from prerigor meat. However, it must be comminuted and salted before a pH of 5.9 is reached or before the ATP level drops enough for rigor mortis to begin (Greaser, 1986). This means that prerigor meat has to be salted immediately after slaughter and before cooling, usually within one hour postmortem (Hoogenkamp, 1986).

Limited research has been done on the amount of salt that is necessary to obtain the benefits of preblending. Hamm (1981) reported that salting of prerigor meat with a minimum of 1.8% NaCl was necessary to increase the WHC of sausages. Puolanne and Terrell (1983a) reported data suggesting that salting prerigor pork (preblending) with 1.0, 2.0, or 3.0% NaCl improved fat retention in

frankfurters but the extent of this fat retention may have been associated with percentages of fat in the finished product. They found that the highest WHC values were achieved with preblends of 4.0% salt that were diluted into batters of 1.5 and 2.0% salt. The prerigor meat blended with higher salt levels and then diluted down to lower levels in the batter gave the best results. Sausage batters of 1.0% salt collapsed during cooking.

FUNCTIONAL PROPERTIES

Muscle proteins are involved in three basic physiochemical interactions: protein-water, protein-lipid, and protein-protein (Acton and Dick, 1984). These basic interactions are described in comminuted meat products as the functional properties of water holding, fat binding, and gelation (Acton et al., 1983) Actomyosin, myosin, and actin are the proteins that are largely responsible for these characteristics.

Water-holding Capacity

The ability of proteins to bind or trap water is required in processed meat products. The myofibrillar system is dominant in waterbinding. There are three types

of water bound in tissue (Hamm, 1960). Constitutional or bound water which is located within the protein molecules has a high water binding energy and makes up a very small amount of the water in tissue. Interfacial water is present on the surface of proteins and shows a relatively restricted mobility. The largest percentage of water is free or bulk water that is trapped between the fibers. This water is expressed during the application of some type of external force. Water-holding capacity (WHC) can be defined as the ability of muscle to retain its bulk phase water when stressed (Fennema, 1977).

Water-holding capacity is largely influenced by pH. It is at minimum at or near the isoelectric point of muscle, pH 5.0, where actomyosin has zero net charge. The filaments and molecules are held close together by opposite attracting forces. At lower or higher pH values the proteins will have a net positive or negative charge giving rise to electrostatic repulsion (Hamm, 1960). Like charges on the molecules repel and the structure is loosened. Small changes in pH may cause relatively large changes in WHC (Asghar et al., 1983).

From work done with rabbit psoas myofibrils, Offer and Trinick (1983) reported that the immobilization of water is apparently determined by the spacial, or lattice, arrangement of the myofibrillar proteins. When adjacent

molecules experienced electrostatic repulsion more water can be immobilized within the larger spaces. If they are attracted electrostatically, the network tightens, and there is less space to trap water.

Most of the water that is held in meat is present in the interfilamental spaces within the myofibrils and in the extracellular spaces between the myofibrils (Hamm, 1986). This water is similar to bulk water. It is assumed that this water is held there by capillarity. Surface tension forces in a capillary the same diameter as a muscle fiber would support a column of water 30 cm high, and one with a diameter equal to the interfilamental spaces would support a column 1,000 times higher (Offer and Trinick, 1983). Only 4 to 5% of the total water in muscle can be tightly bound to the muscle proteins (Hamm, 1960).

Measuring Water-holding Capacity: When measuring WHC, a force of some kind has to be applied to the meat sample so that the amount of loosely bound water that is released can be measured (Hamm, 1986). This force can be some kind of pressure such as centrifugation, drip loss during storage, or heating and pressing, or it can be a suction force. In applying one of these forces, the product is deformed, so the water loss will be likely due to the

force applied plus the changing of the internal structure during the application (Labuza and Lewicki, 1978).

There are several different ways to measure WHC. The selection of an appropriate technique depends on what the data will be used for. To evaluate the water and fat binding of cooked meat batters, cooking loss is the usual technique used. Cooking loss measures the amount of fluid lost during cooking. The raw batter is stuffed into casings and weighed, or weighed into glass tubes, and cooked. The weight loss during cooking and cooling is measured (Townsend et al., 1968). Tsai and Ockerman (1981) described a variation of this where the sample was cooked by microwave. The sample was pressed by a weight and then cooked to 76 - 80°C. They found it to be highly correlated with regular cooking loss, although it did not work well in products containing high salt and phosphate levels.

Fat Binding

The emulsion theory states that fat globules are encased by a proteinaceous membrane in raw and cooked batters (Saffle, 1968). Work done by Theno and Schmidt (1978) indicated that fat globules were not completely encapsulated by a protein membrane. Instead, their

photomicrographs showed proteinaceous deposits on the surface of the fat globules. This interfacial protein membrane maintains a more stable molecular arrangement at a lower surface tension and is thought to be primarily responsible for the stability of a raw emulsion (Jones, 1984). This membrane forms during the chopping stage. The proteins denature and unfold with the hydrophobic side chains orienting towards the fat phase and the hydrophilic side chains towards the aqueous phase. There is recent evidence that the denaturation of myosin may not be necessary to emulsify fat since the effectiveness of the hydrophobicity of the surface proteins of myosin has been suggested (Jones, 1984).

Since most of the hydrophobic sidechains in myosin are located in the globular head region, myosin is fairly surface active and does not need to denature to begin formation of the protein membrane (Li-Chan et al., 1984). Free myosin is very surface active and can participate in this activity while the still intact actomyosin, however, must denature and unfold first (Hamm, 1986).

The interfacial protein membrane is not solely responsible for the stability of a meat emulsion. Other factors that may also influence stability include: pH, ionic strength, melting point and cell membrane integrity of the lipid source, protein gelation properties and

thermal processing conditions (Smith, 1988).

