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CHARACTERIZATION OF METHYLCELLULOSE AND HYDROXYPROPYL METHYLCELLULOSE IN HIGH-MOISTURE RESTRUCTURED HAMS

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DEANNA LEA BLOOM-HOFING

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CHARACTERIZATION OF METHYLCELLULOSE AND HYDROXYPROPYL METHYLCELLULOSE IN HIGH-MOISTURE RESTRUCTURED HAMS

By

Deanna Lea Bloom-Hofing

A THESIS

Submitted to
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ABSTRACT

CHARACTERIZATION OF METHYLCELLULOSE AND HYDROXYPROPYL METHYLCELLULOSE IN HIGH-MOISTURE RESTRUCTURED HAMS

By

Deanna Lea Bloom-Hofing

The objective of this study was to determine if methylcellulose (MC), hydroxypropyl methylcellulose (HPMC), and kappa carrageenan (KC) would increase cook yields and decrease purge values. Four hydrocolloid brine treatment (TRT) combinations and a control (no hydrocolloids) were formulated to produce "test tube" hams. Ham models were analyzed for purge controlling and textural attributes to determine specific brines to be utilized in a commercial study. Five TRTs were formulated for the commercial study: 1) MC 0.4% & KC 0.6%; 2) HPMC 0.6% & KC 0.6%; 3) MC 0.4% & HPMC 0.6% & KC 0.6%; 4) KC 0.6%; and 5) control (no hydrocolloids). Brine solutions (45% addition wt/wt) were mixed into ground ham (5.33 cm, 2.54 cm and 0.9 cm plate), stuffed into fibrous casing and thermally processed to 70°C internally. Treatments 1 and 3 increased ($P<0.05$) cook yields and were perceived more tender by the sensory panel when compared to TRT 5. However, TRT 2 decreased ($P<0.05$) cook yield and purge values. Treatments 1, 2, 3, and 4 decreased purge values by at least 1.5% when compared to the TRT 5 while decreasing lightness (L*) values. Trained sensory panel ratings noted TRTs containing MC and/or HPMC to have a slight mouth residue and off-flavor with decreased juiciness when compared to TRT 4 and 5. Results suggest a hydrocolloid brine solution containing MC with KC may be a positive purge controller while maintaining textural and color attributes.

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This thesis is dedicated to my husband, Josh Hofing. You have been the inspiration, the motivation and the constant source of support throughout this degree. You never gave up on me; you picked me up when I was knocked down, and the first to congratulate me when I was successful. I want to thank you for your endless love, support, patience and last but not least all the hours driving.

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INTRODUCTION

Restructured meat technology provides processors with the opportunity to use under utilized meats, to manufacture products with specific sensory and textural attributes, and portion size with specific compositional standards (Mandigo 1976; Acton 1983). Examples of restructured products are boneless hams, chicken nuggets, and beef steak. A key principle of restructured meat technology is the binding of meat pieces together, resulting in a product with a homogenous "whole muscle" appearance. In order to bind meat pieces, the meat must be "comminuted" or reduced in size (particle size reduction). The purpose of particle size reduction is to facilitate the extraction of salt soluble myofibrillar proteins by increasing surface area (Acton 1983). The addition of salt and/or phosphate combined with mechanical agitation via tumbling, massaging, or mixing results in the formation of protein exudate on the surface of the meat pieces. The protein exudate is a result of cellular disruption of myofibrillar protein and fracturing of the membrane structure which enhances protein extraction, solubilized by salt and phosphate. The myosin protein exudate is the "adhesive" or "glue" that binds muscle fibrils, added water, fat, connective tissue and any non-meat ingredients within the meat matrix (McCormick 1982). The protein exudates form a heat set gel upon thermal processing resulting in higher cook yields, enhanced bind strength, and improved tenderness.

Restructuring uses several particle size reduction processes: chunking, flaking, or chopping (Pearson and Gillett 1996) either singly or in combination. Chunking grinds cold/frozen meat pieces through larger grinder plates (> 2.54 cm dia). Flaking

comminutes frozen meat pieces into "slices" or "flakes" with the desired particle size. The flaking process is the result of a high speed rotating impellar that cuts the meat into thin flakes (Claus and others 1994). Chopping decreases meat particle size at a high rate of speed utilizing rotating knives in a metal rotating bowl. Most chopping is accomplished under vacuum to decrease incorporation of air.

Mechanical agitation as previously stated aids in myofibrillar protein extraction. Tumbling is the rotation of meat and brine in a stainless steel drum with baffles that agitate meat pieces to extract myofibrillar proteins. Adequate tumbling is important because it has a direct impact on product quality, texture and appearance (Lin and others 1990). Tumbling can be accomplished with or without vacuum. Vacuum tumbling extracts air from the system allowing for increased protein-protein interactions that accelerates protein extraction by "opening up/unfolding" the structure of meat proteins, allowing easier incorporation of salt and/or phosphate into the meat. Massaging is a similar process to tumbling but less rigorous. The massaging process involves rotating of meat pieces against themselves and the surface of the metal drum (Cassidy and others 1978). Mixing is the mechanical incorporation of meat and brine in a metal hopper at slow speeds by ribbons, paddles, or solid flight agitators. The agitators are horizontally attached and usually rotate in opposite directions (Hall and others 1986). The mixing process can also be performed with or without vacuum and mixing speed is adjustable. Adequate tumbling/massaging/or mixing times are required as improper times can result in products with poor texture. Mechanically agitating a product too long can result in rubbery texture from over-extraction myofibrillar proteins and too little can create soft texture from under-extraction (Lin and others 1990).

Processors must consider raw material quality when selecting ingredients for restructured meat products. Raw meat materials for restructured products can vary in species (beef vs. chicken), quality (pale, soft, exudative (PSE) vs. dark, firm, dry (DFD)) and composition (moisture, fat, and connective tissue). The restructuring process allows for the inclusion of lower value meat cuts to be formed into a higher value product. Poorer quality meat products such as PSE pork and DFD beef can contribute to color variation and instability, cook yield variations and poor meat binding in restructured meat products (Schmidt and Trout 1984; Trius and others 1994b). Restructuring also allows for tough pieces of meat with more connective tissue to be utilized due to particle size reduction (Huffman and Cordray 1982).

Non-meat ingredients are added to restructured meat products to improve water binding and retention, sensory and textural attributes (Gillett and Carpenter 1992), particularly in the manufacture of added water restructured products. Water is a unique di-polar molecule that is attracted to the electrically charged groups of meat proteins (Aberle and others 2001). This di-polar characteristic provides a basis for water's interactions, binding, and water holding capacity (WHC) with the meat proteins. Water is traditionally a carrier of non-meat ingredients as most are water-soluble or can be dispensed in water with agitation for subsequent addition to meat (Miller 2000).

Protein- and carbohydrate-based non-meat ingredients, soy protein, sodium caseinate, starches, carrageenan and methylcellulose can aid in the binding and retention of larger volumes of added water in restructured meat products. The challenge is to manufacture a restructured product with adequate water binding, minimal purge (released water) and acceptable sensory attributes utilizing proper non-meat ingredients to enhance

these properties within the meat system (Osburn 1996). The addition of protein-based ingredients such as soy proteins results in better binding and improved texture of meat products (Megard and others 1985; Alvarez and others 1990; Ahn and others 1999). A carbohydrate-based ingredient such as modified food starch reduces cooking losses, improves sensory attributes, and textural cohesiveness (Troutt and others 1992). The use of hydrocolloid gums, such as carrageenan improves water holding capacity, uniformity, sliceability, and texture (Trudso 1985). Additionally, methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC) are hydrocolloid gums that have some purge controlling attributes (Steinke 2001) in addition to improved tenderness and juiciness attributes (Hill and Prusa 1988; Mittal and Barbut 1993; Steinke 2001).

This thesis research was conducted in two studies. The objective of Study I was to investigate the effects of MC, HPMC, and kappa carrageenan (KC) individually on water binding, water retention and quality characteristics in water solutions, brine solutions, and a restructured high-moisture ham model meat system. This study determined the hydrocolloid type(s) and levels that may enhance product properties when used in high added water restructured meat products. The objective of Study II was to investigate the effects of incorporating hydrocolloid brine solutions into a high-moisture (45% added water) restructured ham product on cook yield, purge, sensory and textural attributes.

This thesis is formatted as four chapters. Chapter 1 is the review of literature. Chapter 2 covers in detail, the materials and methods used in Study I and II. Appendices are provided with step by step procedures for all protocols and procedures used for each

study. Chapters 3 and 4 are presented in a scientific manuscript format according to the Journal of Food Science style guide.

CHAPTER 1

LITERATURE REVIEW

I. Fresh Meat Properties

Functional properties are defined as the physical or chemical properties within meat proteins that affect their behavior during processing, storage, and consumption (Kinsella 1976; Smith and Culbertson 2000). Functional properties affect product quality and sensory attributes, thus the understanding of proteins' principal components (myosin, actin, other myofibrillar proteins) is necessary. They also dictate the protein's usefulness to the processor, its appeal to the consumer and its ability to be further processed (Aberle and others 2001). Fresh meat protein properties of particular importance are protein solubility, water-holding capacity (WHC), color, and structure, firmness and texture.

Solubility of meat proteins is determined primarily by the amino acids on the surface as well as external factors such as pH and salt addition (Smith and Culbertson 2000). The pH of the meat at the isoelectric point (IP) of 5.0 is ideal for myosin protein-protein interactions. At the IP negative and positive charges of proteins (myosin) are equal, which increases protein-protein interactions and decreases protein-water interactions. A decrease in WHC and textural quality is seen in meat at the IP. At a pH range above or below the IP (5.0) electrostatic repulsion between protein molecules increases and solubility is enhanced. Protein solubility is also a function of salt concentration. As salt concentration is increased, solubility of meat protein will increase, thus allowing for increased WHC due to the extraction of myosin. Salt at a concentration

of about 6.0% solubilizes myosin proteins (Frank 2000) although, typically, 1.5 to 3.0% salt is added to cured meat formulations. The addition of salt allows for meat proteins to swell up to twice their normal size by binding the chloride ion to the protein filaments. Binding with the chloride ion shifts the isoelectric point and increases electrostatic repulsive forces between proteins (Offer and Trinick 1983; Lewis and others 1986; Belton and others; 1987; Miller 2000). The repulsive forces allow proteins to unfold and then swell. The swelling of the proteins provides a higher number of side chains (Lindsay 1985) that can bind water and increase WHC.

Water-holding capacity (WHC) is the ability of meat to retain endogenous or added water during application of external forces such as grinding, heating, cutting or pressing (Hedrick and others 1989; Aberle and others 2001). Raw meat color, texture, firmness, cooked meat juiciness, and tenderness are all dependant on WHC. During normal slaughter and fabrication processes where carcasses are subjected to chilling, generated adenosine triphosphate (ATP) and glycogen converted to lactic acid causes muscle pH to fall from 7.4 to an ultimate pH of 5.4 -5.8 (Hedrick and others 1989; Aberle and others 2001). This drop in pH and onset of rigor alters cellular and extracellular components which contribute to WHC (Offer and Knight 1988). Water holding capacity is also dependant upon bound, immobilized, and free water within the muscle tissue (Northcutt and others 1994). For this reason, processors focus on retaining these different forms (bound, immobilized, free) but primarily free water with non-meat ingredients such as salt and phosphate.

Muscle color is an impression seen by the eye and is dependant upon the light source as well as the consumer (Aberle and others 2001). Consumers relate the color of

raw meat with freshness (Adams and Huffman 1972). Color also varies with the type of processing method utilized such as cured versus uncured and raw versus cooked. Myoglobin is the primary pigment found in muscle. Myoglobin consists of a globular protein portion called globin and a non-protein moiety called heme. The degree of myoglobin present in muscle varies within species of animal, age, sex, and muscle type. For example, as the chronological age of the animal increases, the quantity of myoglobin in muscle increases resulting in a darker meat color (Kauffman and Marsh 1987). This darker color (age or DFD) creates less consumer appeal in a raw meat product (Nold and others 1999).

Rigor state, intramuscular fat and connective tissue content contribute to meat firmness, structure and texture. As muscle is converted to meat there is progressive rigidity to the muscle fibers. This creates increased firmness because of rigor mortis, and solidification of fat within muscle (Aberle and others 2001). Yet, with carcass aging there is increased enzymatic degradation improving tenderness and palatability. Muscle structure is related to WHC. Muscle tissues with poor WHC exhibit a soft, loose structure with a grainy texture compared to tissues with greater WHC which exhibit firm structure and dry texture (Lin and others 1990; Aberle and others 2001). Furthermore, intramuscular fat "marbling" has a positive effect upon muscle firmness and texture, flavor and juiciness. Wood (1985) suggested that leaner pigs have an increased likelihood of drier, less juicy products.

Collagen connective tissue contributes to meat toughness and overall texture of meat products (Whiting 1989). Older animals and muscle groups used for locomotion (chuck, round) have high numbers of insoluble collagen cross-links (Bailey 1984). The

restructuring process including particle size reduction allows for a decrease in detectable amounts of collagen when restructured steaks were evaluated by a sensory panel (Booren and others 1981). For example, 12-30% of consumers determined that restructured steaks manufactured with a high amount of gristle (16.4 mg/g total collagen) were acceptable but not preferred over low-gristle steaks (9.4 mg/g total collagen) (Berry and others 1988). Furthermore, trained panelists found blade tenderized, restructured roasts with high amounts of collagen (17.91 mg/g) to be less flavorful, juicy, and tender than trimmed steaks with less (11.13 mg/g) gristle (Flores and others 1986).

II. Properties of Water and Water Binding in Raw Meat Products

The ability of meat to hold water during processing, packaging, storage and ultimately consumption is critical. Important functional properties that determine finished product quality include water binding and water holding ability of the meat product (Whiting 1988). Water holding capacity (WHC) is necessary not only from an economic standpoint for the meat processor (higher yields) but also for the consumer (more palatable, juicier product). The amount of water added and its classification (bound, immobilized, or free) within meat profoundly influences meat quality (Northcutt and others 1994).

Properties of Water

Water is a unique di-polar molecule that is attracted to the electrically charged groups of meat proteins (Aberle and others 2001). This di-polar characteristic provides a basis for water's interactions and binding with the meat proteins. Water comprises 75%

of skeletal muscle, four times greater than any other chemical component of meat. The functional properties of muscle proteins rely largely on their ability to bind and retain water (Northcutt and others 1994).

Water in meat is classified as bound, immobilized, and free, according to its form of muscle fiber binding (Hamm 1972; Honikel 1987). Bound water is 4-5% of total water in muscle tissue (Aberle 2001; Anonymous 2003. It is associated with the surface of proteins by dipole-dipole interactions and hydrogen bonds to form a single layer on the surface of the protein binding to the muscle fibers. Bound water is never released from muscle tissue even if processed (heated, frozen, freeze dried, etc.) because it is held tightly to the muscle fibers.

Immobilized water is 16-17% of the total water in muscle tissue. Juiciness of meat products is defined by the amount and state (room temperature vs. heated vs. frozen) of immobilized water (Borisova and Oreshkin 1992). Immobilized water is not bound as tightly to the protein molecules; it is released during processing and is affected by environmental conditions such as heating, cooling, and pH. Immobilized water influences the product's ability to retain water during processing.

Free water comprises the largest percentage of total water in muscle at 79%. Capillary forces hold the free water with limited ordering of their molecular structure and their orientation is highly independent of the charged groups (Anonymous 2003). Free water is easily lost via "weep" or "drip" in fresh cuts of meat, or purge in vacuum packed processed products (Hedrick and others 1989). For this reason, processors focus on binding free water by increasing protein hydration with different forms of non-meat ingredients such as salt and phosphate.

Water Binding Capacity

The terms water binding capacity (WBC) and water-holding capacity (WHC) are commonly used interchangeably throughout literature. They are defined as the amount of water that is bound or retained by myofibrillar proteins with the application of external forces such as cutting, heating, grinding, or pressing (Hedrick and others 1989; Smith and Culbertson 2000; Aberle and others 2001). Water binding capacity determines raw meat and cooked meat quality through the binding of tissue water and added water with myofibrillar proteins (Hamm 1960, 1985, 1994; Offer and Knight 1988). Altering of cellular and extracellular components due to changes in pH, onset of rigor, and carcass aging each affect WBC (Offer and Knight 1988) and can change the meat's functional properties (Northcutt and others 1994). Furthermore, the development of heat-set protein gel during thermal processing, from extracted myofibrillar proteins, can also contribute to water binding and retention abilities of the final product (Asghar and others 1985). Water holding capacity in turn has an influence upon cook yields, purge, color, and even texture of the final product.

Added Water

Water is the cheapest non-meat ingredient source ideal for increasing the profitability of meat products for processors. Of all the non-meat ingredients, water constitutes the largest percentage and, as a result, it is almost always listed first on the ingredient label in water added meat products. Specific product labeling must define the amount of water added in order for the meet USDA-FSIS approval (Miller 2000).

Added water in conjunction with non-meat ingredients assists in reducing cook loss and compensates for moisture typically lost during thermal processing of a meat product (Romans and others 1994). It is traditionally a carrier for non-meat ingredients as most non-meat ingredients are water-soluble or can be dispensed in water with agitation for subsequent addition to meat (Miller 2000). However, the addition of water may have a negative impact on meat flavor and shelf-life. Water dilutes out the meat flavor and increases water activity, therefore, provides more free water for microbial growth. The increase of microbial growth decreases meat shelf-life. Furthermore, Prabhu and Sebranek (1997) stated that as the amount of added water increases in restructured meat products, the ability to retain water during thermal processing and minimize purge during storage decreases without the use of purge controllers. Claus and others (1990) demonstrated that the addition of high amounts of water (30%) decreased bologna product firmness, cohesiveness while increasing cook loss and purge.

III. Properties of Restructured Meat Products.

Color

Color is the hue (red, green, blue, etc.) that is detected by the eye. The color of meat products is a prime factor by which consumers judge their acceptability and product selection (Secrist 1982; Chen and Trout 1991). Myoglobin is the primary muscle pigment and the degree of myoglobin present in muscle varies with species of animal, age, sex, and muscle type. Furthermore, the use of lower quality meat raw materials such as PSE pork, can decrease cook yields, meat binding, and decreased color perception

(Wismer-Pederson 1960a, 1960b; Davis and others 1975; Jerimiah 1986; Honkavaara 1988 1990). Shand and others (1995) proved that utilizing PSE pork in cured bone-in ham significantly decreased cook yields, juiciness, flavor, and developed a lighter cured color. It has been shown that the addition of water dilutes the myoglobin (Miller 2000) which results in a paler product color. Akamittath and others (1990) have also demonstrated that restructured beef streaks manufactured with 1.5% salt displayed higher color instability and fat oxidation when compared to treatments with phosphate (0.2%) and tocopherol (0.02%). In another study, restructured beef steaks manufactured with salt (1.0%) and phosphate (0.5%) initially demonstrated the highest color scores (more red color) initially but after a 12 week storage time had the lowest color scores (more brown) when evaluated by a trained panel (Chen and Trout 1991).

Meat Binding and Sliceability

Restructured meat processing procedures such as chunking, grinding, mixing or tumbling allow for efficient brine migration into the meat, enhance the extraction of salt soluble myofibrillar proteins and increase meat protein binding (Krause and others 1978; Ockerman and Organisciak 1978). Yet, to achieve adequate meat protein binding in restructured added water (10-40%) meat products the proper selection and addition of non-meat ingredients is critical. Non-meat ingredients are used to improve protein binding and WHC in processed meat products (Maurer 1979). In addition, they are also used to increase protein content, fat binding properties, or slicing characteristics (Pearson and others 1996). For example, restructured hams containing soy protein isolate (SPI) were found to have higher meat binding strength than control hams (Siegel and others

1979). Alvarez and others (1990) found that the addition of starch (30%) significantly increased meat binding, shear values, and tensile strength when compared to SPI (10%) in restructured mechanically deboned chicken. These beneficial properties of non-meat ingredients allow for increased product quality and consumer satisfaction. Furthermore, Shand and others (1994) demonstrated that while cooking temperature had no significant effect ($P<0.05$) on meat binding in restructured beef rolls, the addition of higher levels of kappa carrageenan (0.5-1.0%) improved binding shown by increased hardness and force to fracture results. Oven roasted turkey breasts containing 0.5% kappa carrageenan (KC) had higher sliceability values than the control turkey breasts (Bater and others 1992).

Cook Yield and Purge

Addition of water to restructured meat products results in "extending" meat proteins and increasing product cook yields (Prabhu and Sebranek 1997). Due to the increased use of purge controllers such as SPI and KC, cook yield values are rising considerably. Although water may be bound during the cook process, SPI and KC may not have the ability to retain the water once packaged. Purge is the loss of water released during storage, which is mostly seen in the product's package at the retail case. This results in consumers shying away from products that have poor appearance due to high amounts of released fluid in the package (Chen and Trout 1991). Siegel and others (1979) demonstrated that water binding induced by SPI increased cook yields and enhanced the meat-to-meat binding by minimizing the effect of excess water on extracted myofibrillar proteins (Siegel and others 1979). Shand and others (1994) reported significant decreases in purge values when utilizing KC at 0.5% and 1.0% in structured

beef rolls. Furthermore, Prabhu and Sebranek (1997) also demonstrated a significant decrease in purge values utilizing KC at 1.5% in ham. However, there is still considerable use of conventional brine solutions (salt, phosphate, cure) that result in lower cook yield values and higher purge values. Acton (1983) found that a traditional brine solution dilutes protein exudates which resulted in decreased cook yields.

Textural Attributes

Texture is a dominant quality characteristic in cooked meat products (Bourne 1982). Textural attributes such as hardness, cohesiveness, and chewiness can be evaluated by a sensory panel (trained, semi-trained, or consumer) or mechanical device (texture analyzer). The addition of water creates a meat protein dilution effect resulting in a softer textured product (Claus and others 1989). Yet, the addition of non-meat ingredients has allowed for an increase in textural attributes. The addition of carrageenan, SPI, phosphates, and salt improves product texture. DeFreitas and others (1997) noted that the addition of KC at 0.5% increased hardness of cooked linked pork sausage when compared to those with no KC. Improved textural attributes such as hardness, binding, and force to fracture values were also documented for structured beef rolls with 0.5%-1.0% KC (Shand and others 1994). Furthermore, beaker pork sausage manufactured with 0.5% KC had increased firmness values (Trius and other 1994b). Textural improvements in restructured meat products is necessary as they are conveying the importance of meat and water binding to make a cohesive, texturally acceptable product.

IV. Functional Properties of Proteins.

Protein Interactions

The production of restructured meat is dependent upon water, fat, and protein binding during processing for acceptable texture after thermal processing. The myosin or actomyosin proteins must be suspended, solubilized, denatured and then aggregated by heat (Gaska and Regenstein 1982; Acton and Dick 1984; Ziegler and Acton 1984) to form a cohesively bound finished meat product. The functionality (hydration/solubility) of myosin during meat processing has a direct impact on yield, texture, moisture and appearance. In the manufacturing of "emulsion type" products the formation of a stable meat batter is the balance between protein-water and protein-protein interactions (Whiting 1987). Meat binding properties can be divided into three categories: 1) protein-water interactions, 2) protein-fat interactions, and 3) protein-protein interactions. These interactions are also influenced by types and amounts of non-meat ingredients added to the formulation and by the processing conditions used (Shand and others 1993; Smith 2001). For example, non-meat ingredients such as salt, soy protein and carrageenan increase meat binding, WHC, and texture by extracting myofibrillar proteins from the meat to serve as a binder between the meat pieces (Siegel and Schmidt 1979). These non-meat ingredients enhance protein-water and protein-fat interactions thus increasing product yields by creating a network between the meat protein and the non-meat ingredient.