Measurement of Fat Binding: The factors that increase WHC in lean meat (pH, ionic strength, state of rigor) also improve the fat binding ability in sausages upon heating. Therefore, fat binding is usually a measure of the amount of fat released during cooking and is determined at the same time as WHC (Hamm, 1986).

Gelation

A myofibrillar protein sol is the chopped, salted meat batter. During heat processing, the proteins take on a three-dimensional structure to form a gel (Acton et al., 1983). In cooked sausages, protein-protein interactions that occur during gelation are mostly responsible for fat and water stability in the finished product (Hamm, 1986). Fat and water are chemically and mechanically stabilized within the protein network. The gel strength of the cooked protein matrix is probably the most important characteristic when estimating the overall stability of most sausage products (Foegeding, 1988).

The mechanism of gel formation differs among proteins. Different proteins have different types of molecular interactions stabilizing the gel. These include hydrogen

bonding, sulfhydryl-disulfide interchange, and ionic bonds (Schmidt et al., 1981).

Factors affecting gelation are temperature, pH, salt, and protein concentration. They work to alter the degree of crosslinking by changing the quaternary structure of the protein, or the charge distribution of the molecules (Schmidt et al., 1981). It is the flexibility of the polymer molecules and the number of connections between them that gives the gel its elastic plastic nature (Schmidt, 1986). It is generally agreed that polypeptide chains crosslink at five or six places during gelation and the other molecules that move between the strands account for the flexibility of the gel (Asghar et al., 1985).

There are two steps to heat-induced gelation (Acton and Dick, 1984). Gelation starts with the partial unfolding of the proteins which is followed by the reaggregation of protein fibers into a crosslinked three-dimensional structure. The protein is denatured during this time with the overall sequence as follows: native protein-----> denatured protein-----> aggregated protein (Ferry, 1948). This process must be orderly for gelation to occur. The slower the proteins aggregate in relation to denaturation, the more time they have to orient themselves and the finer the gel network (Ziegler and Acton, 1984). A random orientation of denatured protein

molecules results in coagulation which forms a coarse structure, and a weaker, less-elastic gel.

Myosin has excellent gel forming abilities (Schmidt et al., 1981). When heated it forms an irreversible gel that has high water binding and strong elastic properties. Gelation of myosin on heating occurs in two stages (Samejima et al., 1981). At temperatures below 50°C several changes occur in protein conformation such as the dissociation of tropomyosin from F-actin, the dissociation of both the F-actin superhelix and actomyosin while myosin is separated into light and heavy chains (Ziegler and Acton, 1984). However, the most important change that takes place during the first stage when the temperature increases from 30 to 50°C is the head-to-head aggregation of myosin molecules. This aggregation seems to be associated with the oxidation of the sulfhydryl groups. In the second stage as heating continues over 50°C, myosin tails begin to denature and unfold. At about 55°C, the myosin tails have unfolded, and undergo rapid aggregation and gelation leading to a noncovalent network formation between the unfolded portions (Samejima et al., 1979). The optimum temperature range for gelation of meat proteins is 65 - 70°C (Ziegler and Acton, 1984).

Heating rate also has an effect on the texture of protein gels. Gels produced by rapid heating at 70°C for

20 minutes are weaker and more susceptible to rupture than gels heated by a linear increase of 12°C per hour to 70°C (Foegeding, 1988).

The properties of a gel network are pH dependent. The optimum pH for maximum gel strength ranges between 6.0 and 6.3 (Ishioroshi et al., 1981). Salt concentration also influences the type of gel formed. Hermannson et al. (1986) found that at 0.2 M KCl, pH 6.0, myosin formed a gel with a fine stranded lacy network. At 0.6 M KCl, however, the gel was coarsely aggregated and spongelike. The difference may be due to the fact that at low ionic strength myosin molecules are assembled as filaments that, when heated, form ordered three-dimensional structures. When myosin molecules are present as monomers at high ionic strength and are heated, they produce head-to-head aggregates (Asghar et al., 1983).

Actin per se does not increase gel strength but, when mixed with myosin, compliments its binding characteristics and increases gel strength (Samejima et al., 1981). Heat gelling properties of actin and myosin are optimum at a myosin to actin ratio of 2.7:1 (Morrissey et al., 1987).

Troponin and tropomyosin do not seem to be actively involved in gelation. They are present at relatively low concentrations and have a low molecular weight compared to actin and myosin (Ziegler and Acton, 1984). Sarcoplasmic

proteins show no gelation ability when heated, although they coagulate at 80°C (Fretheim et al., 1985).

Measurement of Gel Strength: Gelation is important in the formation of texture in many foods. Although a gel system has several distinguishing characteristics, gel strength is often used as the criterion for comparative studies since it is easy and convenient to measure (Asghar et al., 1983). In meat gels the fat:protein ratio has been shown to be a significant factor in gel strength (Huang and Robertson, 1977). The higher the protein content, the greater the gel strength. Gels become weaker with addition of fat. The instrumental methods used to evaluate textural properties have been extensively investigated.

Penetration with a cylindrical steel rod on an Instron Universal Testing Machine is used most often to measure gel strength. The flat end of the rod is pushed through the sample and the force of penetration is recorded on graph paper (Bourne, 1975). Comparing results of this method can be a problem. As the diameter and punch area increase, so does the amount of force necessary to rupture the sample. Huang and Robertson (1977) found a high correlation between the maximum force during penetration and the hardness of the product.

MATERIALS AND METHODS

SAMPLES

Fifteen good to choice quality steers were slaughtered at the Clark Meat Science Laboratory following normal slaughter procedures. The sternomandibularis muscle was removed from the right side of each carcass within one hr after death (prerigor muscle). The control samples remained on the left side of each carcass for 48 hr at 2°C before removal (postrigor muscle).

Following removal, each muscle was trimmed of visible fat and connective tissue. The lean was briefly chopped for 10 sec in a Cuisinart DC-10 Plus food processor to obtain a minced sample. After chopping, 10 g was taken for pH measurement and the remaining lean was retained for the control and experimental treatments.

MEASUREMENT OF pH

A Corning digital pH meter fitted with a Sensorex epoxy-body sealed reference combination electrode was used. The pH meter was standardized with pH 7.0 and 4.0

buffers and was periodically calibrated for ambient temperature. The electrode was rinsed extensively with distilled water after each measurement.

Measurements of pH of prerigor and postrigor muscle samples were taken after 10 g of minced muscle was homogenized with 100 ml of 5 mM iodoacetate solution in an Osterizer blender for one min, resting one min and blending one more min. This mixture was poured into a glass beaker and the pH was measured by inserting the electrode into the mixture and stirring the solution until the readout stabilized.

The iodoacetate solution contained 5 mM iodoacetate, 150 mM KCl and was adjusted to pH 7.0 with NaOH (Greaser, 1986).

PREBLEND TREATMENTS

Four treatments involving the preblending of prerigor meat with different levels of salt (1.5, 2.25, 2.5 and 3.0% NaCl) were studied.

The preblends were prepared at the above stated salt levels with 150 g of lean and 20% water which is an industry standard (Hamm, 1986). The lean, salt and water were placed in a Kitchen-Aid mixer (model K5SS) and mixed at medium speed (setting 6) for 5 min. The mixer was

thoroughly washed and dried between treatments. The preblended samples were placed in 250 ml glass beakers, covered with aluminum foil or plastic wrap, and refrigerated at 1°C for 24 hr before being incorporated into batters.

BATTER PREPARATION AND PROCESSING

The preblends were used to formulate batters with 1.5 or 2.5% salt. The batter formulations (shown in Tables 1 and 2) were adopted from studies done by Whiting (1984). Batters were prepared in a Cuisinart DC-10 Plus food processor. The water in each formulation was added as crushed ice. Fresh pork adipose tissue was obtained from the Clark Meat Science Laboratory, cut into cubes and stored at -10°C prior to use.

During batter preparation, all of the ingredients were placed in the food processor at one time and chopped to an ultimate temperature of 16.0 +/- 0.5°C. Chopping was periodically interrupted to adjust pH, measure temperature, and scrape the sides of the bowl. The temperature was measured with a -10 to 110°C mercury in glass standard thermometer. The batter was adjusted to pH 5.8, which was the pH where the highest gel strength was obtained by Whiting (1984). The preblended samples were adjusted with

Table 1. Batter formulations made with salted blends of prerigor beef.

	% salt in batter			
	1.5		2.5	
	% salt in preblend[a]		% salt in preblend	
Ingredient (g)	1.5	2.25	2.5	3.0
Prerigor preblend	135	136	137	137.7
Pork fat[b]	52	52	52	52
Ice/water	12	12	9.6	9.3
Salt	1	--	1.4	1
Total	200	200	200	200

[a] Preblend made within 1.5 hr postmortem, mixture of lean, salt and 20% water.
[b] Postrigor pork fat

Table 2. Batter formulation made with postrigor beef (control formulation).

	% salt in batter	
Ingredient (g)	1.5	2.5
Postrigor beef[a]	106	106
Pork fat[b]	52	52
Ice/water	39	37
Salt	3	5
Total	200	200

[a] Postrigor beef - 48 hr postmortem
[b] Postrigor pork fat

0.5 M NaOH and the control samples with 1.0 M NaOH. Less than two ml of base were added to each formulation to keep from diluting the batters. The pH was measured by inserting the electrode directly into the batter at three different locations and averaging the readings. The food processor was washed and dried between treatments to prevent contamination.

For each batter, duplicate 30.0 +/- 0.1 g aliquots of batter were weighed into 50 ml glass centrifuge tubes. After the tops of the batters were smoothed down, the tubes were centrifuged at 50 x g for 10 min. The centrifuge tubes were then stoppered and placed in a 70 - 75°C water bath to cook for 30 min. During cooking the batter plug was maintained beneath the water line of the water bath.

WATER-HOLDING CAPACITY

The water-holding capacity (WHC) was determined by weighing the amount of fluid lost during cooking (Whiting, 1984). Immediately after cooking and removal from the water bath, the stoppers of the centrifuge tubes were removed and the exudate was decanted into a beaker. The cooked batters were allowed to cool to ambient temperature. During cooling, the batters were loosened from the sides of the tubes by a thin metal blade and fluid was drained as it

collected in the bottom of the tubes.

Once cooled, the centrifuge tubes and batters were reweighed and the cook loss was calculated as percent fluid lost.

GEL STRENGTH

The cooked batters or meat gels were cooled and gel strength was measured within three hours of cooking. Gel strength was determined on an Instron Universal Testing Machine using the penetration method with a cylindrical punch.

The centrifuge tube containing the gel was fixed in an vertical position on the platform of the machine. A 6.35 mm diameter, flat bottomed steel rod was forced into the top of the gel at a downward speed of 5.0 cm per min (Huang and Robertson, 1977). The range was set at one and a 50 pound load cell was set full scale. The chart speed was 100 cm per min.

The maximum force of initial penetration was recorded in pounds force. The rod was allowed to penetrate the sample to a depth of 4 cm with the machine set for automatic return.

PROXIMATE ANALYSIS

The batters were ground twice through a Moulinex food grinder (model 308) having a grinding plate with orifices of 3.5 mm diameter in preparation for proximate analysis. Moisture was determined following gel strength measurement while the remaining portion was double wrapped in plastic film, enclosed in Ziploc plastic bags, and frozen for later protein and fat analysis.