The ability to bind and retain added water is an important functional attribute in meat products. To increase the meat product's WHC, protein-water interactions need to

be optimized. In order to enhance and maintain protein-water interactions, protein extraction and solubility are necessary. The most important meat proteins for WHC are the salt-soluble proteins (Gillett and others 1977) that are extracted with typical salt levels of 1.5-3.0% in processed meat products; although higher levels (4-8%) may be used for dry-cured hams and sausages. As the concentration of salt is increased (1.0 vs. 1.5%) the sodium and chloride ions bind to the charged groups on the protein fibers and weaken the intermolecular interactions between muscle fibers (Smith and Culbertson 2000). This exposes more water binding sites which increases protein-water interactions and decreases protein-protein interactions. If meat proteins are not solubilized during extraction the final cooked product has poor water binding and a brittle texture (poor sliceability). Additionally, the pH and temperature during processing affects the extractability of muscle proteins. To optimize myofibrillar protein extraction, a pH of approximately 6.0 (Solomon and Schmidt 1980; Dutson 1983) and a temperature between 2-4°C are needed (Osburn 2001).

Protein-fat interactions are important because fat impacts product flavor, texture and mouth-feel. Protein and fat droplets bind together and create a cross-linking matrix between protein and fat that helps lock in moisture by forming a hydrophobic bridge that seals in water. This matrix gives the meat product a smoother, firmer texture, and added juiciness. However, the degree to which protein-fat interactions are needed for finished product quality is still being investigated. Areas and Lawrie (1984) reported that further research is required to determine the degree of protein-lipid interactions to maximize protein-water and protein-protein interactions.

Protein-protein interactions can create adverse finished product attributes. Myofibrillar proteins "prefer" protein-protein interactions resulting in poor product texture, increased purge and tough texture (Uram and others 1984; Hand and others 1987; Claus and others 1989). The pH of the meat at the IP of 5.0 is ideal for myosin protein-protein interactions. At the IP negative and positive charges of myofibrillar proteins are equal, which increases protein-protein interactions and decreases protein-water interactions. Therefore, a decrease in WHC and textural quality is seen in the meat product. However, there are processed meat products that require lower pH values resulting in increased protein-protein interactions. Dry sausages such as pepperoni and summer sausage require a pH lower than 5.0 to increase product flavor and decrease water content. As the pH moves away from the IP, there is a decrease in the number of protein-protein interactions and an increase in protein-water interactions allowing for improved product quality.

For the formulation of a quality processed meat product all three properties (protein-water, protein-fat, protein-protein) must be taken into consideration when selecting final product qualities. Each of the properties are equally important in meat processing, with protein-water interactions being the most influential on increased WHC.

Effect of pH

The pH of meat is important as it influences the WHC, texture and tenderness of meat (Dutson 1983). The pH at which the WHC is at its minimum (~5.0) corresponds to the IP of myosin as well as the myofibril (Offer and Knight 1988). The net charge of the myosin is at its minimum (0) which increases bonding between the proteins. This

increase of protein-protein interactions decreases protein solubility and its ability to bind with water and create protein-water interactions. To increase muscle water binding, the pH of the proteins must move away from the IP which increases electrostatic repulsion between protein molecules thereby enhancing protein solubility. At higher pH levels, the proteins become more negatively charged, thus repelling each other and allowing for the myofibrillar proteins to swell and retain water, resulting in increased WHC (Hamm 1994; Osburn 2001). To create a more optimum environment for both water binding and protein solubility, non-meat ingredients can be added to the meat product. For example, sodium tripolyphosphate (STP) can adjust the meat pH protein net charge (-OH) toward the alkaline side of the pH scale and improve the meat's water binding ability due to an increase in pH. In general, a pH at 6.0 is the most effective at increasing water and processed meat binding. At pH 6.0, the gelling and binding of proteins myosin and actomyosin is ideal (Dutson 1983).

Addition of Non-meat Ingredients

To manufacture restructured meat products with acceptable textural attributes meat processors utilize non-meat ingredients/additives such as salt, phosphate, KC, SPI, and starches. Non-meat ingredients are defined as any type of non-animal based ingredient that is allowed as an additive in meat products by the United States Department of Agriculture (USDA), and the Food Safety and Inspection Service (FSIS) (Pearson and Gillett 1996). They are added to fresh or processed meat product formulations to improve juiciness and/or tenderness, enhance flavor, stabilize or improve color, increase shelf life, control microbial growth, or increase the WHC of a product

(Miller 2000). In addition, they are also used to increase protein content, improve emulsion stability, fat binding properties, or slicing characteristics (Pearson and Gillett 1996). These beneficial properties of non-meat ingredients allow for increased product quality and consumer satisfaction.

Sodium Chloride

Sodium chloride (NaCl) or salt was historically added to meat for preservation purposes when refrigeration was not available. For this application, high levels of salt were either rubbed on the exterior surface or attained by placing the meat into a highly concentrated salt brine for an extended period of time (Miller 2000). The high level of salt decreases water activity, consequently reducing microbial growth and rancidity that contributes to spoilage (Romans and others 1994). However, sodium reduction has been recommended in human diets to decrease hypertension, stroke and renal failure (Sebranek and others 1983). Although the decrease of salt is associated with decreased health risks, it has adverse effects on processed meat quality. Reducing salt by 40% in a frankfurter batter caused an extensive loss of water binding ability and reduced gel strength (Whiting 1984).

Salt is an important ingredient in processed meat products for three primary reasons: 1) it solubilizes proteins to create desired texture, 2) it provides flavor, and 3) it controls microbial growth (Ingram and Kitchell 1967; Rust and Olson 1988). Salt, at a concentration of about 6.0%, solubilizes myosin proteins (Frank 2000). Typically, 1.5 to 3.0% salt is added to cured meat product formulations, with the bulk of the salt added initially to the meat block. This allows the salt soluble myofibrils to swell to twice their

normal size by binding the chloride ion to the protein filaments. Binding with the chloride ion shifts the isoelectric point (-OH) and increases electrostatic repulsive forces between proteins. The repulsive forces allow proteins to unfold and then swell. The swelling of the proteins provides a higher number of side chains (Lindsay 1985) that can bind water and increase WHC. Hamm (1981) showed that salting prerigor or postrigor sausage formulations increased WHC. Furthermore, improved WHC, cooked color scores, and sensory attributes were seen in restructured pork products with 0.75% salt (Schwartz and Mandigo 1976).

Phosphate

Phosphates manufactured from salts of phosphoric acid, include orthophosphates with a single phosphorus atom and polyphosphates with two or more phosphorus atoms (Shimp 1981; Sofos 1986). The basic chemical function of phosphate is to control pH by acting as a buffer to sequester metal ions and increase ionic strength of solutions (Halliday 1978; Steinhauer 1983). Phosphates sequester the ions and increase ionic strength by acting as a polyvalent ion. As the ionic strength of the phosphate increases, the phosphate anions align with oppositely charged groups of proteins, and cause more repulsion between protein molecules which increases the volume of open filament spaces (Barbut and others 1988). This repulsion subsequently enhances WHC by allowing the increase water volume within the protein structure. The allowable limit for phosphates in meat products is 0.5% of the finished product weight (USDA-FSIS 2002).

Of the phosphates used in the meat industry, STP is the most popular. They account for 80% of the phosphates incorporated either as a single phosphate or in blends

(Barbut and others 1988). Phosphates influence water binding, color, texture, coagulation, emulsification, and microbial growth as a result of their chemical effects and reactions with food components (Barbut and others 1988; Dziezak 1990). The addition of about 0.4% polyphosphates to comminuted, cured meat products such as sausages, frankfurters, and bologna, accelerates cure color development, improves protein binding, stabilizes emulsions to prevent fat cook-out, and reduces requirements for curing ingredients (Dziezak 1990). Adding phosphates to cured meat and frozen whole meat decreases the loss of natural juices that occurs from the slaughter to packaging (Dziezak 1990). Fresh meat's loss of natural juices from slaughter to packaging leads to tough texture, reduced juiciness, and susceptibility to freezer burn. When used with salt, phosphates can increase water binding or retention of the fresh meat's immobilized and free water. Additionally, restructured pork products with STP levels of 0.125 to 0.5% improved WHC, while decreasing cook loss and package purge (Schwartz and Mandigo 1976).

Phosphates also enhance sensory characteristics of meat products such as tenderness, overall acceptability, and reduction of warmed-over flavor (Smith and others 1984; Jones and others 1987). Pork roast containing added phosphates were judged by sensory panelists to be more tender, and juicy, with less off-flavor and more palatability than roasts containing acetic acid, sodium ascorbate or the control (Boles and Parrish 1990). Sensory panelists evaluating restructured pork found that STP at 0.375% significantly ($P<0.01$) improved eating texture and flavor when compared to restructured pork with 0.5% STP (Schwartz and Mandigo 1976). Phosphates also help prevent the development of off-flavors and off-odors by inhibiting rancidity in processed meats

(Ellinger 1972). For example, when added to ground pork patties it reduced thiobarbituric acid (TBA) values, a common measurement of lipid oxidation (Keeton 1983; Miller 2000). Further research also showed that lipid oxidation could be inhibited in restructured beef, pork, and turkey steaks for 4, 6, and eight weeks respectively with the use of phosphates at 0.3%. However, off-flavors have been reported when phosphates were added to meat products. When STP was added to beef and pork roasts, panelists sometimes detected a metallic and soapy flavor (Smith and others 1984; Vote and others 2000). Samples with 0.5% phosphate were significantly more soapy than samples without or with lower levels of phosphate (Craig and others 1991).

Carrageenan

Carrageenans are hydrocolloids composed of sulfated linear polysaccharide units extracted from red seaweeds. The polysaccharide chain of carrageenan consists mainly of potassium, sodium, magnesium, calcium, and ammonium sulfate esters of galactose and 3,6-anhydrogalactose copolymers (Glicksman 1969; Glicksman 1983). They are generally recognized as safe (GRAS) by the United States Food and Drug Administration (FDA). During enhanced meat processing, the processes in which a percentage brine solution is added to increase meat functionality, carrageenan is first dispersed within a brine solution, introduced into the meat by injecting or mixing, and finally dissolved within the meat by thermal processing. The carrageenan solution together with meat forms a firm and cohesive gel structure with the meat protein upon cooling (Trudso 1985). This gelling capability makes carrageenan particularly suitable for processed meat products by improving WHC, consistency, sliceability, and texture of meat and poultry

products especially with high levels of added brine (Trudso 1985). Carrageenan forms a stable structure above pH 7; it degrades slightly at pH 5-7 and degrades rapidly below pH 5.

Three major available types of carrageenan are designated kappa, iota, and lambda. Kappa and iota form thermoreversible gels upon heating and cooling and lambda is a nongelling gum, typically used as a thickener. Additionally, at least four other types of carrageenan are recognized: mu, nu, theta, and xi (Trius and Sebranek 1996) but these types are not used in the commercial meat industry at this time.

Kappa carrageenan (KC) has alternating 1, 3 linked D-galactose 4-sulfated and 1,4 linked anhydro-D-galactose units. Kappa exhibits gelling capacity with a greater sensitivity to potassium to form stronger gels. However, these gels are brittle and apt to undergo syneresis. Brittleness can be reduced by the addition small amounts of locust bean gum (Daniel and Weaver 2000) and other non-meat ingredients such as NaCl, potassium chloride, STP. In order to solubilize KC, heat is applied which then creates a gel upon cooling. The KC begins to solubilize and swell at 46°C, completely solubilizes at 66°C, and then starts to gel with the meat proteins when cooled to 44°C (Trius and Sebranek 1996).

Iota carrageenan (IC) is composed of alternating 1,3-linked D-galactose 4-sulfate and 1,4 linked 3,6 anhydro-D-galactose 2-sulfate. It forms more elastic gels than kappa in the presence of potassium cations (Trius and Sebranek 1996). Yet, when calcium cations are present, IC forms relatively strong gels in contrast to KC, which forms weak gels (Rees 1972). Neither iota nor kappa carrageenans are found in pure form, but rather

as mixtures. As a consequence, a small amount of IC is present with KC and vice versa (Trius and Sebranek 1996).

Lambda carrageenan (LC) has 1,3 linked D-galactose 2-sulfate and 1,4 linked D-galactose 2,6 disulfate units. Aqueous solutions of LC are viscous but do not gel (Rees 1969) due to the lack of the 3,6-anhydro-D-galactose units as found in kappa and iota carrageenan (Rinaudo 1988). Additionally, LC is the only type of carrageenan that is not hot water soluble.

Soy Protein Isolate

Soy protein isolate (SPI) is one of the most useful non-meat ingredients (Siegel and others 1979). The major utilization of SPI is to extend meat products with less expensive materials (i.e. water) without introducing egregious flavors, or decreasing the binding quality of the final product (Siegel and others 1979). Soy protein isolate is made from dehulled and defatted soybean flakes (Soy Protein Council 1987). The defatted soybean flakes are then treated with mild alkali to the extract protein. It is then centrifuged to remove the insoluble fibrous residue from the protein. The protein precipitate is conditioned by washing it multiple times and then spray dried to yield SPI (Soy Protein Council 1987). This process results in an isolate that is at least 90% protein with increased digestibility (91-96%) and with increased palatability (Mustakas and Sohns 1976; Soy Protein Council 1987). For example, increased palatability was seen in a study utilizing SPI, taste panelists preferred turkey rolls extended with SPI over non-extended turkey rolls (Kardouche and others 1978).

Soy protein isolate is compatible with a wide range of processing equipment and procedures. It is easily dispersed and increases brine retention in meat products. The United States Department of Agriculture (USDA) permits up to 2% added SPI individually or collectively with other approved extenders such as soy protein concentrate or non-fat dry milk (Soy Protein Council 1987). When SPI is used, 2% addition of SPI is equivalent to 3.5% of other soybean products such as concentrate, flour and grits. Hawley and Tuley (1976) developed a method of introducing SPI into the brines commonly used in the production of cured meat items (Siegel and others 1979). After brine injection, massaging/tumbling is required to distribute the brine uniformly throughout the muscle. Solubilized SPI used in this manner increases cook yield by 30% or more while maintaining a protein content of at least 17% as proposed by the USDA for combination meat products (Siegel and others 1979).

Modified Food Starch

Starch has traditionally been used in meat products to improve quality and to extend the more expensive meat fraction of the product (Skrede 1989). It is a low cost approved ham purge controller that has minimal flavor, especially when compared to SPI. Starches are polysaccharides that consist of repeating glucose units. Starch molecules have one of two molecular structures: a linear structure, known as amylose; and a branched structure known as amylopectin (Hegenbart 1996). Amylose and amylopectin associate through hydrogen bonding and arrange themselves radially in layers to form granules of starch. Granule size and shape can change greatly due to type of starch and degree of chemical modification. For example, the size of a starch granule can range

from 3 microns to over 100 microns. Furthermore, countless varieties of starches can be isolated from many different sources such as corn, potato, rice, tapioca and wheat. The chemical modification process for potato starch cross-binds phosphorous groups, and masks hydroxyl groups with acetyl groups (Skrede 1989). This results in changed molecular properties and functionality (Howling 1980). In addition, each type of starch differs in amylose and amylopectin content as well as granule size and structure. Generally speaking, the amylose gives gel strength and the amylopectin gives high viscosity to solutions. Amylose structures can easily align themselves and associate through hydrogen bonding to form gels (Hegenbart 1996). On the other hand, amylopectin molecules cannot align as easily, thus giving weaker gel strength and less hydrogen bonding.

Sodium Caseinate

Sodium caseinate (SC) is a milk protein. Casein and its caseinate derivatives have functional and nutritive properties which make them useful worldwide (Southward 1985). In addition to availability and high nutritive value, they provide smooth texture and bland flavors (Konstance and Strange 1991; Keeton 2001). Dairy/milk proteins are not to exceed 3.5% by weight of finished products to be labeled as meat. (Frank 2000). Sodium caseinate contains 90% protein, is completely water soluble, absorbs at the fat/water interface in meat emulsions, contributes significantly to binding and firmness, but has no gelation capabilities (Anonymous 2001). In addition, SC's are soluble and viscous in neutral (pH=7.0) or alkaline conditions (pH>7.0) (Jonas and others 1976).

V. Challenges in Raw Meat Manufacturing of Added Water Meat Products.

Raw Meat Quality

Meat processors have tried to select high quality raw materials to create a quality final product. Lower value meat cuts are those that possess marginal to poor quality (Miller 2000). These cuts are likely to be inconsistent in color, lack tenderness and juiciness. Pale, soft, and exudative (PSE) pork and DFD beef are two examples of lower quality raw materials. Pale, soft, and exudative pork is soft in texture, paler in color and wetter on the meat surface due to poor water binding properties. Pale, soft, and exudative pork is a stress related disorder (Motzer and others 1998) that affects 10-30% of all pork carcasses (Miller 1989). The PSE condition occurs when postmortem glycolysis is rapid while carcass temperature is still high (Miller 1989). This combination causes protein denaturation which promotes poor water-holding ability, increased meat softness, purge, and paler color (Trius and others 1994b). For example, restructured ham manufactured with PSE pork demonstrated lower chill yield values, more expressible moisture, and lighter color than normal and 50% normal and 50% PSE hams (Motzer and others 1998). The PSE condition also results in tough and dry cooked products. On the other hand, DFD meat is higher in pH (>6.2), darker in color, firmer in texture and possesses a drier meat surface. Dark, firm and dry meat has a higher water holding capacity which is beneficial for high added water products but has an unacceptable raw meat appearance. Dark, firm and dry pork is due to stress over a period of time which results in the depletion of muscle glycogen (Pearson and Tauber 1984). The DFD condition also affects processed meat quality. For example, the use of DFD meat in the canning

industry causes residual pinkness (Schmidt and Trout 1994). It also increases the microbial spoilage due to the high meat pH and can create "glazy" bacon (Pearson and Tauber 1984).

Manufacturing Technologies

Processing technologies such as comminution, addition of non-meat ingredients, thermal processing, and packaging are used to improve product tenderness, juiciness, and uniformity of color and texture. A key processing principle for manufacturing restructured meat products is the binding and retention of added water. This may be accomplished through the injection of brine solutions into pieces or by direct addition to the meat pieces in a tumbler or mixer. In the restructuring process, products are made from muscle groups that are partially or completely comminuted and reformed to resemble whole muscle. Restructuring uses three basic concepts: chunking and forming, flaking and forming; and tearing and forming (Pearson and others 1996). Restructuring allows for portion control, easier slicing, and more accurate predictions of cook yields (Pearson and Tauber 1984). However, the restructuring process does create problems with color instability and lipid oxidation. Akamittah and others (1990) found that color stability and lipid oxidation are highly correlated. Further research also showed that lipid oxidation could be inhibited in restructured beef, pork, and turkey steaks for 4, 6, and eight weeks respectively with the use of phosphate and salt at 0.3% and 1.5%. Additionally, the restructuring process is a time consuming application that requires additional machinery and labor. It allows for microorganisms to enter the meat while being further processed and a decrease in shelf-life due to microbial growth.

Color

Several quality problems and challenges are encountered in added water restructured meat products. The most serious of these problems are color instability and fat oxidation (Akamittath and others 1990). The color of meat products is a prime factor by which consumers judge their acceptability and product selection (Secrist 1982; Chen and Trout 1991). It has been shown that the addition of water dilutes the concentration of myoglobin, (Miller 2000) which results in a paler product color. Results suggest meat discoloration and lipid oxidation are directly correlated in a study conducted on restructured beef, pork and turkey restructured steaks (Akamittath and others 1990). In addition, the use of lower quality meat cuts (PSE, DFD) can also affect the final product color and consistency. The use of DFD meat in cured meat products increases color variability when used with normal and PSE meat. Restructured ham manufactured with PSE pork demonstrated significantly ($P<0.05$) lower cook yield values, more expressible moisture, and lighter color (Motzer and others 1998).

Binding Ability

Meat binding ability refers to the ability of meat to hold fat and added water during processing (Aberle and others 2001). The restructuring process must reassemble and bind the ground, chopped, or sectioned meat together to form a product that resembles a whole muscle upon cooking (Lin and others 1990). The addition of non-meat ingredients such as SPI and KC can increase meat binding ability. However, the key component for successful restructured meat binding is protein extraction. Mechanical processing procedures such as tumbling, massaging, and mixing can enhance

meat protein extraction. For example, tumbling sectioned and formed ham can aid in the migration of cure and increase the extraction of salt soluble proteins, thereby increasing the binding ability (Krause and others 1978; Ockerman and Organisciak 1978). The extraction of salt soluble proteins during tumbling forms a sticky, protein exudate which coats the surface of meat pieces and allows for binding pieces of meat together. Furthermore, tumbling/massaging/mixing promotes the cohesion of meat pieces, enhances tenderness, juiciness, increases cook yields and improves sliceability. However, determining the adequate time to mechanically extract protein can be difficult and cost ineffective initially to the meat processor. Mixing too much or too little will result in an overly bound or poorly bound and an undesirable product (Lin and others 1990; Osburn 2001). Determining the adequate mixing/tumbling time can require statistical modeling, researching competitor mechanical agitation times, or even a trial and error process.

Product Texture

Although the use of non-meat ingredients such as phosphate, salt, SPI, modified food starch (MFS), KC, and SC have been shown to improve product sensory characteristics such as tenderness and juiciness (Schwartz and Mandigo 1976; Siegel and others 1979; Smith and others 1984; Megard and others 1985; Jones and others 1987; Alvarez and others 1990; Troutt and others 1992; Ahn and others 1999), restructured meat products may exhibit soft and mushy texture after thermal processing. The addition of water creates meat protein dilution resulting in a softer textured finished product (Claus and others 1989). Soft texture and poor product appearance in added water

restructured products is directly correlated to inadequate tumbling/massaging/mixing time. Mechanically agitating the pieces for too little time will cause crumbly, soft texture and agitating for too long will cause tough, rubbery texture (Lin and others 1990). Turkey breasts with 70% added brine demonstrated watery and soft texture with poor binding as the restructured pieces were easily torn apart (Bater and others 1992)

Thermal Processing Yields and Purge

High product cook yield values after thermal processing are a desirable attribute to the meat processor from an economical standpoint. However, conventional brine solutions (salt, phosphate, cure) are still used. These "traditional" brine solutions are providing the meat processor with lower cook yield values when compared to products manufactured with additional non-meat ingredients. Acton (1983) found that a traditional brine solution diluted protein exudates and resulted in decreased cook yields. The addition of high amounts of water to decrease product costs has also increased released fluid or purge in the storage package. Purge is the loss of water during storage, which is mostly seen in the product's package at the retail case. This results in reduced consumer appeal. The addition of non-meat ingredients such as KC, SPI, and MFS can improve cook yield values and decrease purge loss. For example, the use of SPI can increase cook yields by 30% in restructured, combination meat products (Siegel and others 1979). Kappa carrageenan was shown to improve water retention in cooked pork sausage (DeFreitas and others 1997). Modified food starch has been shown to decrease cook loss values in low-fat ground beef patties (Troutt and others 1992). Finally, Van den Hoven (1987) discussed the abilities of SC for water retention and purge control.

VI. Approved Purge Controllers for Meat Products.

Purge controllers approved by the USDA-FSIS have made it possible for meat processors to increase product yields and decrease processing costs. There are four approved purge controllers for ham products: carrageenan, SPI, MFS, and SC. These ingredients each allow for increased water retention and textural enhancement of water-added, restructured meat products. In addition, they also have the ability to increase product shelf-life, binding ability, and nutritional value.

Carrageenan

The addition of KC to restructured and whole muscle meat products has resulted in increased water binding and retention. For example, restructured turkey breasts manufactured with 70% added water and 0.5% KC had 19% higher cook yield values than the control (Bater and others 1992). Prabhu and Sebranek (1997) also demonstrated higher cook yields and lower purge values in hams with 1.5% KC when compared to the control. Additionally, a study utilizing 0.5% KC and/or 0.5% LC in beaker sausage demonstrated lower cook loss values when compared to the controls (Trius and others 1994a).

In a study comparing the three major types (KC, IC, and LC) of carrageenan IC was the most effective at increasing force-to-fracture, true shear strain, and water holding ability (Foegeding and Ramsey 1987). KC is more effective than IC in increasing hardness and equivalent to IC in true shear stress (Foegeding and Ramsey 1987). Kappa carrageenan and IC also improved moisture retention of cooked pork sausage (DeFreitas and others 1997). Kappa carrageenan effectively decreased freeze-and-thaw purge of

cured turkey thigh meat (Bater and others 1993). A combination of LC and KCl was shown to decrease cooking loss of bologna (Trius and others 1994a). Lambda carrageenan has the softest texture among the three major types of carrageenan. For example, a bologna meat batter with LC was more viscous, yet the cooked product was softer in texture exposing LC's inability to create a firm gelling matrix (Trius and others 1994a). A decrease in beaker sausage firmness with LC was also seen in a study that compared LC, KC, and IC conducted by Trius and others (1994a). In conclusion, of the three forms (IC, LC, and KC) of carrageenan used in meat products, KC is the recommended form in restructured and processed products. Kappa carrageenan has been shown in numerous studies to increase cook yields, decrease purge, increase product firmness and meat binding.