Samples were analyzed in duplicate for protein, moisture, and fat by the macro-Kjeldahl (AOAC, 1975), vacuum-oven drying (AOAC, 1975), and the Modified Babcock -sulfuric acid (Kelly et al., 1954) methods, respectively.

STATISTICAL ANALYSIS

The experiment was a completely randomized design with six treatments. For all samples, replicate values for the functional properties and pH within a treatment were averaged for statistical analysis. The data were analyzed by analysis of variance and Duncan's multiple range test (Steel and Torrie, 1960). The computer software program Statgraphics version 2.6 was used in the analysis.

RESULTS AND DISCUSSION

MUSCLE pH

The pH values of the prerigor muscles and the postrigor control muscles are presented in Table 3. The means and standard deviations of both groups are also listed in Table 3.

Immediately following slaughter, the prerigor sternomandibularis (SM) muscle was removed, trimmed of visible fat and connective tissue, and partially chopped to obtain a minced sample which was immediately homogenized in 5 mM iodoacetate - 150 mM KCl buffer. This procedure was completed and the pH was measured within one hour postmortem.

The pH values of the prerigor SM muscles ranged from 6.52 to 6.88 with a mean of 6.70. The control muscles had a pH range of 5.55 to 5.95, with a mean of 5.66 which was significantly lower ($p < 0.01$) than that of the prerigor samples.

All of the prerigor samples had pH values well above 5.9. It is important to mince prerigor muscles with salt before the pH reaches 5.9. At pH 5.9, the ATP levels have been depleted and rigor mortis is initiated (Honikel et

Table 3. pH values of bovine sternomandibularis muscles obtained immediately following slaughter (prerigor) and 48 hours postmortem (control).

	Treatment of Paired Sides	
Sample number	Prerigor	Control (48 hrs pm)
1	6.69	5.60
2	6.82	5.59
3	6.88	5.66
4	6.55	5.57
5	6.70	5.60
6	6.73	5.63
7	6.80	5.56
8	6.68	5.58
9	6.64	5.59
10	6.81	5.62
11	6.69	5.55
12	6.69	5.64
13	6.64	5.82
14	6.71	5.86
15	6.52	5.95
*Mean	6.70	5.66
Standard deviation	0.10	0.12

*The means are significantly different at $p < 0.01$.

al., 1981; Hamm, 1982). With the onset of rigor mortis, the functional properties of muscle proteins, particularly water-holding capacity (WHC) and protein extractability begin to decline rapidly. Thus it is imperative to utilize muscle at elevated pH to take advantage of the characteristic high WHC of prerigor beef (Hamm, 1960; Honikel et al., 1981; Whiting, 1988).

PROCESSING

When the preblends were prepared, 150 g of meat was used for each treatment. With 150 g for four prerigor treatments and 10 g for pH measurement, a total of 610 g of muscle was necessary. Four steers slaughtered towards the end of the study were smaller than the earlier animals. The SM muscles of steers numbers 9, 13, 14, and 15, weighed slightly over 500 g each. Thus preblend formulations for these samples were reduced proportionally to 110 - 120 g each to compensate for the smaller muscle weights. This reduction had no apparent affect on the preparation of the batters.

Salt levels of 2.5% are representative of current industry practice for meat emulsion/batter products (Terrell, 1983). The 1.5% NaCl level was chosen as an extreme reduction in salt, but one that would still

maintain functional properties (Whiting, 1984). The reduction of 1% salt was compensated by increasing the water content 1%.

The preblend batters had initial pH values of approximately 5.6 while the control batters were approximately 5.3. The higher pH of the preblends was due to the effect of the salt added prerigor (Abu-Bakar et al., 1982; Puolanne and Terrell, 1983a; Torres et al., 1988). The combination of low pH and added NaCl causes the inhibition of glycolytic enzymes at a higher pH than low pH with no added NaCl (Hamm, 1977).

The pH of the control batters was adjusted from 5.3 to 5.8 by the addition of 1 M NaOH after the initial 15 sec of chopping. For the preblends, 0.5 M NaOH was added to adjust the pH from 5.6 to 5.8. The maximum addition to the 160 g of control or preblend batters was 2 ml, thereby minimizing change in batter composition. The pH was measured at the end of the chopping when the batter reached 16°C by direct insertion of the pH electrode.

PROXIMATE ANALYSIS

The results of proximate analysis (protein, moisture and fat contents) of the cooked batters expressed on a wet weight basis are summarized in Table 4. Each mean value

listed is the average of duplicate determinations of 15 replications per treatment. The moisture contents for all treatments ranged from 57.64% to 58.52% with an overall mean value of 58.02%. Fat contents ranged from 26.83% to 27.65% with an overall mean value of 27.28%. Differences in moisture and fat contents between treatments were not statistically significant ($p > 0.05$). Puolanne and Terrell (1983b) reported similar results with prerigor preblended beef batters.

The protein contents of all treatments ranged from 11.13% to 12.21% with a mean value of 11.79%. The mean protein content of treatment 6 (2.5% salt batter control) was significantly lower ($p < 0.05$) than those for the four experimental treatments (numbers 1, 2, 3 and 4). There is no apparent explanation for treatment 6 to have lower protein contents than the experimental treatments since many precautions and efforts were employed to minimize compositional differences between treatments. The difference in protein content between treatment 5 (1.5% salt batter control) and treatment 6 was not statistically significant ($p > 0.05$).

Table 4. Percent protein, moisture and fat content of cooked batters.