Soy Protein Isolate

The addition of SPI results in better binding and improved texture of meat products (Megard and others 1985; Alvarez and others 1990; Ahn and others 1999). Soy protein isolate increases cook yield and enhances the binding of the meat pieces by minimizing the effect of excess water on extracted myofibrillar proteins (Siegel and others 1979). Furthermore, SPI provides better fat retention and increased gelling ability than other forms of soy proteins (Porcella and others 2001). It has been shown that SPI also increases the emulsifying capacity and the emulsion stability (Schweiger 1974).

Soy protein isolate also affects textural attributes, specifically firmness, tenderness, and flavor. For example, increased ham injection levels increased sensory panel scores for juiciness and tenderness (Siegel and others 1979). In another study,

utilizing restructured mechanically deboned chicken with 10% SPI improved tenderness when measured by Warner-Bratzler shear and tensile strength (Alvarez and others 1990). In contrast, increasing the level of injection of SPI in hams negatively affected overall acceptability, textural appeal, and flavor (Siegel and others 1979). Thus, proper injection level and SPI concentration level should be evaluated for ideal product quality.

Modified Food Starch

Starch has traditionally been used in meat products to improve quality and to extend the more expensive meat fraction of the product (Skrede 1989). Modified food starch gelatinizes when heated thereby binding relatively large amounts of water. In an experiment conducted comparing five different types (potato flour, modified potato starch, wheat, corn and tapioca) of starches, potato flour was rated the best suited starch for a stuffed, fresh meat sausage followed by wheat, while tapioca was the least suited (Skrede 1989). Modified food starch improved freeze/thaw stability of the sausage (Wotton and Chaudhry 1979; Howlings 1980). The chemical changes in MFS structure, including cross-binding by phosphorus groups and the masking of hydroxyl groups by acetyl groups, strengthen the starch granule by reducing the affinity between the starch molecules. In a study conducted on low fat ground beef patties, potato starch in conjunction with other non-meat ingredients reduced cooking loss and scores for oily mouth coating while increasing pattie cohesiveness (Troutt and others 1992).

Sodium Caseinate

Sodium caseinate increases water and fat binding (Keeton 2001) and is used primarily as an emulsifying agent. Sodium caseinate has been used as stabilizer for pre-emulsified fat in a reduced-fat frankfurter while helping maintain the desired texture that can be lost when salt is reduced and water is added (Su and others 2000). Sodium caseinate does not bind meat pieces well but still provides firmness and water holding capacities (purge controlling) in meat products (Van den Hoven 1987). It allows for increased cook yields and lower purge values, an important purge controlling attribute when adding high (70-110%) amounts of water to meat formulations. Furthermore, solubility and viscosity of SC were altered by addition of salts and increase in temperature (Konstance and Strange 1991).

VII. Potential Purge Controllers

To address consumer concerns with respect to diet/ health issues, the meat processing industry has focused on fat reduction by substitution of fat with added water. Replacement of fat with added water helps ensure a tender, juicy product. Hydrocolloid gums function as water-binding agents in numerous food products (Glicksman 1969) including restructured meat. They are plant derived carbohydrates that provide creamy, slippery properties that are similar to fat (Pearson and Gillett 1996). Cellulose is the most important natural polymer available through renewable sources. However, cellulose has low solubility and therefore to extend its application, a number of cellulosic derivatives have been developed (Hirren and others 1996). Two such derivatives created under these conditions are MC and HPMC. Limited research is available that investigates the incorporation of MC and/or HPMC in meat products. These non-meat ingredients may

increase product yields by improving water binding capacity while minimizing released water in the form of purge during packaging and subsequent storage.

Methylcellulose

Methylcellulose is a water-soluble, cellulose ether formed by an alkali treatment of cellulose and followed by a reaction with methylchloride (Grover 1982). It is used as a binder, emulsifier, stabilizer and thickener in a variety of food products. It thermally gels and reverses upon cooling. For example, in an aqueous solution, MC gels when heated to approximately 50°C and then reverts into a solution upon cooling below room temperature (< 22°C) In addition, MC is used in both pharmaceutical and food industries due to its ability to form excellent films (Donahowe and Fennema 1993). Currently, MC is only allowed up to 0.15% in meat and poultry products based on total product weight (USDA 2001). It is a GRAS product that assists with binding and WHC of a meat product.

In general, cellulose hydrocolloids are used to bind moisture in meat products. However, early research indicated that MC had adverse effects on cook yields, cook loss, and texture. For example, beef patties containing 1% MC or HPMC contained less moisture when compared to patties with no additive (Hill and Prusa 1988). An increase in moisture loss during cooking with the addition of MC (0.2%) was further confirmed with an investigation of lowfat frankfurters (Foegeding and Ramsey 1986). On the other hand, in chicken patties with MC at 0.25% yielded a higher ($P<0.05$) cook yield (75.58%) than that of the control (74.66%) (Steinke 2001). Increased cook yield values may be obtained if MC were incorporated into high-moisture restructured meat products.

Hydroxypropyl Methylcellulose

Hydroxypropyl methylcellulose is another water-soluble, thermally reversible, cellulose derivative. It is a food additive and "may be safely used in food, except standardized foods, as an emulsifier, film former, protective colloid, stabilizer, suspending agent, or thickener, in accordance with good manufacturing practice" (FDA 2001). Unlike MC that forms a very firm gel, HPMC forms semi-firm to soft gels at hotter temperatures (60-90°C) depending on type (E, F, K grade). Hydroxypropyl methylcellulose has three different grades known as E, F, and K that are structurally the same but differ in gelling temperature and viscosity. Grade E is the least viscous (15-4,000 cPs) and has the lowest gelling temperature (<77°C) and grade K is the most viscous (99-100,000 cPs) and has the highest gelling temperature (<85°C). Hydroxypropyl methylcellulose has been mostly used to reduce fat content in fried foods. French fries dipped into a solution of HPMC prior to deep fat frying were less greasy than normal french fries. The addition of HPMC has successfully reduced oil losses during cooking and decreased cooking oil costs (Grover 1986). In a recent study, HPMC reduced the migration of acetic acid from marinated chicken products into frying oil, thus reducing the tocopherol (Vitamin E) loss in peanut oil (Holownia and others 2001). Thus, HPMC can apparently form a barrier at the surface of the product in high temperature environments. This barrier forming ability could also serve to enhance product juiciness. For example, beef patties containing 1.0% HPMC were evaluated by a sensory panel to have increased patty juiciness and tenderness (Hill and Prusa 1988). Furthermore, results proved that the addition of HPMC reduced drip loss and total cook

loss values than control patties. By HPMC forming a surface barrier upon heating it may enable the processor to increase cook yields and decrease purge losses of meat products that contain HPMC.

VIII. Summary of Literature

It is clear in today's economy the meat processor must be a cost effective and efficient force. To achieve such a feat meat processors must produce a consumer appealing and acceptable product that has high yields. The use of approved non-meat ingredients such as KC, SPI, MFS and SC has made the task of increasing product water retention, binding and textural enhancement an easier job. United States Department of Agriculture approved purge controllers (KC, MFS, SC, SPI) have allowed for the addition of higher amounts of water in ham products. Additionally, these ingredients have proved to positively affect sensory attributes and product consistency.

Although, the approved ham purge controllers KC, SPI, MFS, and SC are reliable, easy to use, and proven to be cost effective the meat processing and scientific community must look outside the "box" for other options. Methylcellulose and HPMC are two such "new" options that may enable the meat processor to significantly decrease non-meat ingredient costs by the utilization of lower addition percentages with enhanced water binding and retention abilities. Non-meat ingredients such as SPI and MFS require higher addition levels (1-2%) while MC and HPMC may achieve the same attributes at significantly lower levels (0.2-0.4%). This significant decrease in purge controller percentages will be cost effective for the meat processor. If MC and HMPC can prove

their purge controlling and textural enhancing abilities, it could result in a larger return for the meat processor and innovative processed meat products.

CHAPTER 2

Materials and Methods

This chapter provides detailed descriptions, procedures, and processes utilized during the research project. Due to the extent and depth of each study it was necessary that chapter 2 be devoted to the materials and methods used. Study I focuses on the functional characteristics of hydrocolloid gums in water and brine solutions and in a meat model system. Study II investigates the effects of incorporating various hydrocolloid brine solutions on the sensory, textural and quality attributes of a commercial high-moisture (45%) ham product.

I. *Study I: Evaluation of methylcellulose and hydroxypropyl methylcellulose in water and brine solutions.*

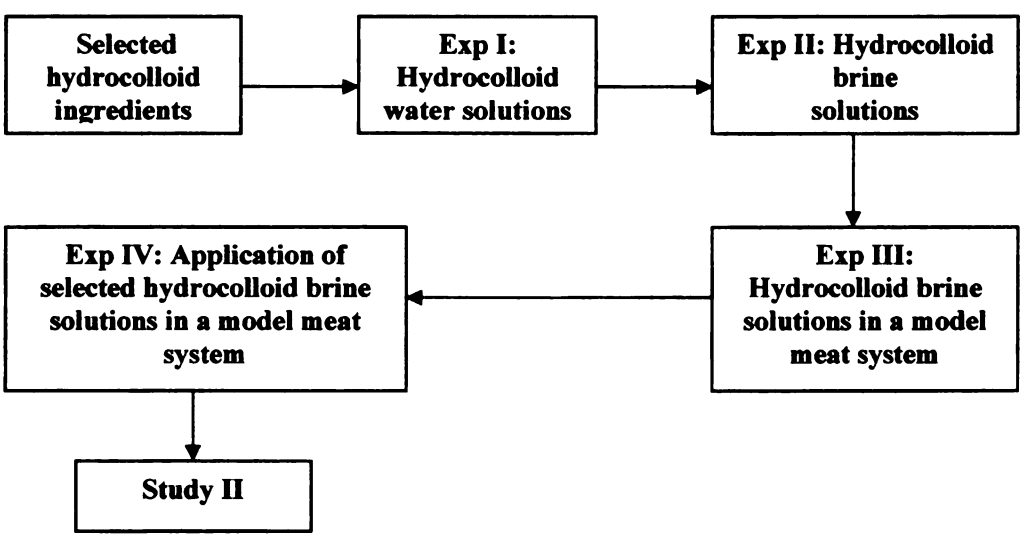
Introduction

As the amount of added water (>45% addition) in restructured meat products increases, the ability to retain water during thermal processing and minimize purge during storage decreases (Prabhu and Sebranek 1997). In previous literature, it has been shown that hydrocolloids can increase water binding and retention (Trudso 1985; Foegeding and Ramsey 1987; Bater and others 1992; Trius and others 1994a; Prabhu and Sebranek 1997). However, research investigating MC hydrocolloids as a potential purge controller has been limited. Therefore, we investigated the functionality of MC, HPMC, and KC in water and brine solutions and in a meat model system to determine

the feasibility of incorporating hydrocolloid brine solutions in a high-moisture restructured ham product.

Study I was conducted in four experiments. Experiment I investigated the functional properties of selected hydrocolloids in a water solution. Experiment II investigated the functionality of the hydrocolloids in a brine solution (water, salt, phosphate as the primary ingredients). Experiment III incorporated various types and levels of hydrocolloids in brine solutions in a meat model system to determine their impact on textural and quality attributes. The results from Experiment III determined which hydrocolloid brine solutions were feasible for commercial restructured ham manufacture. Experiment IV incorporated a combination of hydrocolloids in a brine solution within a meat model system to determine if any beneficial effects were observed with respect to increased water binding and retention during storage. The experiments also validated protocols, hydrocolloid brine and product formulations and narrowed the selection of hydrocolloid brine solutions to be used during pilot plant manufacture of a commercial high-moisture restructured ham.

Figure 1: Study I Flow Diagram



Experimental Design and Data Analysis

For Study I, both Experiment I and II were designed as a 4 x 4 factorial treatment arrangement with the main effects of hydrocolloid type (A4M=MC I; F4M=HPMC I and K4M= HPMC II; KC) and level of incorporation (0.2, 0.4, 0.6, 0.8%) in either a water or brine solution. Experiment III was designed as a 4 x 4 factorial arrangement of treatments with main effects of hydrocolloid type (MC I, HPMC I, HPMC II, KC) and level of incorporation (0.2, 0.4, 0.6, 0.8%) in a brine solution incorporated in a meat model system with an augmented control (no hydrocolloids) (n=17). Experiment IV was deigned as a one-way analysis of variance with four hydrocolloid brine treatment combinations and a control (no hydrocolloids) (n=5). The hydrocolloid solutions were formulated for addition at 45% (wt/wt). The level of significance for all statistical analyses was determined at $P<0.05$ (SAS User's Guide, Version 8.2. Cary, NC: SAS Institute; 2002).

Hydrocolloid Ingredients

Methylcellulose and HPMC food gums under the commercial name METHOCEL™ (Dow Chemical Company, Midland, MI) are water soluble carbohydrate gums made from a natural cellulose source. The molecular structure of MC and HPMC both contain the backbone of cellulose but HPMC possesses hydroxypropyl and methoxyl substitutions (Anonymous 2000). These molecular differences contribute to differences in viscosities, gelation temperatures and gel firmness between MC and HPMC. Methylcellulose I is of medium viscosity (4,000 cPs), hydrates below 13°C and forms a firm gel at 50-55°C. Hydroxypropyl methylcellulose I (HPMC I) is of medium viscosity (4,000 cPs), hydrates below 25°C, and forms a semi-firm gel at 62-68°C.

Finally, HPMC II is of medium viscosity (4,000 cPs), hydrates below 29.5°C, and forms soft gels at 70-90°C.

Kappa carrageenan is a hydrocolloid composed of sulfated linear polysaccharide units extracted from red seaweeds. It is a GRAS substance and is an approved food additive. Due to its ability to be a strong gelling agent, KC can be used for meat applications such as restructured ham. The selected KC for these research studies was Gelcarin® ME 6910 (FMC BioPolymer, Princeton, NJ). Unlike METHOCEL™, KC hydrates upon heating (70°C) and then forms a stable gel upon cooling to <25°C.

Experiments II, III and IV included in the hydrocolloid brine solutions STP (Brifisol 512, BK Giulini Corporation, Simi Valley, CA), food grade sugar, salt, sodium nitrite and sodium erythorbate.

Manufacturing Process

A. Hydrocolloid Water and Brine Solution Manufacturing (Exp. I-IV)

Hydrocolloid water (Exp. I) and hydrocolloid brine (Exp. II) solutions (909 g) were developed and formulated according to the procedures in Appendices 1, 2 and 3. The hydrocolloid ingredients were randomly selected and weighed out (0.2, 0.4, 0.6 or 0.8% of the total solution) and placed in 946.4 mL lidded glass jars (Fisher Scientific Co., Pittsburgh, PA.) with the appropriate amount of water or brine. The solutions were mixed using a 4-blade mixing head: 2-blades perpendicular (2.5 cm across) to the shaft and 2-blades parallel to the shaft (1.3 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Experiment IV investigated the functional properties of hydrocolloid brine solutions containing two or more combinations of hydrocolloid

ingredients. All solutions were covered and stored overnight (approximately 12-16 hrs) in a walk-in cooler (2-4°C). Upon completion of storage (12-16 hrs) required amounts of sodium nitrite (J.T. Baker, Phillipsburg, NJ) to achieve 156 ppm sodium nitrite and 250 ppm sodium erythorbate (Butcher and Packer Supply Co., Detroit, MI) were added to the hydrocolloid solutions and mixed.

B. Model Meat System Processing (Exp. III and IV)

Fresh pork semimembranosus (IMPS 402F) muscles were obtained from a local meat company and delivered to MSU Meat Laboratory. Upon arrival, boxed hams were placed into cooler 2-4°C and 10 kg of ham was randomly selected for each replication. Randomly selected hams were removed of excess fat and the gracilis muscle. Hams were weighed (7.7 kg) according to the appropriate product formulation for each replication (n=3) and covered with Saran™ wrap. Processing of the entire lot fresh ham's occurred within one week of arrival.

Pork semimembranosus muscle was ground through a 0.9 cm plate twice utilizing a Toledo chopper (Model- 5126, Toledo Scale Corp., Toledo, OH). Four hundred grams of freshly ground ham and 180 grams of the designated treatment brine solution were added to a Hobart Kitchen Aid mixer (Model K5-A, Hobart Corporation, Troy, OH) and mixed for 3 min at speed setting 2. The mixer bowl and mixing attachment were thoroughly washed and dried between each treatment formulation.

C. Thermal Processing

Thirty-four grams (in triplicate) of the designated hydrocolloid water (Exp. I) or brine (Exp. II) solutions were placed into 50 mL polycarbonate centrifuge tubes, capped and then placed into a programmed water bath (Model 9510, PolyScience, Niles, IL) that

mimicked a restructured ham thermal processing schedule. Procedures on water bath programming are given in Appendix 4.

Table 1: Programmed Water Bath Schedule

Stage	Time (Min)	Internal Temp (°C)	Bath Temperature (°C)
1	30	0	4.0
2	15	0	43.3
3	30	0	54.4
4	30	0	60.0
5	30	0	65.6
6	60	70.0	79.4
7	30	37.8	35.0

The samples were thermally processed to an internal temperature of 70°C. The same procedures were followed for the manufacture of a high-moisture restructured ham in a model system (Exp. II and IV). For analyses purposes thermally processed, restructured ham was removed from polycarbonate test tubes resulting in a cylindrical, test tube shaped ham sample (i.e. "plug").

Analyses

A. pH determination

Determination of hydrocolloid water and brine solution pH values for all Study I experiments were determined at 5°C using an Accumet pH Meter (AB 15, Fisher Scientific, Co., Pittsburgh, PA) calibrated with phosphate buffers 4.0 and 7.0. Restructured ham raw and cooked pH values (Exp. III and IV) were determined by placing one gram of sample into a 50 mL centrifuge plastic tube and adding ten mL of distilled, deionized water. Samples were homogenized with a Polytron mixer (PT-35, Kinematica, AG, Switzerland) on speed setting 2 for two, 10 sec bursts. The pH of each

sample was measured in duplicate using an Accumet pH meter (AB 15, Fisher Scientific, Co., Pittsburgh, PA) calibrated with phosphate buffers 4.0 and 7.0.

B. Viscosity Analysis in Hydrocolloid Water and Brine Solutions

The viscosity readings of each hydrocolloid water and brine solution (909 g) were measured in the 946.4 mL glass jars (Fisher Scientific Co., Pittsburgh, PA) using a Brookfield Viscometer (Model DV-II, Brookfield Engineering, Co., Stoughton, MA) at speed setting 12. A variety of spindle sizes were used due to differences in viscosity between water and brine solution treatments. Spindle size 2 was used for hydrocolloid water solution (Exp. I) viscosity readings while spindle size 3 was used to determine hydrocolloid brine solution viscosity (Exp. II and III). Spindle size 6 was used for the multi-hydrocolloid brine solution treatments while spindle size 5 was used for the control brine solution (Exp. IV). The selected spindle was lowered into the geometric center of the water or brine solution until the indented ring on spindle was level with solution surface. Viscosity readings were recorded in centipoise (cPs) once the displayed reading was stabilized. Prior to viscosity analysis, the viscometer was calibrated to assure accuracy. The detailed calibration procedure in Appendix 5.

C. Color Analysis

A ColorTec PCM™ Color Meter (Model 6482, ColorTec Associates, Clinton, NJ) with a 10° standard observer and an 8 mm reading orifice was used to measure the color of thermally processed (70°C) hydrocolloid water and brine solution gels (Exp. I and II). The ColorTec was programmed to analyze L* (lightness), a* (redness), b* (yellowness) (Commission Internationale De L'Eclairage (CIE)), with D_{65} illuminant (daylight illuminator), and calibrated on a standard white and black tile. Readings were taken on

the exposed exterior surface of the hydrocolloid water and brine solution gel plugs. Additionally, in experiment III and IV the same procedures were utilized to determine the color (L*, a*, b*) values of the interior surface of thermally processed (70°C) restructured ham "plugs" (thermally processed ham removed from polycarbonate tube; i.e. plug) manufactured with various hydrocolloid brine solutions. Restructured ham "plug" was cut longitudinally down the center of ham to form two equal halves for interior surface color analysis. Three readings per ham sample were taken and averaged for L* (lightness), a* (redness), and b* (yellowness) values.

D. Water Retention (Exp. I and II)

Water binding and retention properties of thermally processed (70°C) hydrocolloid water and brine solution gels were measured. Hydrocolloid water and brine solutions (34g ± 0.1g) containing MC or HPMC were placed in 50 mL polycarbonate centrifuge tubes, thermally processed and removed from the water bath once the targeted 70°C internal temperature was reached. Methylcellulose and HPMC gel upon thermal processing and reverse upon cooling. Solutions containing MC or HPMC were removed at 70°C to assure full gelation and accurate water retention values. Solutions containing KC were removed after cooling to an internal temperature of 37.8°C. Kappa carrageenan solutions were allowed to cool as KC gels upon cooling following thermal processing. Solution temperatures were monitored utilizing three Omega thermocouples (Model TMTSS-020G-6, Omega Engineering, Inc., Stamford, Conn.) inserted through the cap of the polycarbonate tubes. The samples were removed, the tubes inverted to allow the samples to drain into a funnel lined with cheese cloth, and allowed to drip for 1 min. Sample exudate was collected below the funnel spout in a pre-weighed 15 mL graduated

cylinder for 1 minute, weighed and water retention values determined by the following equation:

$$\% \text{ water retention} = \frac{\text{Initial solution wt.- Exudate wt.}}{\text{Initial solution wt.}} \times 100$$

E. Cooked Product Yield and 7-day Purge (Exp. III and IV)

Cooked product yield determinations for restructured hams manufactured in a model system were performed after the ham "plugs" were thermally processed (70°C) and cooled to an internal temperature of 37.8°C. The ham "plugs" were carefully released from the interior surface of the tubes with a flat spatula. The tubes were inverted and the water released from the ham samples was filtered through a funnel lined with cheese cloth and collected in a pre-weighed 15 mL graduated cylinder for 1 min, the cylinder reweighed and percent cook yield determined by the following equation:

$$\% \text{ cook yield} = \frac{\text{Raw meat wt.- Exudate wt.}}{\text{Raw meat wt.}} \times 100$$

The polycarbonate centrifuge tube containing the remaining ham sample was recapped and placed into 2-4°C cooler and chilled for 12-16 hours until an internal temperature of 4°C was reached. The chilled restructured ham plugs were then used for 7-day purge analysis.

To determine percent purge, chilled restructured ham plugs were removed from polycarbonate centrifuge tubes and the sample weight recorded. Each ham plug sample was placed into 12.7 cm x 22.9 cm vacuum bags (Cryovac Sealed Air Corp., Duncan, SC) and heat sealed using an impulse heat sealer (Diagger, Lincolnshire, IL). A non-sterile 20 gauge needle attached to the 1.5 cm diameter rubber hose of a vacuum pump (Welch Vacuum, Skokie, IL) was inserted into the sealed bag to extract air. Each bag

had a vacuum of 43 cm Hg pulled. After air extraction, the bag was heat sealed again to prevent air from flowing back into the bag from the needle insertion point. Packaged restructured ham plugs were stored in a 2-4°C cooler for 7 days. On day 7, each sample package was reweighed, the ham sample plugs removed, the ham sample and vacuum bag blotted dry and both were reweighed. The percent purge loss was determined using the following calculation:

$$\% \text{ purge loss} = \frac{\text{Total pkg. wt. - (Dry pkg. wt + Dry meat wt.)}}{\text{Total pkg. wt.}} \times 100$$

F. Textural Analysis

Gel Strength/Hardness (Exp. I and II)

The gel strength/hardness of thermally processed hydrocolloid water and brine solutions was analyzed on a TA-HD*i* texture analyzer (Texture Technologies Corporation, Scarsdale, NY) utilizing a 5 kg load cell and a 1.3 cm diameter acrylic cylinder attachment (TA-10) 3.5 cm in height. Each hydrocolloid water and brine solution gel plug was analyzed in the 50 mL centrifuge tubes in which they were thermally processed. The MC and HPMC solutions were analyzed at 70°C and the KC solution was analyzed at 37.8°C to assure measurements recorded on fully gelled hydrocolloid solutions. Sample tubes were placed in a molded steel pipe fitting placed on the heavy duty platform (TA-90) to eliminate tube movement and variability during the analysis. The acrylic probe penetrated the gel plug in the geometric center of the sample, depressing the gel 8 mm before retracting. Peak force was recorded in grams with a cross-head speed of 1.7 mm/s. Detailed gel hardness/strength settings for the TA-HD*i*

Textural Analyzer (Texture Technologies Corporation, Scarsdale, NY) are provided in Appendix 6. Detailed protocol for calibration procedures can be seen in Appendix 17.

G. Texture Profile Analysis (TPA):2-cycle Compression (Exp. III and IV)

Experiment III and IV restructured ham test tube plugs were analyzed using the 2-cycle compression test method, utilizing a TA-HD*i* Textural Analyzer (Texture Technologies Corporation, Scarsdale, NY). Two restructured ham samples per treatment were removed from the test tubes, covered to prevent surface drying and kept at 4°C. Two circular samples measuring 2.5 cm (dia) x 2.5 cm (height) were cut horizontally from the center of each ham plug using a size 11, non-sterile surgical blade attached to a scalpel. Treatments were analyzed in duplicate. Each sample was weighed and analyzed. A 5 kg load cell was used to measure hardness, springiness, cohesiveness, chewiness, and resilience using a 75 mm diameter aluminum cylinder plate (TA-30), on a heavy duty platform (TA-90). Samples were compressed to 25% of their original height (75% compression) in a 2-cycle compression at 4-6°C with a crosshead speed of 1.7 mm/s. See Appendix 7 for detailed TA-HD*i* Textural Analyzer (Texture Technologies Corporation, Scarsdale, NY) settings and Appendix 17 for calibration procedures.

II. Study II- Evaluation of methylcellulose, hydroxypropyl methylcellulose and kappa carrageenan in high-moisture restructured hams.

Preliminary Study

A preliminary study was conducted to confirm Study I results. The hydrocolloid brine solutions from experiment IV were evaluated in addition to three control brine solutions. Hydrocolloid brine solutions formulated:

Treatment 1 – 0.4% MC I x 0.6% HPMC I

Treatment 2 – 0.4 % MC I x 0.6% KC

Treatment 3 – 0.6% HPMC I x 0.6% KC

Treatment 4 – 0.4% MC I x 0.6% HPMC I x 0.6% KC

Treatment 5 – Control

Treatment 6 – 0.4% MC I

Treatment 7 – 0.6% HPMC I

Treatment 8 – 0.6% KC

This preliminary study verified protocols and procedures to insure consistent processing for the manufacture of high-moisture restructured hams. Treatment brine solutions were mixed using a Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by Michigan State University at 1200 rpm during the addition of phosphate, salt, and sugar. During the addition of the hydrocolloid gums mixing speed was increased to 1500 rpm to fully entrain hydrocolloid. Total mixing time was 20 minutes per brine. The brines were covered and placed in a 2°C cooler for 12-16 hrs. Upon completion of storage (12-16 hrs), brines were remixed for 1 minute at 1200 rpm. Nitrite and erythorbate were then added and mixed for an additional 2 minutes at 1200 rpm. Fresh pork semimembranosus muscle (gracilis muscle removed) was sorted in 5.7 kg batches per restructured ham treatment. The ham muscles were further divided into three 1.9 kg batches for grinding into three different particle sizes (TORREY Grinder Model

M-32-5, Maquinas Para Mercados, S.A. DE C.V., Mexico). The ground ham muscles (5.7 kg, 1.9 kg of each particle size) and 2.6 kg of either a hydrocolloid or control brine (45% addition) solution was placed into a modified double axle paddle mixer (Model T-268, Keebler Engineering Inc., Chicago, IL) and mixed for 10 min at mixer speed setting 1. Mixed restructured ham batter was placed into a vacuum stuffer (Model 500, VEMAG Maschinenbau GmbH, Germany), stuffed into a pre-soaked fibrous, non-perforated, preclipped casings (Devro-Teepak, Inc., Kansas City, MO.), and clipped using a Tipper Tie Clipper (Model PR465L, Dover Industries Co., Apex, NC). Thermal processing was achieved utilizing a one truck smokehouse (CGI Processing, Model A28-B0101, Automated Manufacturing, Cicero, IL). A processing schedule was established during the process. Thermally processed, restructured hams were placed into a 2-4°C cooked meat cooler and chilled for approximately 16 hours. All restructured ham treatments were evaluated for casing peelability, firmness and sliceability. Restructured ham formulations that exhibited poor sliceability and/or soft texture were eliminated from further investigation. Acceptable restructured ham treatments were 2, 3, 4, 5, and 8. These hams were sliced (1.27 cm), vacuum packaged and stored (2°C) for sensory panel training. Unacceptable restructured hams treatments were 1, 6, and 7. These hams were disposed of properly as they exhibited poor peelability, sliceability, soft in texture, and low cook yields.

Experimental Design and Data Analysis

The experimental design was a one way ANOVA with three treatment combinations (0.4% MC I/0.6% KC, 0.6% HPMC I/0.6% KC, 0.4% MC I/0.6% HPMC

I/0.6% KC) at 45% addition (wt/wt), with a hydrocolloid brine control (KC at 0.6 %; 45% addition wt/wt) and a control (no hydrocolloid; 45% addition, wt/wt). Main effect means were separated by Tukey's Honest Significant Difference test with a predetermined level of $P<0.05$ (SAS User's Guide, Version 8.2. Cary, NC: SAS Institute; 2002). The study was replicated three times.

Hydrocolloid Ingredients

The hydrocolloid ingredients were described previously in Study I.

Manufacturing Process

A. Brine Manufacturing

Three multi-hydrocolloid, a KC, and a control (n=5) brine solutions were prepared for each replication for each treatment group on three consecutive days. Each brine solution was randomly selected and formulated prior to each restructured ham production day. The formulated treatment brine solutions were:

Treatment 1 – 0.4% MC I x 0.6% KC

Treatment 2 – 0.6% HPMC I x 0.6% KC

Treatment 3 – 0.4% MC I x 0.6% HPMC I x 0.6% KC

Treatment 4 – Control

Treatment 5 – 0.6% KC

Treatment brine solutions weighing approximately 11.3 kg each were placed in plastic containers and mixed using Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) at 1200 rpm during the addition of phosphate, salt, and sugar. During the addition of the hydrocolloid gums mixing speed was increased to 1500 rpm to fully entrain hydrocolloid. Total mixing time was 20 minutes per brine. The brines were

covered and placed in a 2°C cooler for 12-16 hrs. Upon completion of 12-16 hrs storage, brines were remixed for 1 minute at 1200 rpm. Nitrite and erythorbate were then added and mixed for an additional 2 minutes at 1200 rpm.

B. Restructured Ham Processing

Approximately 136.1 kg of fresh, boneless, semimembranosus muscle (IMPS 402F), with the gracilis muscle on, were acquired from a local meat company and delivered to MSU Meat Laboratory. Upon arrival, the hams were placed into a cooler (2-4°C). Ham muscles were randomly selected and trimmed to remove the gracilis muscle and external fat. The ham muscles were weighed out according to the appropriate product formulation, placed in plastic meat lugs and covered with Saran™ wrap. The time from ham muscle procurement to commercial restructured ham manufacture of all three replications was one week.

Approximately 29.6 kg of fresh pork semimembranosus muscle (gracilis muscle removed) was sorted in 5.7 kg batches per restructured ham treatment. The ham muscles were further divided into three 1.9 kg batches for grinding into three different particle sizes (Prabhu and Sebranek 1997). One 1.9 kg batch was ground through a 5.33 cm plate (kidney plate), the second batch was ground through 2.54 cm plate and the last batch was ground through a 0.95 cm plate (TORREY Grinder Model M-32-5, Maquinas Para Mercados, S.A. DE C.V., Mexico). The ground ham muscles (5.7 kg, 1.9 kg of each particle size) and 2.6 kg of either a hydrocolloid or control brine (45% addition) solution was placed into a modified double axle paddle mixer (Model T-268, Keebler Engineering Inc., Chicago, IL) and mixed for 10 min at mixer speed setting 1. Upon completion of mixing, a sample for raw proximate analysis and pH determination were collected and

placed into labeled whirl-pak bags. Mixed restructured ham batter was placed into a vacuum stuffer (Model 500, VEMAG Maschinenbau GmbH, Germany), stuffed into a pre-soaked 11.4 cm x 76.2 fibrous, non-perforated, preclipped casing (Devro-Teepak, Inc., Kansas City, MO.), and clipped using a Tipper Tie Clipper (Model PR465L, Dover Industries Co., Apex, NC). Stuffed and clipped ham chubs were weighed and recorded as a treatment group. Each chub weighed approximately 2.3 kg with 3 chubs per treatment group, 6.9 kg per treatment (15 restructured ham chubs per replication). Restructured ham chubs were labeled, hung on smoke sticks, and placed on a smoke truck for thermal processing.

C. Thermal Processing

Thermal processing was achieved utilizing a one truck smokehouse (CGI Processing, Model A28- B0101, Automated Manufacturing, Cicero, IL) and processed according the following smokehouse schedule:

Table 2: Smokehouse Schedule

Stage	Time (Min)	Internal (°C)	Smoke	Dry Bulb (°C)	Wet Bulb (°C)	Fan	Damper
1	15	0	No	43.3	37.8	50	Open
2	30	0	No	54.4	43.3	50	Open
3	30	0	No	60.0	46.1	50	Open
4	30	0	No	65.6	48.9	50	Open
5	45	62.8	No	71.1	54.4	50	Open
6	120	62.8	No	71.1	62.8	50	Open
7	240	70.0	Steam	79.4	71.1	50	Open
Shower	30	54.4	No	1 min on	1 min off	100	Closed

Following the shower cycle, the restructured hams were removed from smokehouse once an internal product temperature of 54.4°C was reached. The restructured hams were allowed to equilibrate to an internal temperature of 37.8°C (30 min) at 20°C. Excess water was removed and the treated products weighed to determine

product cook yields (37.8°C). The restructured hams were then allowed to equilibrate to an internal temperature of 32.2°C (15 min) at 20°C prior to chilling. The hams were placed into a 2-4°C cooked meat cooler and were chilled to 4°C according to Appendix B guidelines (USDA-FSIS).

D. Chilling, Slicing, and Packaging Process

Thermally processed restructured hams were placed into a 2-4°C cooked meat cooler and chilled for approximately 16 hours. Casings were then removed from hams and discarded.

Three restructured ham chubs per treatment were sliced into 1.27 cm thick slices using a Globe meat slicer (Model 775L, Mozley Mfg. Co. Inc., Stamford, CN) and placed on plastic trays according to treatment. Restructured ham slices were randomly selected and vacuum packaged. Two slices were utilized for cooked proximate composition and pH determination; chopped into 1 cm pieces, placed in whirl-pak bags, sealed, labeled and stored in a -28.8°C freezer. Twelve randomly selected ham slices were packaged for trained sensory panel evaluation and packaged into two (6 slices per bag) 30.5 cm x 35.6 cm vacuum package bags (Cryovac Sealed Air Corp., Duncan, SC). One ham slice was randomly selected for day 0 lipid oxidation analysis, packaged in a 12.7 cm x 22.9 cm bag and sealed with no vacuum using an impulse heat sealer (Diagger, Lincolnshire, IL). Four ham slices were randomly selected for textural analysis - two for objective texture profile analysis and two slices for Kramer Shear analysis. These slices were packaged in 17.8 cm x 30.5 cm vacuum package bags. Twenty ham slices were randomly selected for color, purge, and lipid oxidation analyses; 4 slices per day, 2 slices per bag (17.8 cm x 30.5 cm), 2 bags per treatment for evaluation on day 7, 14, 21, 28, and day 56 of

refrigerated (4°C) storage. Extra ham slices packaged in 30.5 cm x 35.6 cm vacuum package bags. All vacuum packaged samples were packaged using a Multivac vacuum packager (AGW, SeppHaggenmuller KG, Germany) with a vacuum setting of 2.5 vacuum and a heat sealer bar setting of 3.0.

Restructured Ham Storage

Vacuum packaged restructured ham slices were placed in a 4°C ± 1°C, walk-in cooler. Packages were laid flat, non-overlapping on white trays which were placed on tables 2.08 meters from a constant light source. The cooler contained 10 lighting fixtures and 2 fluorescent lamps (Model F40SP41, General Electric, Cleveland, OH) per fixture (n=20). Lighting was monitored everyday for a total of 56 days, lamps were changed as needed and never turned off. Foot-candle (FC) readings (FC=80) were taken using a GE Triple Range Light Meter (Model 217, General Electric, Cleveland, OH) from the surface of the ham slice. The light meter was set in the middle range (FC=50-250). The foot-candle reading (FC =80) is equivalent to 24,407 lumens (Appendix 10).

Analyses

A. Hydrocolloid Brine solution and product pH Determination

Brine solution and raw and cooked restructured ham pH values analyses were determined as previously described in Study I.

B. Product Cook YieldDetermination

Cooked product yield was determined as previously described in Study I. Detailed procedure for cook yield can be found in Appendix 11.

C. Color Analysis, TBARS analysis and Purge loss

Objective color determinations for the exterior ham surface (exposed to light) and the interior ham surface (unexposed to light) was measured using a Minolta Chromameter (Model CR-310, Minolta Camera Co., Ramsey, NJ). Three readings were taken and averaged for L* (lightness), a* (redness), and b* (yellowness) values (Commission Internationale De L'Eclairage) (CIE). The chromameter was set on D_{65} illuminant (daylight illuminator), 2° standard observer, with a 50 mm reading orifice. The chromameter was calibrated on a standard white and the pink color tile. Color readings were taken for day 0, 7, 14, 21, and 28.

Thiobarbituric acid reactive substances (TBARS) analysis was conducted on day 0, 14, 28, and day 56, to monitor oxidative rancidity. Day 14 was the day the trained sensory panel evaluated the corresponding samples. Four replicates were run for each sample according to methods established by Tarladgis and others (1960) and Zipser and others (1962) as modified by Rhee (1978) (Appendix 12). Percent purge was determined for days 7, 14, 21, 28, and day 56 of refrigerated (4°C storage) as previously described in Study I.

Proximate Composition

Moisture (oven drying), fat (Soxhlet ether extraction), and protein (nitrogen measurement, Model FP-2000, LECO Co., St. Joseph, MO) were determined according to AOAC (2000) methods found in Appendix 8. Samples were analyzed in triplicate.

Textural Analyses

A. Texture Profile Analysis (TPA):2-cycle Compression

Restructured ham slices were analyzed using the 2-cycle compression test method, utilizing a TA-HD*i* Texture Analyzer (Texture Technologies Corporation,

Objective color determinations for the exterior ham surface (exposed to light) and the interior ham surface (unexposed to light) was measured using a Minolta Chromameter (Model CR-310, Minolta Camera Co., Ramsey, NJ). Three readings were taken and averaged for L* (lightness), a* (redness), and b* (yellowness) values (Commission Internationale De L'Eclairage) (CIE). The chromameter was set on D_{65} illuminant (daylight illuminator), 2° standard observer, with a 50 mm reading orifice. The chromameter was calibrated on a standard white and the pink color tile. Color readings were taken for day 0, 7, 14, 21, and 28.

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Moisture (oven drying), fat (Soxhlet ether extraction), and protein (nitrogen measurement, Model FP-2000, LECO Co., St. Joseph, MO) were determined according to AOAC (2000) methods found in Appendix 8. Samples were analyzed in triplicate.

Textural Analyses

A. Texture Profile Analysis (TPA):2-cycle Compression

Restructured ham slices were analyzed using the 2-cycle compression test method, utilizing a TA-HD*i* Texture Analyzer (Texture Technologies Corporation,

Scarsdale, NY). Texture profile analysis was conducted in conjunction with trained sensory panel analysis on day 14. Two restructured ham slices per treatment (n=10) were removed from vacuum packaged bags and held at 4°C. Two circular samples 1.9 cm diameter x 1.3 cm thick, were cut from the center from each ham slice using a #12 stainless steel hand corer. Quadruplicate sample were analyzed for each restructured ham treatment (n=60). A 5 kg load cell was used to measure hardness, springiness, cohesiveness, chewiness, and resilience using a 75 mm diameter aluminum cylinder plate (TA-30), on a heavy duty platform (TA-90). Samples were compressed to 25% of original height (75% compression) in a 2-cycle compression at 4-6°C with a crosshead speed of 1.7 mm/s. Appendix 13 describes the TA-HD*i* Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY) settings and Appendix 17 has calibration procedures.

B. Kramer Shear Force Determination

Restructured ham slices were analyzed using the Kramer 5-blade shear force test method, utilizing a TA-HD*i* Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY). Shear force analysis was conducted in conjunction with trained sensory panel analysis on day 14. Two restructured ham slices (4-6°C) per treatment were removed from vacuum packaging and covered to prevent surface drying at 4°C. A rectangular sample measuring 7.9 cm x 6.4 cm x 1.3 cm was cut from the center of each ham slice using a pre-made plastic template. A 50 kg load cell with a crosshead speed of 1.7 mm/s was used to measure peak force in Newtons (N) required to shear the restructured ham slice. The 5-blade shear attachment was applied perpendicularly to the sample. The blades were set to completely shear through ham sample. The peak force

required to shear through the restructured ham slice was reported in force per unit mass of sample (N/g). Appendix 14 describes the TA-HD*i* Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY) settings for Kramer shear force analysis. Additionally, Appendix 17 describes detailed calibration procedures.

Trained Sensory Panel Evaluation

A trained sensory panel was utilized to determine specific sensory attributes of each restructured ham product. The panel was trained according to AMSA (1995) and Meilgaard and others (1991). Each restructured ham treatment was evaluated using an 8 point hedonic scale, where 1=extremely soft and 8=extremely hard, 1=extremely dry and 8=extremely juicy, 1=no residue/mouth coating and 8=abundant residue/mouth coating, 1=no off-flavor detected and 8=abundant off-flavor. An example of the trained sensory ballot is found in Appendix 15. Restructured ham slices were stored at 4°C and evaluated after 14 days of refrigerator storage. Samples were transferred to the Michigan State University sensory testing facility and placed in a 4°C cooling unit. Samples were prepared by cutting 1.27 cm^3 cubes from the center portion of each ham slice and were served cold (4-6°C). To minimize positional bias, the order of sample preparation was randomized within each session (Meilgaard and others 1991).

Testing took place in climate controlled, partitioned booths with cool incandescent light. Three cubes were placed in a plastic custard dish and held, covered to prevent surface drying in a 4°C cooling unit until serving. Each sample was served to panelists through a vertical sliding door that separated the food preparation area from the sensory testing area. Panelists were instructed to handle sample cubes with supplied

wooden toothpicks, and tasted for hardness, juiciness, residue/mouth coating, and off-flavor intensity. Expectorant cups were provided to prevent taste fatigue as the panelists were instructed not to swallow the samples. Distilled, deionized water and unsalted soda crackers were used to clean the palate between samples. Fifteen (4 treatments, 1 control and 3 replications) samples were evaluated in one day. The day was divided into 3 sessions with 5 samples evaluated per session. The panelists were standardized for each session by evaluating 1 warm-up sample and discussing the results. The warm-up samples were either the control or the KC treatment. There was 5 minutes between each sample and a 15 minute break between sessions. The serving order was randomized by treatment and replication (Appendix 16).

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CHAPTER 3

EVALUATION OF HYDROCOLLOID SOLUTIONS TO IMPROVE FUNCTIONAL ATTRIBUTES OF HIGH MOISTURE RESTRUCTURED HAMS IN A MODEL SYSTEM

ABSTRACT

Hydrocolloid solutions containing either 0.2, 0.4, 0.6, or, 0.8% methylcellulose (MC), hydroxypropyl methylcellulose (HPMC) and kappa carrageenan (KC) were evaluated as purge controllers to determine their effects on high-moisture restructured ham attributes in a model system. Brine solutions (45% addition w/w) were added to restructured "test tube" hams, which were subsequently cooked to 70°C internally. Treatment brines decreased ($P<0.05$) purge loss by 6.0% and brines containing KC and HPMC had higher ($P<0.05$) cook yields. Results suggest that brines formulated with KC and HPMC or MC will increase cook yields and decrease purge loss.

Chapter 3 is formatted in manuscript style according to the Journal of Food Science

Keywords: purge controllers, hydrocolloids, restructured ham

Introduction

Hydrocolloids are plant-derived, long-chain carbohydrate polymers. Many hydrocolloids have the ability to thicken and gel as a solution as well as exhibit meat gelling, emulsifying and stabilizing properties (Pearson and Gillett 1996). They function as water-binders in numerous food systems (Glicksman 1969) including restructured meat products. Approved purge controllers (USDA-FSIS 2002) allow processors to manufacture high-added-water products (i.e., hams) while decreasing the negative impacts of losing this added water during storage (purge).

Hydrocolloid gums such as carrageenan, xanthan gum, and alginates have been studied in meat and poultry products. However, limited research is available that investigates the incorporation of methylcellulose (MC) and/or hydroxypropyl methylcellulose (HPMC) into meat products. MC and HPMC are capable of forming a gel to bind water during thermal processing. Steinke (2001) showed that chicken patties manufactured with viscous, supergelling MC at 0.25% had higher cook yields than control patties (75.5% versus 74.5%, $P<0.05$). Earlier studies utilizing 1% MC and HPMC in lean beef patties decreased cook yields (Hill and Prusa 1988). This was further confirmed with a study utilizing MC (0.2%) in low-fat frankfurters conducted by Foegeding and Ramsey (1986). Lower viscosity carboxymethyl cellulose and higher viscosity microcrystalline cellulose were used individually (1% solution) in low-fat breakfast sausage and were shown to decrease moisture retention after cooking (Mittal and Barbut 1993). Hill and Prusa (1988) stated that total drip loss after cooking and evaporative losses for lean ground beef patties increased as the percent MC increased (0.5 to 1.0%), but decreased for HPMC (0.5 to 1.0%). These studies pose a question as to

whether the use of MC or HPMC in meat products may decrease purge values as a result of less available free water in the product after thermal processing (lower cook yields). The differences in MC and HPMC gel forming ability and viscosity may be the reasons for differences noted in the meat product attributes investigated in these studies.

The incorporation of different METHOCEL™ (The Dow Chemical Co., Midland, MI) type hydrocolloid gums, such as A4M (MC), F4M and K4M (HPMC) may prove to enhance the cook yield of higher (45%) added-water products while minimizing purge during storage due to their gel forming capabilities at various temperatures. An additional reason for investigating these hydrocolloids is their ability to bind water at lower usage levels (< 1.0%). Steinke (2001) utilized 0.25% MC (supergelling) in ground chicken patties and reported increased cook yields. Yet, Hill and Prusa (1988) demonstrated lower moisture retention with 1.0% MC and HPMC added to beef patties.

Other researchers have utilized different METHOCEL™ types singularly in meat products with differing results. However, the combination of hydrocolloids (MC, HPMC, KC) has not been studied by others. The combining of MC and/or HPMC with KC may provide a potential synergistic or additive effect when incorporated into meat products as a brine solution, thereby promoting water binding and retention during thermal processing and subsequent storage. Utilizing hydrocolloid gums that gel upon thermal processing (MC and HPMC) with KC that gels upon cooling following thermal processing may entrap added water in the cooking and cooling process. Our hypothesis was that hydrocolloid gums (MC, HPMC, and KC) in a brine solution may participate in protein-hydrocolloid interactions resulting in a higher water binding and water retention in high-moisture restructured ham model meat system.