Treatment[a]	Protein		Moisture		Fat	
	Mean	SE[b]	Mean	SE	Mean	SE
1	11.88[d]	0.16	58.17	0.33	27.09	0.50[c]
2	12.21[d]	0.13	57.64	0.23	27.27	0.41
3	11.96[d]	0.21	57.65	0.25	27.28	0.41
4	11.97[d]	0.16	58.04	0.32	26.83	0.35
5	11.61[d,e]	0.14	58.07	0.44	27.65	0.52
6	11.13[e]	0.10	58.52	0.28	27.52	0.41
Mean	11.79		58.02		27.27	

[a]
1. 1.5% Salt preblend, 1.5% salt final batter
2. 2.25% Salt preblend, 1.5% salt final batter
3. 2.5% Salt preblend, 2.5% salt final batter
4. 3.0% Salt preblend, 2.5% salt final batter
5. 1.5% Salt batter control
6. 2.5% Salt batter control

[b] Standard error of treatment means

[c] Steer #5 lost emulsion of this treatment when cooked, n=14 for treatment 1, n=15 for treatments 2-6.

[d,e] Means with unlike superscripts are significantly different ($p < 0.05$).

WATER-HOLDING CAPACITY

Data concerning the WHC of batters of the various treatments expressed as the percent weight lost as fluid during cooking, or cook loss, are presented in Table 5. The fluid exuded from batters during cooking was mainly water. The amount of fat released during cooking was negligible, only a few droplets per treatment. This was not enough to measure accurately in a 10 ml calibrated conical test tube. This finding is in agreement with the results of Whiting (1984), who found that fat binding was the functional property least affected by a reduction in salt content. WHC was the first attribute of the meat batter to fail with reduced salt content while gel strength was second. The mean values for cook loss for the batters of the six treatments ranged from 4.55 to 9.75% (Table 5) while the overall mean cook loss was 6.33%. One value (steer #5) from the 1.5% salt preblend, 1.5% salt final batter treatment was not included in the results. During cooking, this batter lost 30.1% of its weight as fluid which was about 25% fat and the remainder was a red-colored aqueous fluid. This was an obvious batter failure although there were no apparent reasons why it destabilized when other samples of the same treatment

Table 5. Percent mean cook loss of experimental and control batters.

Treatment[a]	Replications	Mean	SE[b]
1	14	6.24[c]	0.47
2	15	6.93[c]	1.61
3	15	4.55[c]	0.36
4	15	4.85[c]	0.30
5	15	9.75[d]	1.12
6	15	5.64[c]	0.77
Mean		6.33	

[a]
1. 1.5% Salt preblend, 1.5% salt final batter
2. 2.25% Salt preblend, 1.5% salt final batter
3. 2.5% Salt preblend, 2.5% salt final batter
4. 3.0% Salt preblend, 2.5% salt final batter
5. 1.5% Salt batter control
6. 2.5% Salt batter control

[b] Standard error

[c,d] Means with unlike superscripts are significantly different at $p<0.05$.

showed no indications of destabilization or batter failure.

An analysis of variance was completed to determine the effects of the individual steers and treatments on cook loss. The results (Table 5) showed that the steers per se had no effect on the cook loss of the batters. Conversely, cook loss was significantly ($p < 0.01$) affected by the treatments.

When the treatment means for cook loss were compared (Tables 5 and 6), the mean for the 1.5% salt final batter of the control treatment was significantly different ($p < 0.05$) from the others. It had a much higher cook loss, 9.75%, while the other treatment means ranged from 4.55 to 6.93%.

Although not statistically significant ($p > 0.05$) there were differences in cook loss among the preblends. The 1.5% salt preblend, 1.5% salt final batter and the 2.25% salt preblend, 1.5% salt final batter had mean cook losses of 6.24 and 6.93% respectively, while the 2.5% salt preblend, 2.5% salt final batter and the 3% salt preblend, 2.5% salt final batter showed higher WHC with 4.55 and 4.85% cook losses. The 2.5% salt control batters had a mean cook loss of 5.64%. These differences are shown graphically in Figure 1.