The first objective of this study was to investigate the effects of MC, HPMC, and KC on water binding, water retention and functional attributes in hydrocolloid water and brine solutions and in a restructured ham model system. The second objective was to determine if combinations of hydrocolloids in a brine solution incorporated into a restructured ham model system demonstrated a synergistic effect on cook yields, purge values and textural attributes.

Materials and Methods

Evaluation of methylcellulose and hydroxypropyl methylcellulose in water and brine solutions.

Study I was conducted in four experiments. Experiment I investigated the functional properties of selected hydrocolloids in a water solution. Experiment II investigated the functionality of the hydrocolloids in a brine solution (water, salt, phosphate as the primary ingredients). Experiment III incorporated various types and levels of hydrocolloids in brine solutions in a meat model system to determine their impact on textural and quality attributes. The results from Experiment III determined which hydrocolloid brine solutions were feasible for commercial restructured ham manufacture. Experiment IV incorporated a combination of hydrocolloids in a brine solution within a meat model system to determine if any synergistic effects were observed with respect to increased water binding and retention during storage.

Experimental Design and Data Analysis

Experiment I and II were designed as a 4 x 4 factorial treatment arrangement with the main effects of hydrocolloid type (A4M=MC I; F4M=HPMC I; K4M=HPMC II; KC) and level of incorporation (0.2, 0.4, 0.6, 0.8%) in either a water or brine solution. Experiment III was designed as a 4 x 4 factorial arrangement of treatments with the main effects of hydrocolloid type (MC I, HPMC I, HPMC II, KC) and level of incorporation (0.2, 0.4, 0.6, 0.8%) in a brine solution. The brines were incorporated into a restructured

ham model system and treatments were compared to a control (no hydrocolloid). Experiment IV was designed as a one-way analysis of variance with four hydrocolloid brine treatment combinations and a control (no hydrocolloids). All hydrocolloid brine solutions were added to the ham at 45% (wt/wt). Each experiment was replicated three times. The level of significance for all statistical analyses was determined at $P<0.05$ (SAS User's Guide, Version 8.2. Cary, NC: SAS Institute).

Hydrocolloid Ingredients

Methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC) food gums under the commercial name METHOCEL™ (Dow Chemical Company, Midland, MI) were used. Methylcellulose I (MC I) is of medium viscosity (4,000 cPs), hydrates below 13°C and forms a firm gel at 50-55°C. Hydroxypropyl methylcellulose I (HPMC I) is of medium viscosity (4,000 cPs), hydrates below 25°C, and forms a semi-firm gel at 62-68°C. Finally, HPMC II is of medium viscosity (4,000 cPs), hydrates below 29.5°C, and forms soft gels at 70-90°C.

The selected KC for these research studies was Gelcarin® ME 6910 (FMC BioPolymer, Princeton, NJ). Experiments II, III and IV brine solutions contained salt (1.8%), sodium tripolyphosphate (STP) (0.3%, Brifisol 512, BK Giulini Corporation, Simi Valley, CA), food grade sugar (0.26%), sodium nitrite (150 ppm) (J.T. Bakeer, Phillipsburg, NJ.) and sodium erythorbate (250 ppm) (Butcher and Packer Supply Co., Detroit, MI).

Manufacturing Process

A. Hydrocolloid Water and Brine Solution Manufacturing (Exp. I-IV)

Hydrocolloid water (Exp. I) and hydrocolloid brine (Exp. II) solutions (909 g) were formulated. The hydrocolloid ingredients were used to formulate water or brine solutions at 0.2, 0.4, 0.6 or 0.8% of the total solution. The solutions were mixed using a 4-blade mixing head attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). The hydrocolloid brine solutions also contained salt, STP, sodium nitrite, and sodium erythorbate at the percentages previously described.

Experiment IV brine solution treatments were: Treatment (TRT) 1: MC I/HPMC I at 0.4/0.6%, TRT 2: MC I/KC at 0.4/0.6%; TRT 3: HPMC I/KC at 0.6/0.6% and TRT 4: MC I/HPMC I/KC at 0.4/0.6/0.6%, and the control (CONT) brine: no hydrocolloid. All solutions were covered and stored overnight (12-16 hrs) in a walk-in cooler (2-4°C).

Due to the differences in thermal gelling between MC/HPMC and KC gel plugs were analyzed for water retention and color at different temperatures. Treatments containing MC and HPMC are "hot" gelling hydrocolloids; therefore, they were analyzed at 70°C. Kappa carrageenan forms a gel upon cooling following thermal processing; therefore, KC was analyzed at 37.8°C.

B. Model Meat System Processing (Exp. III and IV)

Fresh pork semimembranosus (IMPS 402F) muscles were obtained from a local meat company and placed into a cooler 2-4°C. Muscles were denuded and the gracilis muscle was removed. Muscles were weighed (7.7 kg) according to the appropriate product formulation for each replication (n=3) and covered with Saran™ wrap.

Pork semimembranosus muscle was ground through a 0.9 cm plate twice utilizing a Toledo chopper (Model- 5126, Toledo Scale Corp., Toledo, OH). Four hundred grams of freshly ground muscle and 180 g of the designated treatment brine solution were added to a Hobart Kitchen Aid mixer (Model K5-A, Hobart Corporation, Troy, OH) and mixed for 3 min at speed setting 2.

C. Thermal Processing

Thirty-four grams (in triplicate) of the designated hydrocolloid water (Exp. I) or brine (Exp. II) solutions were placed into 50 mL polycarbonate centrifuge tubes, capped and then placed into a programmed water bath (Model 9510, PolyScience, Niles, IL) that mimicked a restructured ham thermal processing schedule. The samples were thermally processed to an internal temperature of 70°C. The same procedures were followed for the manufacture of a high-moisture restructured ham in a model system (Exp. III and IV). For analyses purposes, thermally processed (70°C) restructured ham was removed from polycarbonate tubes, resulting in a cylindrical, tube shaped ham sample (i.e. "plug").

Analyses

A. pH determination

Hydrocolloid water and brine solution pH values for all experiments were determined at 5°C using an Accumet pH Meter (AB 15, Fisher Scientific, Co., Pittsburgh, PA). Restructured ham raw and cooked pH values (Exp. III and IV) were determined by homogenizing one gram of sample with 10 mL of distilled, deionized water using a Polytron mixer (PT-35, Kinematica, AG, Switzerland).

B. Viscosity Analysis in Hydrocolloid Water and Brine Solutions

The viscosity readings of each hydrocolloid water and brine solution (909 g) were measured in 946.4 mL glass jars (Fisher Scientific Co., Pittsburgh, PA) using a Brookfield Viscometer (Model DV-II, Brookfield Engineering, Co., Stoughton, MA) at speed setting 12. The selected spindle was lowered into the geometric center of the water or brine solution until the indented ring on the spindle was level with solution surface. Viscosity readings were recorded in centipoise (cPs) once the displayed reading was stabilized.

C. Color Analysis

A ColorTec PCM™ Color Meter (Model 6482, ColorTec Associates, Clinton, NJ) with a 10° standard observer and an 8 mm reading orifice was used to measure the exterior surface color of thermally processed (70°C) hydrocolloid water and brine gels (Exp. I and II). The ColorTec was programmed to analyze L* (lightness), a* values (Commission Internationale De L'Eclairage (CIE)), with a D_{65} illuminant (daylight illuminator), and calibrated on standard white and black tiles. For Experiments III and IV the same procedures were utilized to determine the color (L* (lightness), a* (redness), and b* (yellowness)) values of the interior surface of thermally processed (70°C) restructured ham plugs. Three readings per gel or ham sample were taken and averaged.

D. Water Retention (Exp. I and II)

Hydrocolloid water and brine solutions (34g) containing MC or HPMC were placed in 50 mL polycarbonate centrifuge tubes and thermally processed (70°C internal temperature) in a programmable water bath. Solutions containing KC were removed after cooling to an internal temperature of 37.8°C, and the tubes were inverted and

allowed to drip for 1 min. Sample exudate was collected, weighed and water retention values were determined as a percentage of initial weight.

E. Cooked Product Yield and 7-day Purge (Exp. III and IV)

Cooked product yield determinations for restructured hams manufactured in a model system were performed after the ham plugs were thermally processed (70°C) and cooled to an internal temperature of 37.8°C. The tubes were inverted and the water released from the ham samples was collected. Weights (raw meat, cooked meat, polycarbonate tube) were recorded and percent cook yield was determined as a percentage of initial weight. The polycarbonate centrifuge tube containing the remaining ham sample was recapped and chilled (2-4°C) for 12-16 hrs.

To determine percent purge, chilled restructured ham plugs were removed from polycarbonate centrifuge tubes and the sample weight recorded. Ham plugs were vacuum packaged in 12.7 cm x 22.9 cm bags (Cryovac Sealed Air Corp., Duncan, SC) and stored in a 2-4°C cooler for 7 days. On day 7, each sample package was reweighed, the ham sample plugs removed, the ham sample and vacuum bag blotted dry and both were reweighed. The percent purge loss was determined as a percentage of initial weight.

F. Textural Analysis

Gel Strength/Hardness (Exp. I and II)

The gel strength/hardness of thermally processed hydrocolloid water and brine solutions was analyzed on a TA-HD*i* texture analyzer (Texture Technologies Corporation, Scarsdale, NY) utilizing a 5 kg load cell and a 1.3 cm diameter acrylic probe attachment (TA-10) 3.5 cm in height. Each hydrocolloid water and brine solution gel plug was analyzed in the 50 mL centrifuge tubes in which they were thermally processed.

Sample tubes were placed in a molded steel pipe fitting placed on a heavy duty platform (TA-90) to eliminate tube movement and variability during the analysis. The probe penetrated the gel plug in the geometric center of the sample, depressing the gel 8 mm before retracting. Peak force was recorded in grams with a cross-head speed of 1.7 mm/s.

G. Texture Profile Analysis (TPA):2-cycle Compression (Exp. III and IV)

Experiment III and IV restructured ham samples were analyzed using the 2-cycle compression test method, utilizing a TA-HD*i* Textural Analyzer (Texture Technologies Corporation, Scarsdale, NY). Two circular samples measuring 2.5 cm (dia) x 2.5 cm (height) were cut from the center of each ham plug. Each sample was weighed and analyzed. A 5 kg load cell was used to measure hardness, springiness, cohesiveness, chewiness, and resilience using a 75 mm diameter aluminum cylinder plate (TA-30), on a heavy duty platform (TA-90). Samples were compressed to 25% of their original height (75% compression) in a 2-cycle compression at 4-6°C with a crosshead speed of 1.7 mm/s.

Results and Discussion

Experiment I

Significant two-way interactions ($P<0.01$) were observed for hydrocolloid water solution pH, viscosity, color (L*), water retention, and gel hardness (Figure 2). Kappa carrageenan pH values were higher than MC I (A4M), HPMC I (F4M), and HPMC II (K4M) at all levels. The elevated pH value of KC could be attributed to the sulfated units that KC possesses and allows for KC to be slightly basic (Trius and Sebranek 1996, Daniel and Weaver 2000) (Figure 2). Viscosity values for all hydrocolloid gums were similar at 0.2% (Figure 2). As the hydrocolloid percentage increased, the solutions containing MC I, HPMC I, and HPMC II were more viscous. A slight increase in viscosity occurred between 0.2 and 0.4% was observed, but from 0.4 to 0.8% hydrocolloid addition viscosity values increased to a greater extent. Kappa carrageenan's lower viscosity values remained constant at all the levels of addition. The less viscous solutions demonstrated by KC can be advantageous to the meat processor utilizing a brine injection systems. Water retention of MC I at all levels (0.2-0.8%) was higher than all remaining treatments (Figure 2). From 0.2 to 0.4% (MC I) there was an increase of approximately 40% water retention and then plateaued from 0.4 to 0.8%. Water retention for solutions containing KC and HPMC II remained consistently lower at all levels. Treatment HPMC I showed similar results to KC and HPMC II from 0.2 to 0.4%. However, with the increased addition of HPMC I water retention was improved by more than 20%. As hydrocolloid addition increased, L* values decreased (data not shown). Gel hardness values of MC I increased with higher hydrocolloid levels (Figure 2). At

FIGURE 2: Two-way interactions (P<0.01) for pH, viscosity, water retention, and gel hardness (Exp I).

Fig 2a: pH

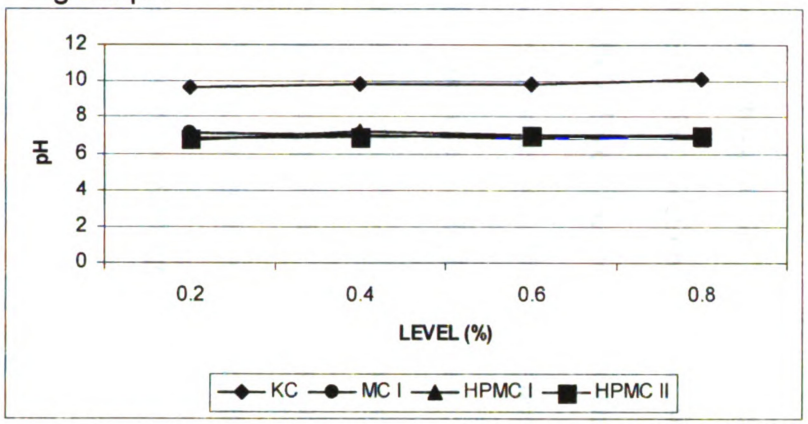


Fig 2b: Viscosity

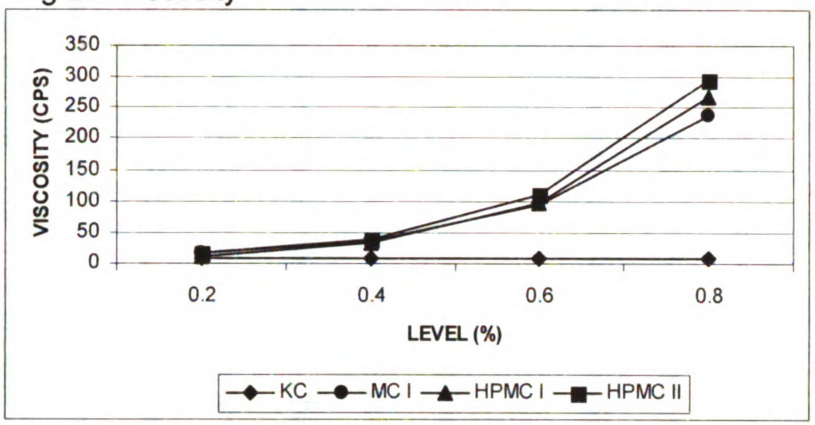


Fig 2c: Water Retention

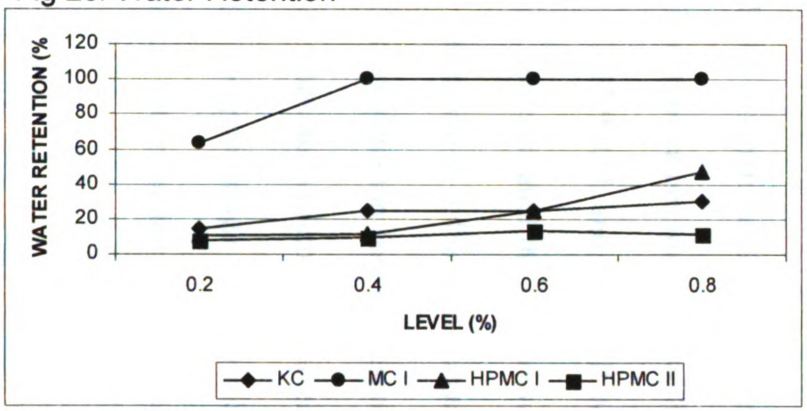
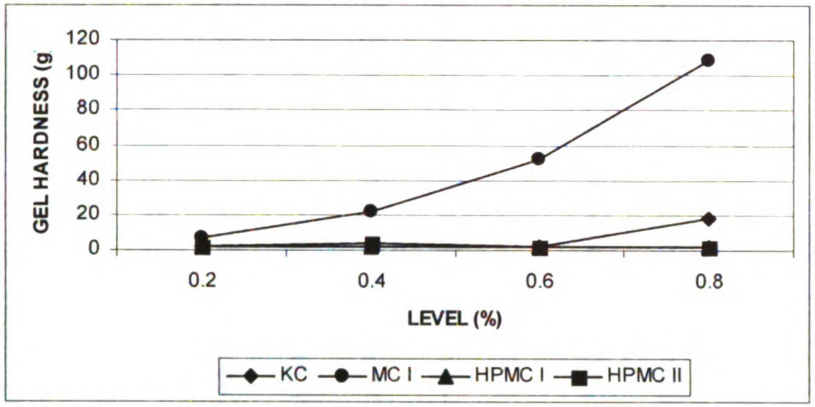


Fig 2d: Gel Hardness



0.2% addition, MC I had similar hardness values compared to KC, HPMC I, and HPMC II. However, from 0.4 to 0.8%, MC I had the greatest gel hardness values. These results were expected as MC I forms a firmer gel upon heating when compared to HPMC I and HPMC II (Anonymous 2001). For KC, HPMC I, and HPMC II the observed gel hardness values were low across all levels of addition, with KC at 0.8% being higher.

Experiment II

Hydrocolloid brine solutions exhibited significant ($P<0.0001$) two-way interactions for viscosity and water retention values (Figure 3). Brine viscosity values for all hydrocolloid gums were similar at 0.2% (Figure 3). Kappa carrageenan brine solutions remained the least viscous at all levels (0.2-0.8%). As the hydrocolloid percentage increased from 0.4-0.6%, the brine solutions containing MC I, HPMC I, and HPMC II were more viscous. From 0.6-0.8% viscosity levels of MC I, HPMC I, and HPMC II tended to plateau. The high viscosity values observed may be beneficial for meat coating systems (Grover 1986; Priya and others 1996; Anonymous 2000); however, they may be detrimental for injection systems. Water retention values improved with the increase of hydrocolloid level (Figure 3). Treatments KC, HPMC I, and HPMC II water retention values were similar at 0.2%. Treatment MC I demonstrated the highest water retention at 0.2%. However, MC I decreased water retention at 0.4% then increased water retention from 0.6 to 0.8%. The authors have no explanation for this response; however, these results suggest that a processor should consider utilizing MC I either above or below 0.4% for optimum water retention. As the percentage of hydrocolloid increased, brine solutions containing HPMC II tended to retain higher percentages of water.

Figure 3: Two-way interactions (P<0.0001) for viscosity and water retention in hydrocolloid brine solutions (Exp II).

Fig 3a: Viscosity

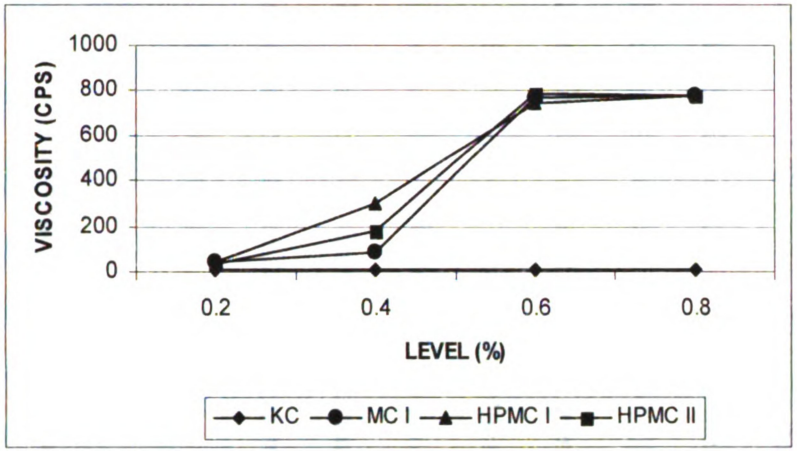
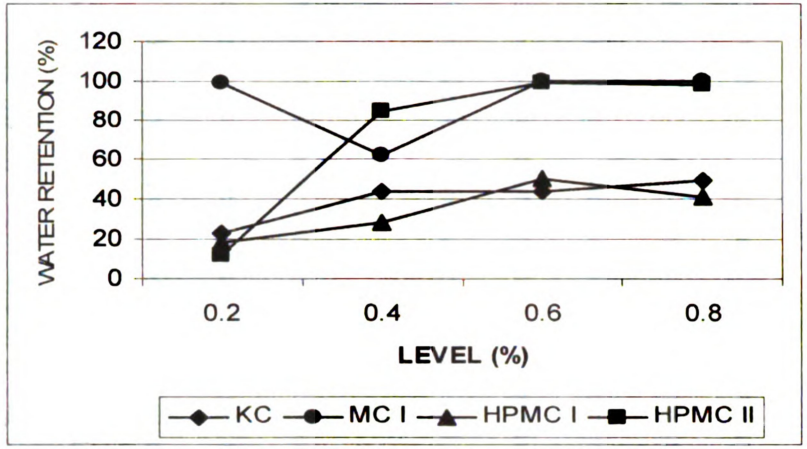


Fig 3b: Water Retention



No significant differences (P>0.05) were seen for pH, L* values, and gel hardness for hydrocolloid addition levels (Table 3). Kappa carrageenan brine gels were darker (L*=40.82), while HPMC I gels were the lightest (L*=69.30). MC I exhibited significantly (P<0.05) higher gel hardness values compared to KC, HPMC I, and HPMC II. The hydrocolloid brine solution treatments containing HPMC I or HPMC II were similar in gel hardness while KC formed the softest gel.

Experiment III

Significant two-way interactions (P<0.05) were observed for brine pH, brine viscosity, restructured ham cook yield, 7-day purge (Figure 4), hardness, chewiness, and resilience (Figure 5). Brine pH values for all treatments were similar at 0.6% with KC (Figure 4). The pH values ranged from 7.1 to 7.6 and tended to increase as concentration increased. Viscosity levels for all treatments at 0.2% were similar to the control (Figure 4). Kappa carrageenan low (6.3 cPs) viscosity measurements are similar to those seen in Experiment I and II. As the hydrocolloid percentage increased from 0.4 to 0.6%, the brine solutions containing MC I, HPMC I, and HPMC IIwere more viscous.

Cook yield values for the control and KC were higher at all levels than MC I, HPMC I and HPMC II (Figure 4). Trius and others (1994b) demonstrated that the addition of KC at 0.5% significantly decreased cook loss values in beaker sausage when compared the control. Additionally, hams manufactured with 1.5% KC had increased cook yield values when compared to the control (Prabhu and Sebranek 1997). Treatment HPMC II showed a cook yield increase from 0.6 to 0.8%. Treatment MC I had the highest cook yield value at 0.4% when compared to HPMC I and HPMC II. These results seen for MC I at 0.4% contradict cook yield values seen in experiment II. Ideally,

Table 3: Least square means for pH, color, and gel hardness of hydrocolloid brine solutions (Exp II).

	Hydrocolloid Type[e]				Levels[f]				
	KC	MC I	HPMC I	HPMC II	0.2	0.4	0.6	0.8	SEM[j]
Brine pH[g]	7.28[a]	7.19[b]	7.20[b]	7.21[b]	7.21	7.24	7.24	7.20	0.02
Color (L*)[h]	40.8[d]	50.4[c]	69.3[a]	59.5[b]	52.6	52.5	54.6	58.4	1.9
Gel Hardness (g)[i]	2.2[b]	146.0[a]	7.6[b]	7.6[b]	5.0	17.4	48.5	92.6	33.8

[a-d] Means having different superscripts within rows are significantly different ($p<0.05$).

[e] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I:METHOCEL™ A4M, hydroxypropyl methylcellulose I and II: METHOCEL™ F4M and K4M averaged over all levels.

[f] Level (0.2-0.8%) of hydrocolloid type added to brine solution averaged over all types.

[g] pH of hydrocolloid brine solution at 5°C.

[h] Color (Commission International De L'Eclairage) (CIE); reflectance (L*)of gelled hydrocolloid brine solution utilizing a ColorTec colormeter.

[i] Gel Hardness of heated brine solutions measured in grams using a 5kg load cell and a 1.25 cm diameter acrylic probe.

[j] Standard error of the mean (SEM).

FIGURE 4: Two-way interactions (P<0.05) for brine pH, brine viscosity, cook yield, and 7-day purge of varying combinations of hydrocolloid brine solutions in a meat model system (Exp III).