The cook loss fluid from batters of the control

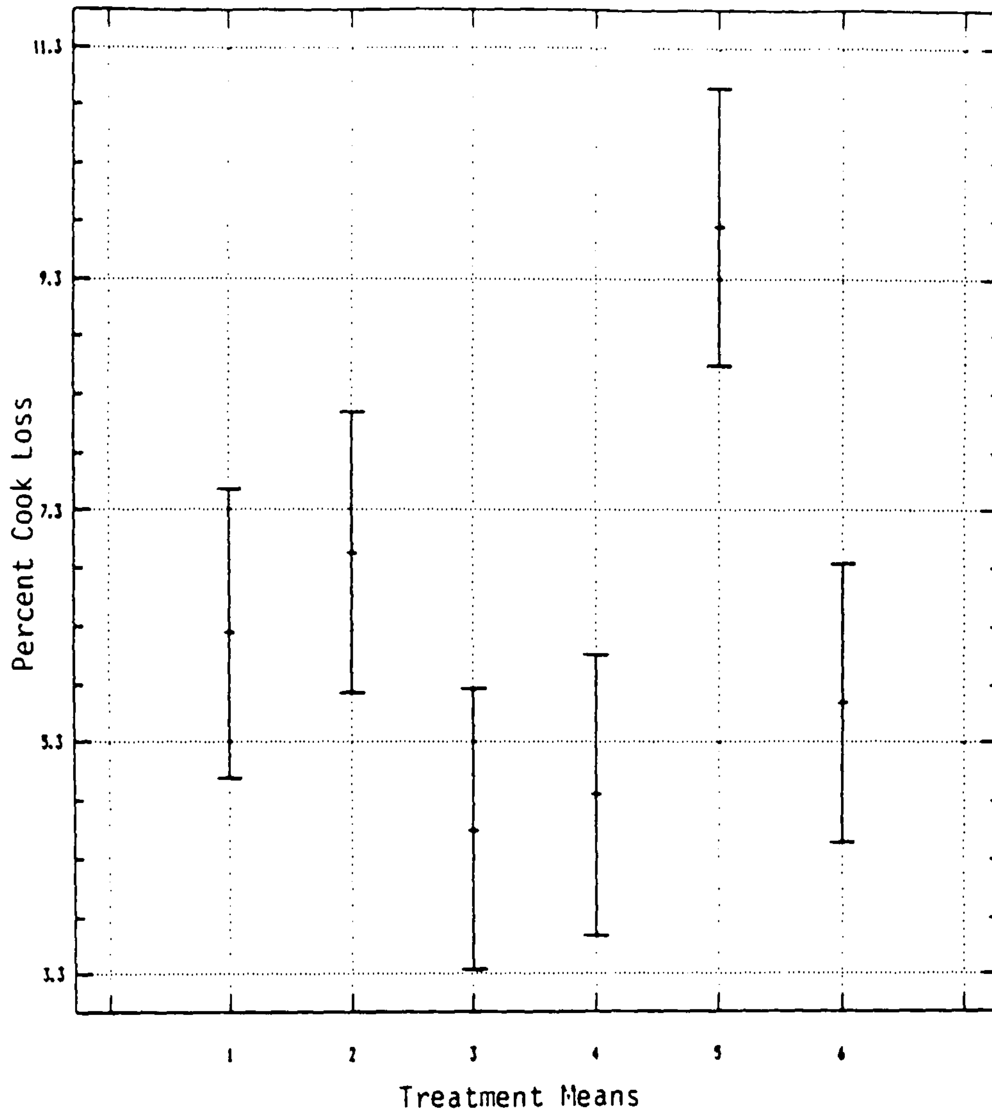

Figure 1. Effect of prerigor, preblended beef and reduced salt levels on cook loss. (Bars represent 95% confidence intervals)

treatments, both the 1.5 and 2.5% salt batters, was either clear or amber colored. Some batters, however, released red-colored fluid. This was particularly noticeable with the 1.5% salt preblend, 1.5% salt final batters and the 2.25% salt preblend, 1.5% salt final batters. Batters from these two treatments showed the greatest incidence of red-colored cook loss fluid (Table 7). One or two samples in each of the other two preblend treatments, those yielding 2.5% salt final batters, had red-colored cook loss fluid. There was no red-colored cook loss in any of the postrigor control samples.

Myoglobin is responsible for the red color of muscle. It is a conjugated protein composed of the iron-porphyrin complex, heme, combined with a simple globin protein (Livingston and Brown, 1981; Francis, 1985). Myoglobin is present in the sarcoplasmic protein fraction of muscle and it is water soluble. Thus it can be easily leached into the broth or fluid released from meat during cooking (Govindarajan, 1973). The reddish-brown broth from meat cooked at 60 to 77°C indicates a high heme pigment content (Buchowski et al., 1988).

Denaturation of the sarcoplasmic fraction occurs rapidly when pH levels less than 6.0 are combined with temperatures greater than 35°C (Govindarajan, 1973; Cross et al., 1986). Heme pigment is partially destroyed when

Table 6. Analysis of variance for cook loss of experimental and control batters.

source	Sum of Squares	D.F.	Mean Sq.	F-ratio	Sig. Level
Main effects	438.7	19	23.1	4.22	$p<0.01$
Cook loss, steer	170.1	14	12.2	2.22	ns
Cook loss, treatment	268.6	5	53.7	9.82	$p<0.01$
Residual[a]	377.6	69	5.5		
Total (corrected)	816.3	88			

[a] 1 missing value, steer #5 treatment 1.5% salt preblend, 1.5% salt final batter, has been excluded.

Table 7. Number of treatments with red-colored cook loss fluid.

Treatment	Number of samples with red broth
1.5% salt preblend, 1.5% salt batter	11
2.25% salt preblend, 1.5% salt batter	10
2.5% salt preblend, 2.5% salt batter	1
3.0% salt preblend, 2.5% salt batter	2
1.5% salt batter control	0
2.5% salt batter control	0

meat products are cooked and nonheme iron is released (Igene et al., 1979). The mechanism for this iron release from myoglobin has not been determined. It is believed that oxidative cleavage of the porphyrin ring is involved (Schricker and Miller, 1983). Factors that are known to promote oxidation of heme pigments include high temperatures, low pH, salt, low oxygen atmosphere and aerobic bacteria (Livingston and Brown, 1981; Cross et al., 1986). It is well-documented that salt promotes the oxidation of heme pigments (Igene et al., 1979; Hamm, 1986; Schricker and Miller, 1983). The fact that the preblends experienced red cook loss while the control samples did not may be due to the oxidative effect of salt in the prerigor preblended meat. The preblended samples were mixed with salt 24 hours before preparation of the emulsions, enough time for pigment oxidation to develop. Salt was not added to the postrigor control samples until the emulsions were prepared.

Within the preblended treatments, the increased red cook loss in the 1.5% salt final batters over the 2.5% salt final batters may be partially explained by the solubilization and swelling of myosin. With increasing salt concentrations, myofibrillar proteins take up more water and increasing amounts of myosin are solubilized along with the sarcoplasmic proteins, which includes

myoglobin (Offer and Trinick, 1983). When this mixture is cooked, the heat-induced gelation of myosin may trap the sarcoplasmic proteins in the network, reducing loss (Schmidt, 1986).

Buchowski et al. (1988) reported that long heating times (> 1 hour) and small samples sizes resulted in very high losses of heme iron. It was suggested that to retain meat pigment, meat should be cooked at temperatures high enough to denature the heme proteins instantly and prevent leaching.

GEL STRENGTH

To measure gel strength, a flat-bottomed cylindrical rod was used to penetrate the batter. The maximum force of initial penetration was measured in units of pounds force by an Instron Universal Testing Machine. This penetration force measures the strength of the protein-protein interactions after heat gelation (Whiting, 1987).