Fig 4a: Brine pH

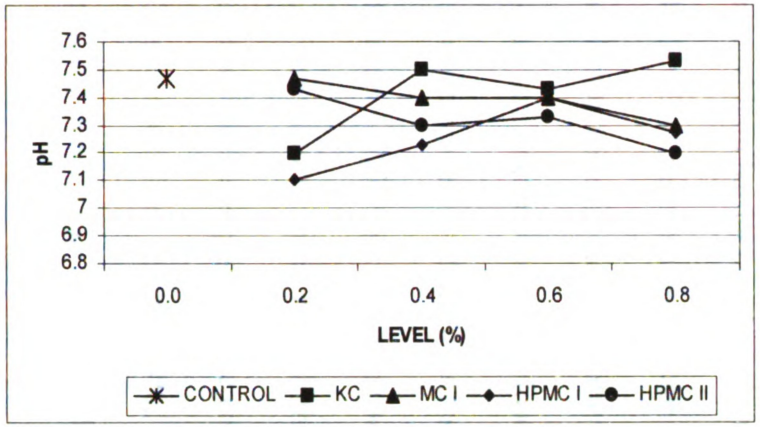


Fig 4b: Brine Viscosity

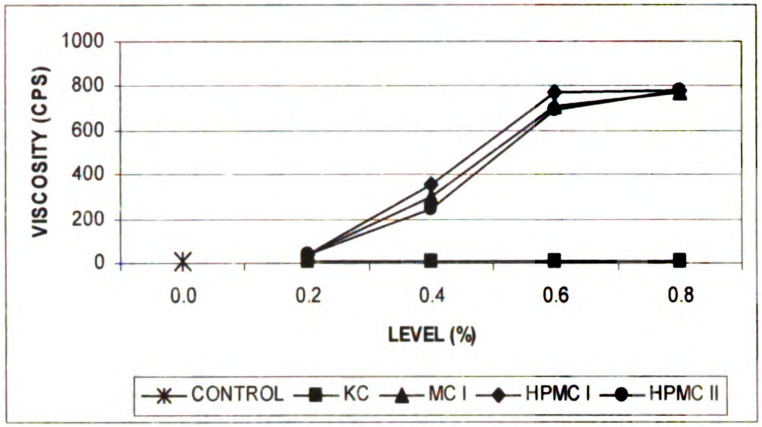


Fig 4c: Cook Yield

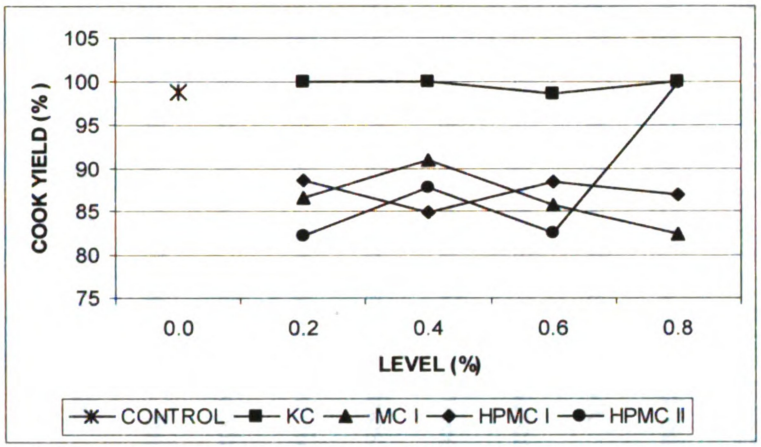
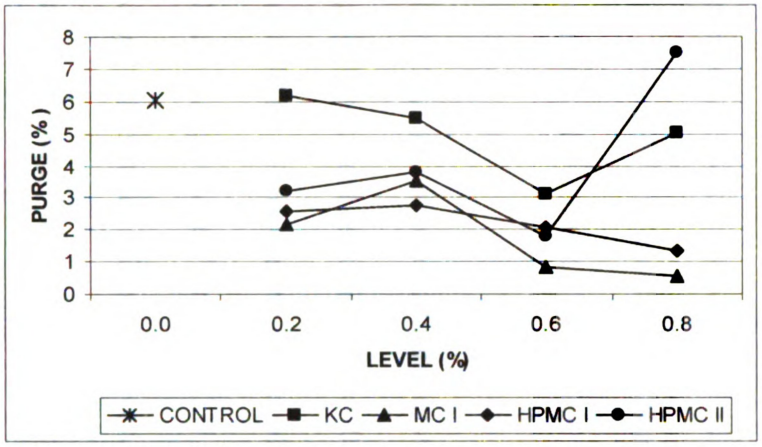


Fig 4d: 7-day Purge



MC I at 0.4% is creating a protein-hydrocolloid interaction that allows for increased water binding in a meat system (Figure 4). Overall, lower cook yield values for MC I, HPMC I, and HPMC II (except HPMC II 0.8%) were expected as earlier studies utilizing MC and HPMC at 1.0% in beef patties showed decreases in cook yield values (Hill and Prusa 1988). Furthermore, a study utilizing 0.2% MC in low-fat frankfurters demonstrated decreased cook yields when compared to the control (Foegeding and Ramsey 1986).

From 0.2 to 0.4% hydrocolloid addition, 7-day purge values tended to increase for all treatments (Figure 4). However, increasing hydrocolloid addition over 0.4% suggested a decrease in purge values for MC I and HPMC I. Increasing hydrocolloid percentages from 0.6 to 0.8% tended to increase 7-day purge values for HPMC II and KC. Overall, MC and HPMC presented lower purge values than KC and the control, demonstrating METHOCEL™'s ability as a potential purge controller.

Restructured ham hardness values decreased with the increased addition of MC I, HPMC I, and HPMC II percentages (Figure 5). In previous studies, Shand and others (1993) indicated that there is general softening effect with the addition of MC that decreases binding and textural values. However, KC did suggest that with increased addition there was improved product hardness. These results confirmed data reported by DeFreitas and others (1997) that stated the addition of 0.5% KC increased hardness of pork sausage. Restructured beef rolls with 0.5 and 1.0% KC showed a significant increase in hardness when compared to the control (Shand and others 1994). Chewiness values for KC increased from 0.2 to 0.4%, then plateaued from 0.4-0.6% and finally decreased from 0.8% (Figure 5). Treatments MC I, HPMC I, and HPMC II steadily

FIGURE 5: Two-way interactions (P<0.0001) for hardness, chewiness, and resilience of restructured ham manufactured with varying levels of hydrocolloid brine solutions in a meat model system.

Fig 5a

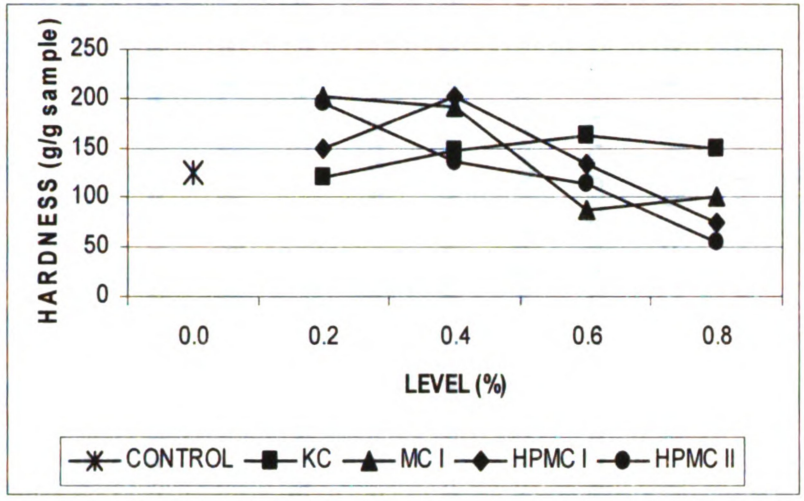


Fig 5b

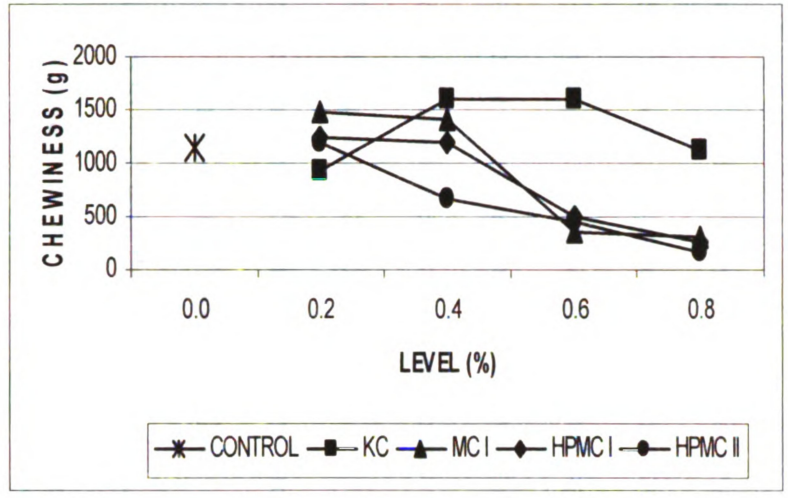
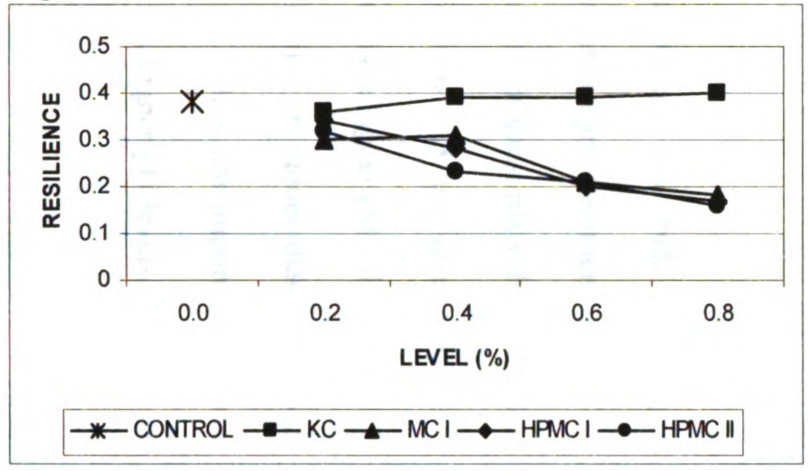


Fig 5c



became less chewy with the increased addition of hydrocolloid percentages. Resilience values were similar for all treatments at 0.2% (Figure 5). Kappa carrageenan increased resilience values at higher hydrocolloid addition levels. Resilience values for MC I, HPMC I, and HPMC II suggest that at increased percentages product resilience is decreased. Resilience is defined as the products ability to retain its bound form when subjected to outside (texture analyzer) forces. These results suggest that the addition of MC or HPMC will decrease the products ability to withstand environmental factors (i.e. textural analysis, slicing, packaging, etc.)

Significant main effects were seen for meat sample raw pH, cooked pH, springiness and cohesiveness (Table 4). Raw restructured ham treatment pH values ranged from 6.09 to 6.15 with the control and KC having the highest pH values. Cooked restructured ham treatment pH values ranged from 6.25 to 6.33 and level pH values ranged from 6.25 to 6.33. The control and KC tended to have higher pH values than MC I, HPMC I, and HPMC II. Control cooked ham had higher pH values than treatments, with the exception of 0.8% level of addition. These pH values are important as water binding and retention is partially dependent upon pH. At higher pH levels, the proteins become more negatively charged, thus repelling each other and allowing for the myofibrillar proteins to swell and retain water, resulting in increased WHC (Hamm 1994; Osburn 2001). In general, a pH at 6.0 is the most effective at increasing water and processed meat binding. At pH 6.0, the gelling and binding of proteins myosin and actomyosin is ideal (Dutson 1983).

Color values (L*, a*, b*) were not different ($P<0.05$) (Table 4). The control and KC were approximately 2 points higher in L* values resulting in a lighter cooked

Table 4: Least square means for pH, color, and texture of restructured ham manufactured with hydrocolloid brine solutions in a model meat system (Exp III).

		Hydrocolloid Type[c]				Levels[d]					
	Control	KC	MC I	HPMC I	HPMC II	0.0	0.2	0.4	0.6	0.8	SEM[k]
Raw pH[e]	6.15[a]	6.12[ab]	6.11[ab]	6.09[b]	6.12[ab]	6.15[a]	6.12[ab]	6.11[ab]	6.10[b]	6.11[ab]	0.01
Cook pH[f]	6.33[a]	6.30[ab]	6.25[b]	6.26[b]	6.26[b]	6.33[a]	6.26[b]	6.28[b]	6.25[b]	6.30[ab]	0.01
Color[g]											
L*[NS]	64.0	64.3	62.6	62.1	62.1	64.0	62.8	63.1	62.7	62.6	2.5
a*[NS]	1.0	0.7	1.2	1.3	1.4	1.0	1.1	1.2	1.3	1.1	0.3
b*[NS]	12.9	12.2	12.5	12.7	12.8	12.9	12.6	12.1	12.5	12.9	0.3
Texture[h]											
Springiness (mm/g)[i]	1.3[a]	1.2[ab]	1.0[ab]	1.0[ab]	0.9[b]	1.3[a]	1.1[ab]	1.1[ab]	1.0[ab]	0.8[b]	0.1
Cohesiveness[j NS]	0.7	0.7	0.6	0.8	0.5	0.7	0.9	0.6	0.6	0.5	0.3

[a-b] Means having different superscripts within rows are significantly different ($p<0.05$).

[c] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I METHOCEL™ A4M, hydroxypropyl methylcellulose I and II METHOCEL™ F4M and K4M averaged over all levels.

[d] Level (0.0-0.8%) of hydrocolloid type added to brine solution and meat model averaged over all types.

[e] Raw ham batter pH at 4°C.

[f] Cooked ham pH at 4°C.

[g] Color (Commission International De L'Eclairage) (CIE); reflectance (L*)of gelled hydrocolloid brine solution utilizing a ColorTec colormeter.

[h] Texture profile analysis: 2- cycle compression using a 5 kg load cell, 75 mm plate and a heavy duty platform.

[i] Springiness is the height the food recovers between the first and second compression.

[j] Cohesiveness is the ratio of positive force area during the 2nd compression to that during the first compression (A_2/A_1).

[k] Standard error of the mean (SEM).

[NS] Not significant ($P>0.05$).

ham product when compared to MC I, HPMC I, and HPMC II. Prabhu and Sebranek (1997) suggest no color differences were seen with the addition of 1.5% KC in ham when compared to the control. However, Mittal and Barbut (1993) reported that low-fat cooked breakfast sausage containing 1% carboxymethyl cellulose decreased L* values compared to low-fat breakfast sausage containing no hydrocolloid gums. Higher a* and b* values were observed in treatments containing MC I, HPMC I, and HPMC II. These results suggest a trend that MC I, HPMC I, and HPMC II may have the potential to improve added water restructured ham meat color by decreasing the dilution muscle protein.

Addition of hydrocolloid gums decreased springiness (mm/g) (Table 4). The control was the springiest treatment with HPMC II being the least springy. These results may be due to the decrease in protein-protein interactions and an increase in protein-hydrocolloid interactions, consequently producing a softer, less springy product. Treatment HPMC I was the most cohesive and treatments MC I and HPMC II were the least cohesive.

Finally, screening for treatments to be utilized in experiment IV was established upon consideration of cook yield and purge values with textural hardness. Throughout experiment III, HPMC II at 0.2, 0.4, and 0.6% suggested the least amount of water retention (cook yield, purge) (Figure 4) and the softest texture. In addition, HPMC II at 0.8% exhibited high cook yields (100%). However, it also demonstrated the highest purge loss (7.8%) as well as soft, crumbly texture thereby eliminating HPMC II from consideration in experiment IV (Figure 4). Treatments MC I, HPMC I, and KC were selected for further use. In the evaluation of hydrocolloid addition levels, it was found

that MC I at 0.4%, HPMC I at 0.6%, and KC at 0.6% combined the most effective combination of increased cook yields, decreased purge values with adequate textural firmness.

Experiment IV

Significant differences ($P<0.05$) were observed for brine viscosity, cook yield, color (L*), 7-day purge (Table 5), hardness, cohesiveness, chewiness, and resilience (Table 6). No significant differences ($P<0.05$) were observed for brine pH, restructured ham raw pH, cooked pH, color (a* and b* values) (Table 5) and springiness (Table 6). Treatments (TRT) within this study are defined as TRT 1: MC I/HPMC I at 0.4/0.6%, TRT 2: MC I/KC at 0.4/0.6%; TRT 3: HPMC I/KC at 0.6/0.6% and TRT 4: MC I/HPMC I/KC at 0.4/0.6/0.6%, and the control (CONT) brine: no hydrocolloid.

Hydrocolloid brine pH values for all treatments ranged from 7.23 to 7.37 (Table 5). Raw meat model pH values ranged from 6.35 to 6.43 and cooked pH values ranged from 6.50 to 6.56 (Table 5). Hydrocolloid brine solution viscosities ranged from 6.3 to 7783.3 centipoise (cPs). Treatment 1 and 4 brines were the most viscous (>7600 cPs). The CONT was significantly the least viscous ($P>0.05$) brine at 6.3 cPs. This result was expected as the CONT was a traditional brine solution with no hydrocolloids added.

Restructured ham L* values for the CONT were higher ($P<0.05$) than TRT's 1 to 4. Treatments 1 to 4 had lower L* values suggesting that the addition of MC or HPMC will improve added water ham color by decreasing reflectance, creating a darker cured meat color (Table 5). Treatment 1 tended to have higher a* values and the CONT had the least redness (a*). These results are in support the theory that the addition of water

Table 5: Least square means for brine viscosity, pH, cook yield, color, and 7-day purge of a restructured ham manufactured with varying combinations of hydrocolloid brine solutions in a model meat system.

	Hydrocolloid Type[c]					
	Control	MC I/HPMC I	MC I/KC	HPMC I/KC	MC I/HPMC I/KC	
Level[f]	0.0	0.4 / 0.6	0.4 / 0.6	0.6 / 0.6	0.4 / 0.6 / 0.6	SEM[n]
Brine pH[g NS]	7.37	7.27	7.33	7.23	7.33	0.04
Brine Viscosity (cPs)[h]	6.3[d]	7690.0[a]	1070.0[c]	3026.7[b]	7783.3[a]	69.2
Raw pH[i NS]	6.40	6.35	6.37	6.43	6.38	0.02
Cook pH[j NS]	6.50	6.53	6.53	6.57	6.53	0.02
% Cook Yield[k]	99.9[a]	96.0[b]	96.3[b]	100.0[a]	100.0[a]	0.4
Color[l]						
L*	66.6[a]	63.6[b]	63.4[b]	62.8[b]	63.4[b]	0.2
a* [NS]	0.6	1.0	1.2	1.0	1.2	0.2
b* [NS]	11.3	12.00	11.5	11.7	11.6	0.7
% 7-Day Purge[m]	7.4[a]	1.4[b]	1.2[b]	0.8[b]	1.3[b]	0.2

[a-d] Means having different superscripts within rows are significantly different ($p<0.05$).

[c] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I: METHOCEL™ A4M, hydroxypropyl methylcellulose I: METHOCEL™ F4M .

[f] Level (0.0, 0.4 & 0.6%) of hydrocolloid type added to brine solution and meat model.

[g] pH of brine solution at 5°C.

[h] Brine viscosity analyzed in centipoise (cPs) at 5°C.

[i] Raw meat pH at 4°C.

[j] Cooked meat pH at 4°C.

[k] Cook yield= Cooked weight/Raw weight*100. Restructured ham cooked to an internal temperature of 71°C.

[l] Color (Commission International De L'Eclairage) (CIE); reflectance (L*), redness (a*), yellowness (b*) on the interior surface of the cooked restructured ham model meat system samples at 4°C utilizing a ColorTec colormeter.

[m] 7-Day percent purge of vacuum packaged, restructured ham samples.

[n] Standard Error of the Mean (SEM).

[NS] Not significant ($P>0.05$)

dilutes the concentration of proteins that are responsible for meat color (Miller 2000) which can result in a paler product color with the use of a CONT brine solution. The b* values were similar.

Treatments 1 and 2 had lower cook yield values than the control or TRTs 3 and 4. However, all these cook yield values are greater than 95%, thereby deeming the addition of hydrocolloid gums in combination successful for increasing cook yields when compared to hydrocolloids gums utilized singularly (Exp III). This suggests that the combination of MC and/or HPMC with KC may create a synergistic effect in which cook yields are increase by more than 10% when compared to experiment III cook yield values.

The 7-day purge values ranged from 0.8 to 7.4% (Table 5). The CONT exhibited the highest purge loss of 7.4%, which is consistent with the results from the previous experiment (Exp III). Treatments 1 to 4 lowered purge loss by at least 6.0% when compared to the CONT. Treatment 3 displayed the lowest purge loss value of 0.8%. These results suggest that there are definite decreases in purge loss while increasing cook yield values over 95%.

Treatment 3 was significantly the hardest (190.0 g) and TRT 1 was the softest (86.6 g) (Table 6). The addition of MC I and HPMC I (TRT1) together in a brine solution may have a softening and tenderizing effect upon cooked meat products. For example, beef patties containing 1.0% HPMC were evaluated by a sensory panel to have increased tenderness (Hill and Prusa 1988). Softening and tenderizing trends with the addition of 0.5 or 1.0 % MC to beef rolls was also reported by Shand and others (1993). However, increased softness values are not desirable in restructured meat products.

Table 6: Least square means for TPA of restructured ham manufactured with varying combinations of hydrocolloid brines in a model meat system.

	Hydrocolloid Type[d]					
	Control	**MC I/HPMC I**	**MC I/KC**	**HPMC I/KC**	**MC I/HPMC I/KC**	
Level[e]	0.0	0.4 / 0.6	0.4 / 0.6	0.6 / 0.6	0.4 / 0.6 / 0.6	SEM[l]
Texture[f]						
Hardness (g/g sample)[g]	114.4^{bc}	86.6^{c}	172.8^{ab}	190.0^{a}	122.6^{bc}	15.2
Springiness (mm/g)[h] NS	1.3	0.9	1.1	1.1	1.0	0.1
Cohesiveness[i]	0.70^{a}	0.51^{c}	0.70^{a}	0.66^{a}	0.59^{b}	0.01
Chewiness (g)[j]	1193.4^{ab}	396.3^{b}	1346.6^{ab}	1495.2^{a}	662.9^{ab}	228.2
Resilience[k]	0.36^{a}	0.19^{c}	0.34^{a}	0.32^{a}	0.25^{b}	0.01

[a-c] Means having different superscripts within rows are significantly different ($p<0.05$).

[d] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I: METHOCEL™ A4M, hydroxypropyl methylcellulose I: METHOCEL™ F4M.

[e] Level (0.0, 0.4 & 0.8%) of hydrocolloid type added to brine solution and meat model.

[f] Texture profile analysis: 2- cycle compression using a 5 kg load cell, 75 mm plate and a heavy duty platform.

[g] Hardness is the peak force during first compression / sample weight (g).

[h] Springiness is the height the food recovers between the first and second compression.

[I] Cohesiveness is the ratio of positive force area during the 2nd compression to that during the first compression (A_2/A_1).

[j] Chewiness is the product of Hardness*Cohesiveness*Springiness.

[k] Resilience is the ratio of the area during the 1st plate withdrawal over the 1st plate penetration.

[l] Standard Error of the Mean (SEM).

[NS] Not significant ($P>0.05$)

Restructured products with high amounts of added water can lose textural integrity; consequently, increased hardness values are desired (Shand and others 1994). Springiness and cohesiveness values were the highest for the CONT and the lowest for TRT 1 (Table 6). These results demonstrate that TRTs containing MC and/or HPMC are less likely to spring back to normal size and bind as a cohesive unit. This suggests that MC and/or HPMC will result in a softer, looser bound end product. Chewiness values ranged from 396.3 to 1495.2 g/sample with TRT 3 being the chewiest and TRT 1 have the least amount of chewiness (Table 6). The CONT tended to have the highest amount of resilience with TRT 1 having least. These results suggest that the addition of MC and/or HPMC may promote a softening effect in restructured ham products that makes them less resilient, less springy, and less cohesive as the CONT. However, these results may also be due to the increased binding of water compared to the CONT resulting in the textural attributes recorded.

Conclusions

The ability of MC I and/or HPMC I with KC to increase water binding and retention while maintaining ham quality was demonstrated in Experiment IV. The data suggest there may be a potential synergistic effect between MC I and/or HPMC I with KC. More research is needed to determine synergistic effects as this study was not designed to determine synergistic effects. This can be done by a statistically planned study. Overall, high-moisture restructured ham in Experiment IV had higher cook yields and lower purge values when compared to the Experiment III. However, when MC I and HPMC I were utilized singularly in a meat system (Experiment III) they performed as previous studies had suggested. Hill and Prusa (1988) and Foegeding and Ramsey (1986)

both determined at the use of METHOCEL™ significantly decreases water binding abilities.

Study I determined that the use of varying combination hydrocolloid brine solutions in a high-moisture restructured ham (Experiment IV) has purge controlling attributes. Although this study was performed bench top, there is still sizeable evidence that these combination treatments (Experiment IV) will be an advantage in commercial ham production. These formulations will be scaled up and issues will be addressed in study II concluding with a trained sensory panel.

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CHAPTER 4

EVALUATION OF HYDROCOLLOID INGREDIENTS AS PURGE CONTROLLERS IN HIGH-MOISTURE RESTRUCTURED HAM

ABSTRACT

Hydrocolloid brine solutions were formulated using methylcellulose (MC), hydroxypropyl methylcellulose (HPMC) and kappa carrageenan (KC): 1) MC 0.4% & KC 0.6%; 2) HPMC 0.6% & KC 0.6%; 3) MC 0.4% & HPMC 0.6% & KC 0.6%; 4) KC 0.6%; 5) Control: no hydrocolloids, and evaluated as purge controllers. TRTs (45% addition wt/tw) were mixed into a restructured ham formulation ground and thermally processed to 70°C. TRT 1 and 3 increased ($P<0.05$) cook yields and decreased purge values by >1.5%. TRT 1, 2, and 3 improved ham exterior and interior L* surface values and textural values. TRTs containing MC and/or HPMC with KC may control purge and maintain product quality attributes.

This chapter is formatted in manuscript style according to the Journal of Food Science.

Key Words: hydrocolloids, purge controllers, restructured ham

Introduction

As the amount of added water in high-moisture (>45% addition) restructured ham increases, the ability to retain water during thermal processing and minimize purge during storage decreases (Prabhu and Sebranek 1997). With the addition of non-meat ingredients such as binders, extenders, or purge controllers, increased water binding and retention has been documented. Kappa carrageenan (KC) is a purge controlling hydrocolloid that is readily utilized, industry-accepted, and processor-friendly. Previous studies have shown that the addition of 0.5% KC improves cook yield, decreases purge values, and improves sliceability in cured turkey breast and turkey ham sectioned and formed products (Bater and others 1992; Bater and others 1993). Shand and others (1994) utilized 0.5 and 1.0% KC in lean structured beef rolls resulting in improved texture, increased water retention, and decreased purge. Additionally, 0.5% KC was incorporated into cooked pork sausage to effectively decrease freeze/thaw purge values (DeFreitas and others 1997). Bater and others (1993) also found that the addition of 0.5% KC decreased freeze/thaw purge values by 1.5% in cured ham-like turkey product.

The incorporation of methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC) may also enhance restructured product tenderness and juiciness. The utilization of MC and/or HPMC may enable the meat processor to further use lower quality, tough meat cuts with more connective tissue due to their tenderizing ability. Hill and Prusa (1988) noted the addition of 1% HPMC to lean ground beef patties increased tenderness and juiciness when compared to the control. Shand and others (1993) also saw a significant decrease in hardness values for structured beef rolls with 0.5 and 1.0% MC.

Chicken patties with 0.25 and 0.5% MC were more tender and juicy when compared to the control (Steinke 2001).

The combining of MC and/or HPMC with KC may provide a potential synergistic effect when incorporated into meat products as a brine solution, thereby promoting water binding and retention during thermal processing and subsequent storage. Utilizing hydrocolloid gums that gel upon thermal processing (MC and HPMC) with KC that gels upon cooling following thermal processing may entrap added water during the cooking and cooling process. Additionally, phosphates within the brine solution will contribute to water holding capacity and flavor enhancement (Barbut and others 1988; Matlock and others 1984; Keeton and others 1984), while salt improves WHC, cooked color scores, and sensory attributes (Schwartz and Mandigo 1976). However, further research is necessary to determine if MC and/or HPMC with KC exhibit a synergistic purge controlling effect in high-moisture restructured ham. The hypothesis was high-moisture restructured ham manufactured with varying combinations of hydrocolloids (MC, HPMC, KC) can control purge without detrimental effects on textural and sensory attributes.

The specific objective of this study was to investigate the effects of incorporating hydrocolloid brine solutions into a high-moisture (45% added water) restructured ham product on cook yield, purge, and quality attributes.

Materials and Methods

Preliminary Study

A preliminary study was conducted to confirm Study I results in a pilot plant setting. The hydrocolloid brine solutions from Experiment IV (Study I) and three control hydrocolloid brine solutions were used to manufacture added water (45% wt/wt) restructured hams. Hydrocolloid (A4M: MC I; F4M: HPMC I; KC; Control: no hydrocolloids) brine solution treatments (TRT) formulated were:

TRT 1 – 0.4% MC I x 0.6% HPMC I

TRT 2 – 0.4% MC I x 0.6% KC

TRT 3 – 0.6% HPMC I x 0.6% KC

TRT 4 – 0.4% MC I x 0.6% HPMC I x 0.6% KC

TRT 5 – Control

TRT 6 – 0.4% MC I

TRT 7 – 0.4% HPMC I

TRT 8 – 0.6% KC

Ground ham muscle (5.7 kg) and 2.6 kg of either a hydrocolloid or control brine (45% addition) solution were mixed together for 10 min in a modified double axel paddle mixer (Model T-268, Keebler Engineering Inc., Chicago, IL). Mixed restructured ham batter was placed into a vacuum stuffer (Model 500, VEMAG Maschinenbau GmbH, Germany), stuffed into pre-soaked 11.4 cm x 76.2 cm fibrous, non-perforated, preclipped casings (Devro-Teepak, Inc., Kansas City, MO.), and clipped using a Tipper Tie Clipper (Model PR465L, Dover Industries Co., Aspex, NC). Restructured hams were thermally

processed to an internal temperature of 70°C utilizing a one truck smokehouse (CGI Processing, Model A28- B0101, Automated Manufacturing, Cicero, IL). Thermally processed restructured hams were placed into a 2-4°C cooked meat cooler and chilled to 4°C for approximately 16 hrs according to Appendix B guidelines (USDA-FSIS). All restructured ham treatments were subjectively evaluated for casing peelability, ham firmness, sliceability, and cook yield. Restructured ham formulations that exhibited poor cook yields, sliceability and/or soft texture were eliminated from further investigation. Acceptable restructured hams were formulated from TRT 2, 3, 4, 5, and 8. These hams were sliced (1.27 cm), vacuum packaged and stored (2°C) for sensory panel training.

Experimental Design and Data Analysis

The experimental design for this study was a one-way ANOVA with three treatment combinations (0.4% MC I/0.6% KC, 0.6% HPMC I/0.6% KC, 0.4% MC I/0.6% HPMC I/0.6% KC) at 45% addition (wt/wt), with a hydrocolloid brine control (KC at 0.6 %; 45% addition wt/wt) and a control (no hydrocolloid; 45% addition, wt/wt). Main effect means were separated by Tukey's Honest Significant Difference test with a predetermined level of significance ($P<0.05$) (SAS user's guide, version 8.2. Cary, NC: SAS Institute, Inc., 2002).

Hydrocolloid Ingredients

The hydrocolloid ingredients were described previously in Chapter 3.

Manufacturing Process

A. Brine Manufacturing

Three multi-hydrocolloid brine solutions, a KC, and a control brine solutions were prepared for each replication for each treatment group (Appendix 9). Each brine solution was formulated prior to each restructured ham production day. The formulated treatment brine solutions were:

Treatment 1 – 0.4% MC I x 0.6% KC

Treatment 2 – 0.6% HPMC I x 0.6% KC

Treatment 3 – 0.4% MC I x 0.6% HPMC I x 0.6% KC

Treatment 4 – 0.6% KC

Treatment 5 – Control

Treatment brine solutions (11.4 kg) were placed in plastic containers and mixed using a Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by Michigan State University at 1200 rpm during the addition of phosphate, salt, and sugar. During the addition of the hydrocolloid gum(s) mixing speed was increased to 1500 rpm to fully entrain hydrocolloid. Total mixing time was 20 minutes per brine. The brines were covered and placed in a 2°C cooler for 12-16 hrs. Upon completion of storage (12-16 hrs), brines were remixed for 1 minute at 1200 rpm. Nitrite and erythorbate were then added and mixed for an additional 2 minutes at 1200 rpm.

B. Restructured Ham Processing

Fresh, boneless, semimembranosus muscle (IMPS 402F), with the gracilis muscle on, was acquired from a local meat company. Ham muscles were randomly selected and trimmed to remove the gracilis muscle and external fat. The ham muscles were weighed according to the appropriate product formulation, placed in plastic meat lugs and covered with Saran™ wrap.

Fresh pork semimembranosus muscles (gracilis muscle removed) were sorted in 5.7 kg batches per restructured ham treatment. The ham muscles were further divided into three 1.9 kg batches for grinding into three different particle sizes (Prabhu and Sebranek 1997). One 1.9 kg batch was ground through a 5.33 cm plate (kidney plate), the second batch was ground through 2.54 cm plate and the last batch was ground through a 0.95 cm plate (TORREY Grinder Model M-32-5, Maquinas Para Mercados, S.A. DE C.V., Mexico). The ground ham muscles (5.7 kg, 1.9 kg of each particle size) and 2.6 kg of either a hydrocolloid or control brine (45% addition) solution (Appendix 9) were placed into a modified double axel paddle mixer (Model T-268, Keebler Engineering Inc., Chicago, IL) and mixed for 10 min. Upon completion of mixing, a sample for raw proximate analysis and pH determination were collected. Mixed restructured ham batter was placed into a vacuum stuffer (Model 500, VEMAG Maschinenbau GmbH, Germany), stuffed into pre-soaked 11.4 cm x 76.2 cm fibrous, non-perforated, preclipped casing (Devro-Teepak, Inc., Kansas City, MO.), and clipped using a Tipper Tie Clipper (Model PR465L, Dover Industries Co., Apex, NC). Stuffed and clipped ham chubs were weighed and recorded as a treatment group. Restructured ham chubs were hung on smoke sticks and placed on a smoke truck for thermal processing.

C. Thermal Processing

Thermal processing was achieved utilizing a one truck smokehouse (CGI Processing, Model A28- B0101, Automated Manufacturing, Cicero, IL) to an internal temperature of 70°C (Table 7).

Table 7: Smokehouse Schedule

Stage	Time (Min)	Internal (°C)	Smoke	Dry Bulb (°C)	Wet Bulb (°C)	Fan	Damper
1	15	0	no	43.3	37.8	50	Open
2	30	0	no	54.4	43.3	50	Open
3	30	0	no	60.0	46.1	50	Open
4	30	0	no	65.6	48.9	50	Open
5	45	62.8	no	71.1	54.4	50	Open
6	120	62.8	no	71.1	62.8	50	Open
7	240	70.0	Steam	79.4	71.1	50	Open
Shower	30	54.4	No	1 min on	1 min off	100	Closed

Following the shower cycle, the restructured hams were removed from smokehouse once an internal product temperature of 54.4°C was reached. The restructured hams were allowed to equilibrate to an internal temperature of 37.8°C (30 min) at 20°C. Excess water was removed and the treated products were weighed to determine product cook yields (37.8°C). The restructured hams were then allowed to equilibrate to an internal temperature of 32.2°C (15 min) at 20°C prior to chilling.

D. Chilling, Slicing, and Packaging Process

Thermally processed restructured hams were placed into a 2-4°C cooked meat cooler and chilled for approximately 16 hours to an internal temperature 2-4°C according to Appendix B guidelines (USDA-FSIS). Casings were then removed from hams and discarded.

Three restructured ham chubs per treatment were sliced into 1.27 cm thick slices using a Globe meat slicer (Model 775L, Mozley Mfg. Co. Inc., Stamford, CN). Restructured ham slices were randomly selected and vacuum packaged. Two slices were packaged for cooked proximate composition and pH determination and stored in a -

28.8°C freezer. Twelve randomly selected ham slices were vacuum packaged (30.5 cm x 35.6 cm bags) (Cryovac Sealed Air Corp., Duncan, SC) for trained sensory panel evaluation. One ham slice was randomly selected for day 0 lipid oxidation analysis, packaged and heat sealed (Diagger, Lincolnshire, IL). Four ham slices were randomly selected for textural analysis - two for objective texture profile analysis and two slices for Kramer Shear analysis then packaged into 17.8 cm x 30.5 cm bags. Twenty ham slices were randomly selected for color, purge, and lipid oxidation analyses; 4 slices per day, 2 slices per bag (17.8 cm x 30.5 cm), 2 bags per treatment for evaluation on day 7, 14, 21, 28, and day 56 of refrigerated (4°C) storage. All vacuum packaged samples were packaged using a Multivac vacuum packager (AGW, SeppHaggenmuller KG, Germany) with a vacuum setting of 2.5 vacuum and a heat sealer bar setting of 3.0.

Restructured Ham Storage

Vacuum packaged restructured ham slices were placed in a 4°C, walk-in cooler. Packages were laid flat, non-overlapping on white plastic trays which were placed on tables 2.08 meters from a constant light source. The cooler contained 10 lighting fixtures and 2 fluorescent lamps (Model F40SP41, General Electric, Cleveland, OH) per fixture (n=20). Lighting was monitored everyday for a total of 56 days, burnt lamps were changed as needed and remained on throughout the study. Foot-candle (FC) readings (FC=80) were taken using a GE Triple Range Light Meter (Model 217, General Electric, Cleveland, OH) from the surface of the ham slice. The foot-candle reading (FC =80) is equivalent to 24,407 lumens.

Analyses

A. Hydrocolloid Brine solution and product pH Determination

Brine solution and raw and cooked restructured ham pH values analyses were determined as previously described in Chapter 3.

B. Product Cook Yield Determination

Cooked product yield was determined as previously described in Chapter 3.

C. Color Analysis, TBA analysis and Purge loss

Objective color determinations for the exterior ham surface (exposed to light) and the interior ham surface (unexposed to light) was measured using a Minolta Chromameter (Model CR-310, Minolta Camera Co., Ramsey, NJ). Three readings were taken and averaged for L* (lightness), a* (redness), and b* (yellowness) values (Commission Internationale De L'Eclairage (CIE)). The chromameter was set on D_{65} illuminant (daylight illuminator), 2° standard observer, with a 50 mm reading orifice. The chromameter was calibrated on a standard white and the pink color tile. Color readings were taken for day 0, 7, 14, 21, and 28.

Thiobarbituric acid reactive substance (TBARS) analysis was conducted on day 0, 14, 28, and day 56, to monitor oxidative rancidity. Four replicates were run for each sample according to methods established by Tarladgis and others (1960) and Zipser and others (1962) as modified by Rhee (1978). Percent purge was determined for days 7, 14, 21, 28, and day 56 of refrigerated (4°C storage) as previously described in Chapter 3.

Proximate Composition

Moisture (oven drying), fat (Soxhlet ether extraction), and protein (nitrogen measurement, Model FP-2000, LECO Co., St. Joseph, MO) were determined according to AOAC (2000) methods. Samples were analyzed in triplicate.

Textural Analyses

A. Texture Profile Analysis (TPA):2-cycle Compression

Restructured ham slices were analyzed using the 2-cycle compression test method, utilizing a TA-HD*i* Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY). Two restructured ham slices per treatment were removed from vacuum packaged bags and held at 4°C. Two circular samples 1.9 cm diameter x 1.3 cm thick, were cut from the center from each ham slice. Each treatment was analyzed in quadruplicate. A 5 kg load cell was used to measure hardness, springiness, cohesiveness, chewiness, and resilience using a 75 mm diameter aluminum cylinder plate (TA-30), on a heavy duty platform (TA-90). Samples were compressed to 25% of original height (75% compression) in a 2-cycle compression at 4-6°C with a crosshead speed of 1.7 mm/s.

B. Kramer Shear Force Determination

Restructured ham slices were analyzed using the Kramer 5-blade shear force test method, utilizing a TA-HD*i* Texture Analyzer (Texture Technologies Corporation, Scarsdale, NY). Two restructured ham slices per treatment were removed from vacuum packaging and covered to prevent surface drying at 4°C. A rectangular sample measuring 7.9 cm x 6.4 cm x 1.3 cm was cut from the center of each ham slice using a pre-made plastic template. A 50 kg load cell with a crosshead speed of 1.7 mm/s was used to measure peak force in Newtons (N) required to shear the restructured ham slice.

Trained Sensory Panel Evaluation

A trained sensory panel (n=6)was utilized to determine specific sensory attributes of each restructured ham product. The panel was trained according to AMSA (1995) and

Meilgaard and others (1991). Each restructured ham treatment was evaluated using 8 point hedonic scale where 1=extremely soft and 8=extremely hard, 1=extremely dry and 8=extremely juicy, 1=no residue/mouth coating and 8=abundant residue/mouth coating, 1=no off-flavor detected and 8=abundant off-flavor. Samples were prepared by cutting 1.27 cm^3 cubes from the center portion of each ham slice and were served cold (4-6°C). To minimize positional bias, the order of sample preparation was randomized within each session (Meilgaard and others 1991).

Testing took place in climate controlled, partitioned booths with cool incandescent light. Three cubes were placed in a plastic custard dish and held, covered to prevent surface drying in a 4°C cooling unit until served. Each sample was served to panelists through a vertical sliding door that separated the food preparation area from the sensory testing area. Panelists were instructed to handle sample cubes with supplied wooden toothpicks, and tasted for hardness, juiciness, residue/mouth coating, and off-flavor intensity. Expectorant cups were provided to prevent taste fatigue as the panelists were instructed not to swallow the samples. Distilled, deionized water and unsalted soda crackers were used to clean the palate between samples. Fifteen (4 treatments, 1 control and 3 replications) samples were evaluated in one day. The day was divided into 3 sessions with 5 samples evaluated per session. The panelists were standardized for each session by evaluating 1 warm-up sample and discussing the results. The warm-up samples were either the control or the KC treatment. There was 5 minutes between each sample and a 15 minute break between sessions.

Results and Discussion

Differences ($P<0.05$) between treatments were observed for cook yield, textural measurements (TPA and Kramer shear), sensory attributes and proximate composition. No significant ($P<0.05$) treatment by day interactions for purge, lipid oxidation, and color (L*, a*, b*) were seen from day 0-56. Significant main effect differences ($P<0.05$) between day of storage (7-56) were also observed for purge loss, lipid oxidation and color (L*, a*, and b*). No significant main effect differences between treatments ($P>0.05$) were observed for brine pH, restructured ham raw pH, cooked pH, and raw batter % fat proximate composition. No main effect differences ($P>0.05$) were seen between storage days for color (L*, a*, and b*). Treatments (TRT) within this study will be referenced as follows: TRT 1: MC I/KC at 0.4/0.6%, TRT 2: HPMC I/KC at 0.6/0.6%; TRT 3: MC I/HPMC I/KC at 0.4/0.6/0.6%, TRT 4: KC at 0.6%, and TRT 5: the control brine: no hydrocolloid.

Brine pH measurements between treatments ranged from 7.27 to 7.43 (Table 8). Treatment 1 had the highest brine pH value and TRT 4 the lowest. Restructured ham raw pH values ranged from 6.42 to 6.47 and cooked ham pH values ranged from 6.50 to 6.53. No differences in pH (brine, raw ham, cooked ham) due to treatments were observed.

Treatment 5 raw restructured ham moisture was the highest and TRT 1 had the lowest % moisture content (raw) (Table 8). Raw percent fat values ranged from 1.3 to 1.4%. Raw ham protein content values were the highest for TRT 1 and the lowest for TRT 4. The dilution of meat protein is due to 45% brine addition. Cooked ham percent Moisture content varied by more than 3% between TRTs. TRT 4 had the highest cooked moisture composition at 77.0%, 2% higher than the other treatments within the study and

Table 8: Least square means for pH and proximate composition of high-moisture restructured ham manufactured with varying combinations of hydrocolloid brines.

	Hydrocolloid Type[d]					
Treatment[e]	**1**	**2**	**3**	**4**	**5**	
	MC I/KC	**HPMC I/KC**	**MC I/HPMC I/KC**	**KC**	**Control**	
Level[f]	0.4 / 0.6	0.6 / 0.6	0.4 / 0.6 / 0.6	0.6	0.0	**SEM[k]**
Brine pH[g] [NS]	7.43	7.37	7.40	7.27	7.30	0.07
Raw pH[h] [NS]	6.47	6.45	6.47	6.43	6.42	0.01
Cooked pH[i] [NS]	6.52	6.53	6.53	6.52	6.50	0.01
Proximate Composition[j]						
Raw						
% Moisture	79.2^{c}	80.5^{bc}	80.0^{bc}	81.3^{ab}	82.0^{a}	0.4
% Fat[NS]	1.4	1.3	1.4	1.3	1.4	0.1
% Protein	16.5^{a}	15.4^{ab}	15.5^{ab}	15.1^{b}	16.0^{ab}	0.3
Cooked						
% Moisture	75.7^{a}	73.3^{b}	73.2^{b}	77.0^{a}	75.3^{ab}	0.5
% Fat	1.6^{b}	2.3^{ab}	2.1^{ab}	2.2^{ab}	2.5^{a}	0.2
% Protein	20.5^{bc}	22.5^{a}	22.3^{a}	19.5^{c}	21.3^{ab}	0.4

[a-c] Means having different superscripts within rows are significantly different ($p<0.05$).
[d] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I: METHOCEL™ A4M, hydroxypropyl methylcellulose I: METHOCEL™ F4M.
[e] Treatment identification of brine solution.
[f] Level (0.0, 0.4 & 0.6%) of hydrocolloid type added to brine solution and meat model.
[g] pH measurement of brine at 5°C.
[h] pH measurement of raw ham samples at 4°C, 1 week post-processing.
[i] pH measurement of cooked ham samples at 4°C, 1 week post-processing.
[j] Proximate Composition: Percent moisture, fat, and protein of raw and cooked high-moisture restructured ham samples.
[k] Standard error of the mean (SEM).
[NS] Not significant ($P>0.05$)

significantly higher than TRT 2 and 3. These results are supported by higher cooked product moisture content (76-78%) in structured beef rolls with 0.5 and 1.0% KC (Shand others 1994). Bater and others (1992) utilizing 0.5% KC in roasted turkey breast also demonstrated higher percent moisture values when compared to the control. Numerically TRT 4 raw and cooked restructured ham samples consistently recorded the highest percent moisture content and the lowest percent protein composition.

Cook yield values between the treatments ranged from 83.1 to 91.6% (Table 9). TRTs 1 and 3 had the highest cook yield values at 91.9 and 91.6% respectively, significantly higher than TRT 2 and 5. TRT 5 had the lowest cook yield value at 86.1% and TRT 2 was similar to TRT 5 at 83.2%. TRTs 1 and 3 may be demonstrating a synergistic or additive effect between MC I and KC that allows for increased water binding. Numerous studies have shown that utilizing MC or HPMC singularly will significantly decrease moisture retention (Foegeding and Ramsey 1986; Hill and Prusa 1988; Shand and others 1993; Mittal and Barbut 1993). The decrease in cook yields due to the addition of MC and HPMC was also shown in Study I, Experiment III. However, there is no previous research combining MC and/ or HPMC with KC to substantiate these cook yield results. Chicken patties with 0.25% MC had a significantly higher cook yield value (75.58%) when compared to the control (74.66%) (Steinke 2001).

Purge values between treatment ranged from 4.3 to 0.9% and storage day purge values ranged from 2.0 to 2.5% (Table 9). TRT 2 had the lowest purge value at 0.90%, a 3.4% greater ($P<0.05$) purge reduction when compared to TRT 5 (4.3%) and greater than 1.9% purge reduction when compared to TRT 4 (2.8%). Increasing length of storage suggested an increase in purge values. Day 56 storage was the highest in purge loss

Table 9: Least square means for TBARS, percent purge, and percent cook yield of high-moisture restructured ham manufactured with varying combinations of hydrocolloid brines.