Mean values of pounds force required to penetrate the cooked batters of the six treatments ranged from 0.67 to 0.97 pounds (Table 8). The mean value for all treatments was 0.84 pound.

An analysis of variance was used to determine the effects of the individual steers and treatments on gel

strength (Table 9). The steers themselves did not have a significant effect on gel strength, but the treatments were significant at $p < 0.01$.

The treatment means were compared by multiple range analysis (Table 8). The four preblended treatments had significantly stronger gel strengths than the two postrigor control treatments ($p < 0.05$).

There were no significant differences in gel strength between batters of varying salt levels of the preblend treatments, although the 3.0% salt preblend, 2.5% salt final batter and the 2.5% salt preblend, 2.5% salt final batter were slightly stronger at 0.96 and 0.97 pounds force respectively than the 1.5% salt preblend, 1.5% salt final batter and 2.25% salt preblend, 1.5% salt final batter with 0.88 pound force each. There were no differences in gel strength between preblend batters with either 1.5 or 2.5% salt levels. The control batters had significantly ($p < 0.05$) weaker gel strengths than the preblended batters. These differences are presented graphically in Figure 2.

There was no significant difference in the gel strength of the two control, or standard, treatments. The 1.5% salt batter control had a gel strength of 0.67 lb force while the 2.5% salt control was 0.69 lb force. This conflicts with the work done by Whiting (1984) who

Table 8. Gel strength of experimental and control batters.

Treatment[a]	Replications	Mean	SE[b]
1	14	0.88[c]	0.04
2	15	0.88[c]	0.03
3	15	0.97[c]	0.04
4	15	0.96[c]	0.04
5	15	0.67[d]	0.04
6	15	0.69[d]	0.04
Mean		0.84	

[a]
1. 1.5% Salt preblend, 1.5% salt batter
2. 2.25% Salt preblend, 1.5% salt batter
3. 2.5% Salt preblend, 2.5% salt batter
4. 3.0% Salt preblend, 2.5% salt batter
5. 1.5% Salt batter control
6. 2.5% Salt batter control

[b] Standard error

[c,d] Means with unlike superscripts are significantly different at $p<0.05$.

Table 9. Analysis of variance for gel strength of experimental and control batters.

Source	Sum of Squares	D.F.	Mean Sq.	F-ratio	Sig. Level
Main Effects	1.56	19	0.08	3.86	$p<0.01$
Steer	0.29	14	0.02	0.96	ns
Treatment	1.27	5	0.25	11.99	$p<0.01$
Residual[a]	1.48	69	0.02		
Total (corrected)	3.04	88			

[a] 1 missing value, steer #5 treatment 1.5% salt preblend, 1.5% salt final batter, has been excluded.

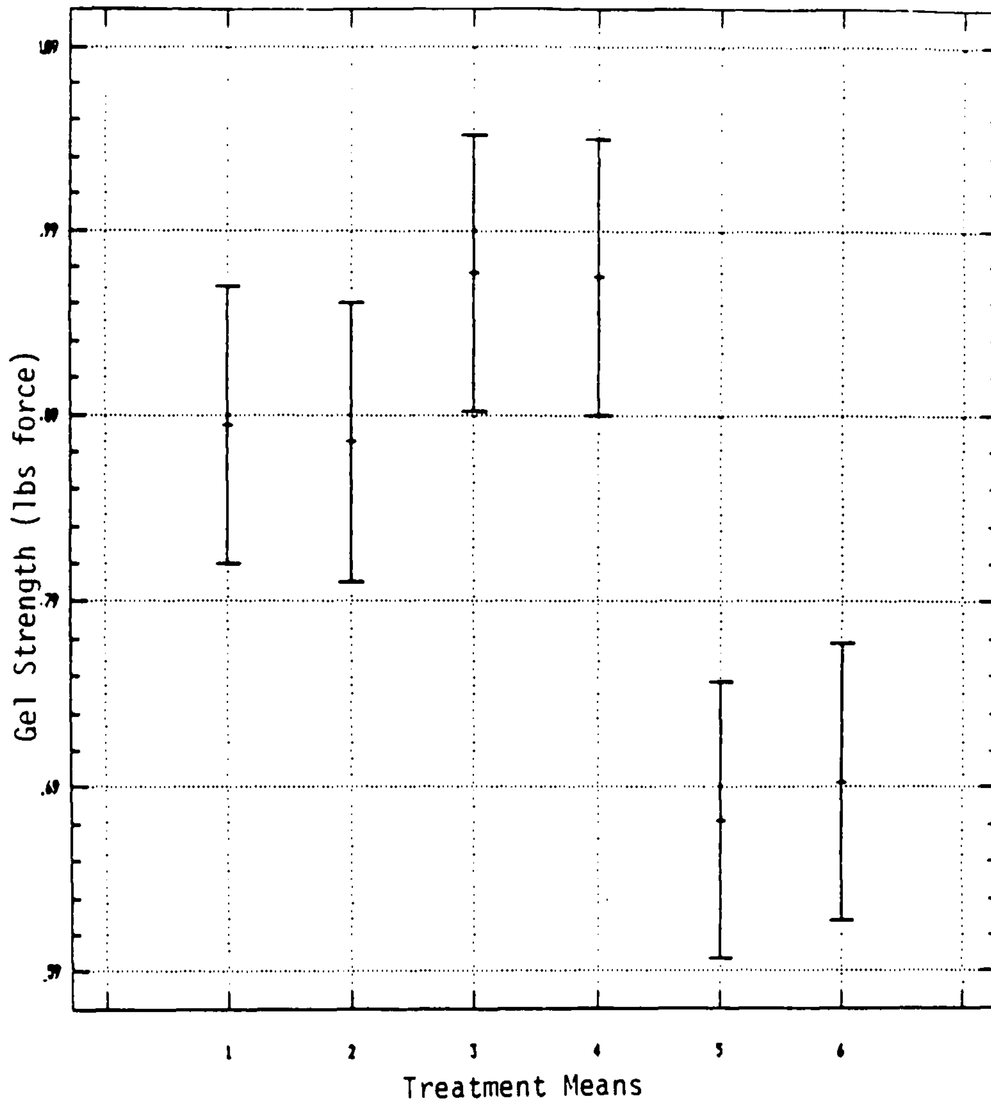

Figure 2. Effect of prerigor, preblended beef and reduced salt levels on gel strength. (Bars represent 95% confidence intervals)

observed a marked decrease in gel strength as salt content decreased from 2.5 to 1.5% in batters made with postrigor beef using the same formulation.

Gel strength in this study seemed to be more dependent on the state of rigor when salt was added than on the amount of salt added. More protein is extracted when salt is added prerigor than when added postrigor (Abu-Bakar et al., 1982). Muscle proteins are highly soluble in salt solutions immediately after animal death (Hamm, 1982). As ATP is depleted and rigor mortis begins, protein solubility decreases concurrently with the increased crosslinking of actin and myosin to form the rigid complex of actomyosin (Morrissey et al., 1987; Honikel et al., 1981).

Gels do not reach appreciable strength until the myosin tail has unfolded enough for subsequent crosslinking to occur (Smith, 1988; Ziegler and Acton, 1984). When preblended with salt, myosin can begin to solubilize and unfold 24 hours in advance of batter preparation and thermal treatment.

Limited data are available on the gelation character of comminuted meat systems in an industrial sense. Most of the work completed thus far has been done with model systems of purified myosin. Acton et al. (1981) reported maximum gel strengths at pH 5.0 - 5.5 in myosin gels.

They exhibited a spongy texture which is in contrast to myosin gels at pH 6.0 that formed a uniform and opaque, but weaker, gel.

CORRELATION COEFFICIENTS

Correlation coefficients were calculated comparing cook loss, gel strength, treatment and the individual steers. These results are shown in Table 10. There was a significant negative correlation between cook loss and gel strength of -.37 ($p<0.01$). Treatments with higher cook losses tended to have weaker gels.

There was a slightly stronger negative correlation, -0.43, between gel strength and treatments that was significant at $p<0.001$. The cook loss and treatments showed no significant correlation ($p>.05$). The preblended prerigor treatments may account for some of this as there were no significant differences within treatments.

Table 10. Correlation coefficients among experimental variables.

	Cook loss	Gel strength	Steer	Treatment
Cook loss	--	-.37*	-.12	.09
Gel strength	-.37*	--	-.02	-.43**
Steer	-.12	-.02	--	-.01
Treatment	.09	-.43**	-.01	--

* $p<0.01$
** $p<0.001$

PRACTICAL APPLICATION

Prerigor preblended meat may be used to help retain the functional properties of reduced salt emulsion-type products. Prerigor meat has a higher WHC and better "fat emulsifying" properties than postrigor meat (Hamm, 1982). When prerigor meat is ground and salted, these superior processing qualities are maintained.

In the present study the cook loss of the preblended 1.5% salt final batters was not significantly ($p > 0.05$) different than the preblended 2.5% salt final batters or the 2.5% salt batter control.

The red-colored cook loss fluid of the preblended 1.5% salt final batters may cause potential problems in commercially manufactured products. The heme pigments that leached out with the cook loss fluid may detract from the appearance or color stability of the final product.

The gel strength of both the prerigor, preblended 1.5 and 2.5% salt final batters was significantly ($p < 0.05$) stronger than the 1.5 and 2.5% salt batter control treatments. The rigor state of the muscle, possibly related to the amount of actomyosin formation, had more effect on gel strength than the salt content.

The use of prerigor, preblended beef in reduced salt

products has a promising future. However, in a meat plant the processing schedule must be closely coordinated with the slaughter schedule. The meat must be hot-boned, minced, and salted immediately following slaughter to maintain the high WHC characteristic of prerigor meat.

Other alternatives that may be employed in reduced salt products are the addition of phosphates to increase protein extractability, WHC and firmness, and to inhibit oxidative changes. Also the use of higher quality meat ingredients and the partial substitution of potassium chloride for sodium chloride may be applicable (Terrell, 1983).

CONCLUSIONS

The stability and gel strength of meat batters made with prerigor beef and reduced salt levels were determined. The evidence indicates that it is possible to make an acceptable reduced salt product using prerigor, preblended beef.

Water-holding capacity was the first attribute of the meat batters to decrease with reduced salt content while gel strength was second. Fat-binding ability was not affected within the parameters of this study. The 1.5% salt final batter of the control treatment had a significantly higher ($p < 0.05$) cook loss than the other treatments. The preblended 1.5% salt final batters had cook losses that were not significantly different from any of the three 2.5% salt final batters - preblended or control.

The implications of the red-colored cook loss that was observed in both of the preblended 1.5% salt final batter treatments were not determined. The loss seemed to have no significant ($p > 0.05$) effect on the functional properties of the batters studied. However, the sensory qualities of the batters were not considered.

The gel strength measurements indicated that the

observed in both of the preblended 1.5% salt final batter treatments were not determined. The loss seemed to have no significant ($p>0.05$) effect on the functional properties of the batters studied. However, the sensory qualities of the batters were not considered.

The gel strength measurements indicated that the preblended treatments possessed superior gelation characteristics when compared to the postrigor control treatments. The preblended 1.5 and 2.5% salt final batters exhibited significantly stronger ($p<0.05$) gel strengths than the 1.5 and 2.5% salt batter control treatments. Apparently more protein was solubilized initially and was available for subsequent crosslinking in the prerigor, preblended batters.

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