	Hydrocolloid Type[e]											
Treatment[f]	**1**	**2**	**3**	**4**	**5**							
	MC I/KC	**HPMC I/KC**	**MC I/HPMC I/KC**	**KC**	**Control**	**Days**						
Level[g]	0.4 / 0.6	0.6 / 0.6	0.4 / 0.6 / 0.6	0.6	0.0	0	7	14	21	28	56	**SEM[k]**
% Cook Yield[h]	91.9[a]	83.2[c]	91.6[a]	90.0[ab]	86.1[bc]							0.9
% Purge[i]	1.49[c]	0.90[d]	1.31[c]	2.79[b]	4.31[a]	-	2.0[b]	2.2[ab]	2.1[b]	2.1[b]	2.5[a]	0.1
TBARS[j]	0.09	0.011	0.010	0.09	0.010	0.08[b]	-	0.11[a]	-	0.10[ab]	0.11[a]	0.01

[a-d] Means having different superscripts within rows are significantly different ($p<0.05$).

[e] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I: METHOCEL™ A4M, hydroxypropyl methylcellulose I: METHOCEL™ F4M.

[f] Treatment identification of brine solutions

[g] Level (0.0, 0.4 & 0.6%) of hydrocolloid type added to brine solution and meat model.

[h] % Cook yield= Cooked weight/Raw weight*100. Restructured hams cooked to 70°C.

[i] % Purge = dry sample wt + dry bag wt. / total sample package (sample + bag) weight.

[j] TBARS = 2-Thiobarbituric acid reactive substances test evaluating mg malonaldehyde/kg of restructured ham sample per treatment and on day 0, 14, 28 and 56.

[k] Standard error of the mean (SEM).

while day 7 was the lowest. TRT 4 purge values are similar to high-moisture ham manufactured with 1.5% KC in a study conducted by Prabhu and Sebranek (1997). Shand and others (1994) also had a significant decrease in purge values by 2.2 and 1.6% when utilizing KC at 0.5 and 1.0% in structured beef rolls when compared to the control (10% purge). TRTs 1, 2, and 3 were the most effective at decreasing purge loss. Treatment 1 combined the highest cook yield value (91.9%) with a purge loss value of 1.5%. These values are significantly higher than TRT 5. This is a decrease of purge by 2.8% when compared to the TRT 5 and a decrease of 1.3% when compared to TRT 4. These decreases in water loss are of special interest from an industry perspective. Over time decreasing purge by 2.8% and increasing cook yields by 5.8% may create profitable revenues for the meat processor. Additionally, the increase in water retention and binding can also be beneficial to the consumer as it would potentially decrease product cost at the retail case. The binding of more water could also provide a product that is blander in flavor, lower in calories, and more appealing to a wider consumer population.

Lipid oxidation (TBARS) values ranged from 0.08 to 0.114 for all treatment and storage days indicating very little lipid oxidation (Table 9). No differences between treatments were significant ($P>0.05$). Days 14 and 56 had the highest TBARS values while day 0 TBARS analyses were the lowest. Although, there was a difference between days this difference is not of practical significance.

Color was analyzed on the exposed and unexposed surfaces of the ham samples. There were significant differences ($P<0.05$) between treatments for lightness (L*), redness (b*), and yellowness (a*) on the exposed and unexposed ham slice surfaces (Table 10). These variations in color may be due to the inconsistency of the ham slice

surface. Prior to restructuring, inside ham muscles were ground to 3 different particle sizes (5.33 cm, 2.54 cm and 0.95 cm). This creates a very non homogenous surface area compared to the homogeneity that would be seen in frankfurters and other emulsified products. During color analysis, ham slice would be expected to vary in the portion of particle sizes displayed in the exterior and interior surfaces of each individual ham slice, resulting in variation of color measurements. Lightness (L*) measurements for TRT 2 exposed and unexposed ham surfaces were lower compared to other treatments (Table 10). TRTs 4 and 5 tended to have the lightest colored ham samples for both the exposed and unexposed readings. Mittal and Barbut (1993) reported that low-fat cooked breakfast sausage containing 1% carboxymethyl cellulose decreased L* values compared to low-fat breakfast sausage containing no hydrocolloid gums. Steinke (2001) also found chicken patties with 0.25 and 0.50% MC resulted in a lighter colored product. Steinke's (2001) findings contradict L* results seen within this study.

Lightness measurements between storage days (0-28) were different ($P<0.05$) for unexposed areas (Table 10). Numerically, day 0 reported the highest L* values between days. Overall, TRTs 1, 2, and 3 exhibit an ability to sustain acceptable cured meat color over storage time. This is a valuable attribute since ham with 45% added water is initially lighter in color. Redness (a*) values for TRT 3 samples were redder in color for exposed and unexposed a* values than the other treatments. These results also suggest future research needs to be conducted to identify the reasoning for why TRT 1, 2, and 3 retain more redness (a*) when compared to TRT 4 and 5. TRT 4 tended to have lower redness values when compared all remaining TRTs. Generally, as the length of storage increased, redness values increased for both the exposed and unexposed surfaces.

Table 10: Least square means for color analyses of restructured high-moisture ham manufactured with varying combinations of hydrocolloid brines.

	Hydrocolloid Type[f]										
Treatment[g]	**1**	**2**	**3**	**4**	**5**						
	MC I/KC	**HPMC I/KC**	**MC I/HPMC I/KC**	**KC**	**Control**	**Days**					
Level[h]	0.4 / 0.6	0.6 / 0.6	0.4 / 0.6 / 0.6	0.6	0.0	0	7	14	21	28	**SEM[l]**
Surface Color[i]											
Exposed L*	68.2^{cd}	67.3^{d}	68.3^{bc}	69.2^{a}	69.1^{a}	68.8^{j}	68.3	68.4	68.3	68.4	0.2
Unexposed L*	68.3^{bc}	67.5^{c}	68.3^{bc}	69.2^{ab}	69.7^{a}	69.1^{a}	68.8^{ab}	68.2^{ab}	68.0^{b}	68.9^{ab}	0.3
L* Difference[k]	1.1	1.4	1.6	1.4	1.2	1.1	1.4	1.4	1.2	1.7	0.2
Exposed a*	18.1^{bc}	18.4^{ab}	18.9^{a}	17.8^{c}	18.0^{bc}	17.8^{a}	18.1^{ab}	18.4^{a}	18.5^{a}	18.5^{a}	0.1
Unexposed a*	18.6^{bc}	18.9^{ab}	19.1^{a}	18.1^{d}	18.2^{cd}	17.7^{c}	18.2^{b}	18.9^{a}	18.8^{a}	19.2^{a}	0.1
a* Difference	0.9	0.9	0.6	0.6	0.8	0.5^{b}	0.7^{b}	0.9^{ab}	0.6^{b}	1.1^{a}	0.1
Exposed b*	4.34^{c}	4.53^{b}	4.71^{a}	3.86^{d}	3.60^{e}	4.10	4.26	4.22	4.20	4.25	0.04
Unexposed b*	4.55^{b}	4.60^{b}	5.00^{a}	4.03^{c}	3.78^{d}	4.18^{b}	4.46^{a}	4.43^{a}	4.38^{a}	4.51^{a}	0.04
b* Difference	0.36^{a}	0.21^{b}	0.36^{a}	0.26^{ab}	0.22^{ab}	0.20	0.30	0.32	0.28	0.32	0.04

[a-e] Means having different superscripts within rows are significantly different ($p<0.05$).

[f] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I: METHOCEL™ A4M, hydroxypropyl methylcellulose I: METHOCEL™ F4M.

[g] Treatment identification of brine solutions

[h] Level (0.0, 0.4 & 0.6%) of hydrocolloid type added to brine solution and meat model.

[i] Color (Commission Internationale De L'Eclairage) (CIE); reflectance (L*), redness (a*), yellowness (b*) of cooked restructured ham samples on the exposed and unexposed surface at 4°C utilizing a ColorTec colormeter.

[j] NS= Values without superscripts are not significant ($P>0.05$).

[k] Values reported are statistically analyzed absolute differences between exposed and unexposed surface color for the repetitions (1-3).

[l] Standard error of the mean (SEM).

Unexposed surfaces did have higher a* values than exposed surfaces due to less light exposure. Yellowness (b*) values for TRTs 1, 2, and 3 were higher than TRT 4 and 5 for both exposed and unexposed surfaces. Unexposed b* values were higher in yellowness scores than the exposed ham surface measurements between the five treatments. As the storage day increased, b* values also increased for the unexposed ham surface.

Hardness (kg/g sample) values ranged from 0.16 to 0.34 (Table 11). TRTs 2, 4 and 5 were harder than TRT 3. Treatment 3 was the softest in texture. These results are supported by a study conducted by Hill and Prusa (1988) that documented lean beef patties treated with 1% MC or HPMC were significantly more tender than the control. DeFreitas and others (1997) noted that the addition of 0.5% KC increased hardness of cooked pork sausage. Increased hardness values were also documented for structured beef rolls with 0.5 and 1.0% KC (Shand and others 1994) and beaker pork sausage manufactured with 0.5% KC (Trius and others 1994). These examples of increased hardness values are desirable attributes in high-moisture ham products. As the amount of water is increases in a high-moisture restructured ham there is a loss of textural integrity. Hydrocolloid gums may give the processor the ability to increase water levels yet maintain textural quality. Treatment 5 exhibited the highest values for springiness, cohesiveness, chewiness, and resilience while TRT 3 exhibited the lowest. Mittal and Barbut (1993) also found that cellulose gums decreased springiness and cohesiveness in low-fat cooked breakfast sausage. These results indicate that the addition of MC and/or HPMC may create a softer, looser bound product that is less resilient to external factors.

Kramer shear force (kg/g) values ranged from 0.37 to 0.50 kg/g with TRT 3 requiring the least force to shear throughthe ham slice (Table 11). TRT 4 required the

Table 11: Least square means for TPA and 5-blade Kramer shear of high-moisture restructured ham manufactured with varying combinations of hydrocolloid brines.

	Hydrocolloid Type[d]					
Treatment[e]	**1**	**2**	**3**	**4**	**5**	
	MC I/KC	**HPMC I/KC**	**MC I/HPMC I/KC**	**KC**	**Control**	
Level[f]	0.4 / 0.6	0.6 / 0.6	0.4 / 0.6 / 0.6	0.6	0.0	**SEM[n]**
TPA[g]						
Hardness (kg/g sample)[h]	0.26^{ab}	0.32^{a}	0.16^{b}	0.34^{a}	0.34^{a}	0.02
Springiness (mm/kg)[i]	0.88^{a}	0.86^{ab}	0.78^{b}	0.91^{a}	0.93^{a}	0.02
Cohesiveness[j]	0.59^{b}	0.55^{bc}	0.52^{c}	0.70^{a}	0.71^{a}	0.01
Chewiness (kg)[k]	0.53^{bc}	0.62^{ab}	0.24^{c}	0.82^{ab}	0.84^{a}	0.08
Resilience[l]	0.26^{b}	0.23^{b}	0.19^{c}	0.35^{a}	0.36^{a}	0.01
Kramer Shear[m]						
Force (kg/g)[NS]	0.42	0.48	0.37	0.50	0.41	0.04

[a-c] Means having different superscripts within rows are significantly different ($p<0.05$).
[d] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I: METHOCEL™ A4M, hydroxypropyl methylcellulose I: METHOCEL™ F4M .
[e] Treatment identification for the brine solutions
[f] Level (0.0, 0.4 & 0.8%) of hydrocolloid type added to brine solution and meat model.
[g] Texture profile analysis: 2- cycle compression using a 5 kg load cell, 75 mm plate and a heavy duty platform.
[h] Hardness is the peak force (kg) during first compression / sample weight (kg).
[i] Springiness is the height the food recovers between the first and second compression.
[j] Cohesiveness is the ratio of positive force area during the 2nd compression to that during the first compression (A_2/A_1).
[k] Chewiness is the product of Hardness*Cohesiveness*Springiness.
[l] Resilience is the ratio of the area during the 1st plate withdrawal over the 1st plate penetration.
[m] Kramer Shear: utilizing 50 kg load cell, 5-blade attachment, and heavy duty platform.
[n] Standard Error of the Mean (SEM).
[NS] Not significant ($P>0.05$)

most force to shear through the ham slice (0.50 kg/g). These results suggest a trend that with the addition of MC and HPMC in combination (TRT 3) tenderness increases. The addition of hydrocolloids to the formulation may be diluting the protein network; decreasing protein-protein interactions thereby decreasing product bind. Studies conducted on low-fat beef patties showed lower shear force values for patties that were manufactured with hydrocolloid gums (Hill and Prusa 1988; Troy and others 1999). Steinke (2001) also documented lower shear force values for cooked chicken patties treated with 0.25 and 0.50% MC (2.74-2.96 N) compared to the control (3.94 N). These studies indicate that the addition of MC and KC (TRT 1) may increase the tenderness of a finished product by the creation of protein-hydrocolloid interactions.

Hardness, juiciness, mouth residue/coating and intensity of off flavor were evaluated by a trained sensory panel (Table 12). Hardness values ranged from 2.2 to 3.3 on an 8-point hedonic scale; with TRTs 4 and 5 being the hardest and TRT 2 the softest in texture. In general, TRTs 1, 2, and 3 were softer than the TRT 5. Previous sensory studies noted that the addition of 1.0% HPMC increased tenderness in low-fat ground beef patties (Hill and Prusa 1988). Additionally, perceived hardness by the sensory panel and hardness results from texture profile analysis can be correlated. Both textural analyses, results suggest a trend that with the increase use of hydrocolloid gums (TRT 1, 2, and 3) there is a decrease in firmness.

Juiciness values ranged from 2.0 to 3.7 with TRT 4 and 5 (3.7 and 3.5) being evaluated the as the juiciest. In a previous study, panelistsperceive d turkey breasts with 0.5% KC to be juicier than breasts containing starch or the control (Bater and others 1992). Yet, a study conducted on high-moisture hams reported that hams with 1.5%

Table 12: Least square means for trained sensory attributes of high-moisture restructured ham manufactured with varying combinations of hydrocolloid brines.

	Hydrocolloid Type[e]					
Treatment[f]	**1**	**2**	**3**	**4**	**5**	
	MC I/KC	**HPMC I/KC**	**MC I/HPMC I/KC**	**KC**	**Control**	
Level[g]	0.4 / 0.6	0.6 / 0.6	0.4 / 0.6 / 0.6	0.6	0.0	**SEM[i]**
Attributes[h]						
Hardness	2.4^{bc}	2.2^{c}	2.4^{bc}	3.3^{a}	3.0^{ab}	0.2
Juiciness	2.6^{b}	2.4^{b}	2.0^{b}	3.7^{a}	3.5^{a}	0.2
Mouth Residue/ Coating	2.9^{b}	3.7^{ab}	4.1^{a}	1.5^{d}	2.0^{cd}	0.2
Intensity of Off-Flavor	1.1^{b}	1.2^{ab}	1.4^{a}	1.0^{b}	1.0^{b}	0.1

[a-d] Means having different superscript within rows are significantly different ($p<0.05$).

[e] Hydrocolloid Type: kappa carrageenan Gelcarin® ME 6910, methylcellulose I: METHOCEL™ A4M, hydroxypropyl methylcellulose I: METHOCEL™ F4M.

[f] Treatment identification of brine solutions

[g] Level (0.0, 0.4 & 0.6%) of hydrocolloid type added to brine solution and meat model.

[h] Trained sensory panel conducted at MSU evaluated attributes based on an 8 point hedonic scale:
1=extremely soft/extremely dry/ no residue/ no off-flavor;
8= extremely hard/ extremely juicy/ heavy residue/ high intensity. Evaluation temperature = 4°- 6°C.

[i] Standard Error of the Mean (SEM).

carrageenan received lower juiciness scores than those without carrageenan (Prabhu and Sebranek 1997). The decrease in perceived juiciness scores seen by Prabhu and Sebranek (1997) may be due to high amounts of KC (1.5%) added. When comparing juiciness between treatments, ham slices containing MC and/or HPMC (TRT 1, 2, and 3) scored significantly lower in juiciness values. These results contradict Hill and Prusa (1988) who observed an increase in juiciness with the addition of 1.0% HPMC and MC in low-fat beef patties. Additionally, Steinke (2001) utilizing 0.25 and 0.50% MC in chicken patties stated that the addition of MC increased perceived juiciness. Furthermore, Mittal and Barbut (1993) reported that the addition of carboxymethyl and microcrystalline cellulose at 1.0% did not effect juiciness perception by a sensory panel. Difference in these results from previous studies may be due to the combination of MC and/or HPMC with KC.

Mouth coating/residue values ranged from 1.5 to 4.1 on an 8-point hedonic scale (Table 12). Treatment 3 had the highest (4.1) perceived mouth residue/coating with TRT 2 (3.7) being similar in mouth-residue to TRT 3. These results were expected as MC and/or HPMC can form a slick coating on surfaces. For example, HPMC has been used as a surface barrier in fried foods. French fries dipped in HPMC prior to frying resulted in less greasy French fries (Grover 1986). Additionally, fried Boondis manufactured with 1.0 % HPMC decreased oil content by 22.7% when compared to the control (Priya and others 1996).

No off-flavors were detected by TRTs 4 and 5 by the trained sensory panel (Table 12). Treatment 3 was perceived to have the most off-flavor (1.4) between the treatments. The addition of 1.0% HPMC to low-fat beef patties significantly increased

the intensity of off-flavor when compared to the control (Hill and Prusa 1988). Off-flavor intensity and residue/mouth coating may be the biggest draw backs of using MC and HPMC in combination as it may severely hinder consumer acceptability.

Conclusions

The results of this study indicate that the addition of MC and/or HPMC with KC can control purge in restructured high-moisture ham. Specifically, TRT 1 demonstrated high cook yield values and decreased purge values when compared to TRT 4 and 5. Additionally, TRT 1 had a positive effect upon color (L*, a*, b*) values and stability. Lightness values of TRTs 1, 2, and 3 were decreased and held over a 28 day storage period when compared to TRT 4 and 5. Texture profile analysis and Kramer shear values also indicated that TRT 3 was more tender requiring less force to shear. Increased mechanical tenderization results were confirmed by the trained sensory panel. The addition of MC I with KC (TRT 1) has demonstrated to it maybe a valuable purge controller. However, the use of MC and/or HPMC does have a potential set back. Trained sensory panelists have detected an off-flavor associated with MC and HPMC. This is supported by previous a study conducted by Hill and Prusa (1988) utilizing 1% MC and HPMC. Based on these results, TRT 1 should be studied further due its purge controlling and quality assuring abilities. Future research should be directed towards the masking of MC's off-flavor to make this application more appealing to the meat processor and consumer.

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APPENDICES

APPENDIX 1: Experiment I Water Solution Formulation and Procedures

Solution Formulations:

Treatment	Hydrocolloid (g)	Hot water (g)	Ice+ chilled water (g)	Total wt. (g)
0.2% MC or HPMC	1.82	302.39	604.79	909.00
0.4% MC or HPMC	3.64	301.79	603.57	909.00
0.6% MC or HPMC	5.45	301.18	602.37	909.00
0.8% MC or HPMC	7.27	300.58	601.15	909.00
0.2% KC	1.82	0.00	907.18	909.00
0.4% KC	3.64	0.00	905.36	909.00
0.6% KC	5.45	0.00	903.55	909.00
0.8% KC	7.27	0.00	901.73	909.00

MC or HPMC Brine Manufacture:

1. Add appropriate amount of hot water (85°C) according to treatment from above table to 946.4 mL glass jar.

2. Add MC (A4M) or HPMC (F4M, K4M) (The Dow Chemical Company, Midland, MI).

3. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all is added).

4. Add ½ and ½ water and ice mixture (< 4.4°C) slowly to dispersed MC or HPMC solution. Mix for 10 minutes (begin timing once all water is added).

6. Repeat steps for each MC/HPMC marinade (n=12).

KC Solution Manufacture:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to 946.4 mL glass jar.

2. Add KC (Gelcarin ME 6910, FMC BioPolymer, Princeton, NJ) and mix for 10 minutes (begin timing once all KC is added).

3. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all is added).

4. Repeat steps for each KC marinade (n=4)

APPENDIX 2: Experiment II and III Brine Solution Formulations and Procedures

Brine Formulations:

	45% Addition			**0.20 %**	
	lbs	g	45%	ppm	
Water	1.89	858.06			
Salt	0.0803	36.46	1.80		
Nitrite	0.000784	0.36		156.18	('156)
Sugar	0.0119	5.40	0.27		
Erythorbate	0.001263	0.57		251.76	('550)
Phosphate	0.0135	6.13	0.30		
MC/HPMC/KC	0.0089	4.04	0.200		
Total	2.006647	911.0175			

	45% Addition			**0.40 %**	
	lbs	g	45%	ppm	
Water	1.88	853.52			
Salt	0.08	36.32	1.80		
Nitrite	0.000783	0.36		156.18	('156)
Sugar	0.012	5.45	0.27		
Erythorbate	0.001262	0.57		251.72	('550)
Phosphate	0.0135	6.13	0.30		
MC/HPMC/KC	0.01784	8.10	0.400		
Total	2.005385	910.4448			

	45% Addition			**0.60 %**	
	lbs	g	45%	ppm	
Water	1.87	848.98			
Salt	0.08	36.32	1.80		
Nitrite	0.000783	0.36		156.17	('156)
Sugar	0.012	5.45	0.27		
Erythorbate	0.001262	0.57		251.86	('550)
Phosphate	0.0135	6.13	0.30		
MC/HPMC/KC	0.02674	12.14	0.600		
Total	2.004285	909.9452			

	45% Addition			0.80 %	
	lbs	g	45%	ppm	
Water	1.86	844.44			
Salt	0.08	36.32	1.80		
Nitrite	0.000782	0.36		156.15	('156)
Sugar	0.012	5.45	0.27		
Erythorbate	0.001261	0.57		251.80	('550)
Phosphate	0.0135	6.13	0.30		
MC/HPMC/KC	0.0356	16.16	0.800		
Total	2.003143	909.4269			

MC or HPMC Brine Manufacture:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to 946.4 mL glass jar.

2. Add Brifisol 512 sodium phosphate (BK Giulini Corporation, Simi Valley, CA).

3. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all phosphate is added).

4. During phosphate mixing time, place MC (A4M) or HPMC (F4M, K4M) (The Dow Chemical Company, Midland, MI) in a beaker with the salt and sugar. Mix well by hand to fully disperse MC or HPMC.

5. Add MC or HPMC mixture and mix with drill mixer for 10 minutes (begin timing mixing once all mixture is fully added).

6. Repeat steps for each MC/HPMC marinade (n=12).

KC Brine Manufacture:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to 946.4 mL glass jar.

2. Add Brifisol 512 sodium phosphate (BK Giulini Corporation, Simi Valley, CA).

3. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B

Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all phosphate is added).

4. Add salt and mix for 2 minutes (begin timing once all of salt is added).

5. Add KC (Gelcarin ME 6910, FMC BioPolymer, Princeton, NJ) and mix for 3 more minutes (begin timing once all KC is fully added).

6. Add sugar and mix for 2 more minutes (begin timing once all sugar is added).

7. Repeat steps for each KC marinade (n=4).

Nitrite and Erythorbate Addition:

1. 12-16 hours after initial brine manufacturing.

2. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all is added).

3. Add sodium nitrite (J.T. Baker, Phillipsburg, NJ) then sodium erythorbate (Butcher and Packer Supply Co., Detroit, MI) and mix for an additional minute.

4. Repeat for each treatment (n=16)

APPENDIX 3: Experiment IV Brine Formulations and Procedures

Brine Formulations:

	45% Addition				**Control**
	lbs	g	45%	ppm	
Water	1.9	862.60			
Salt	0.0803	36.46	1.80		
Nitrite	0.000784	0.36		156.19	('156)
Sugar	0.0119	5.40	0.27		
Erythorbate	0.001263	0.57		251.63	('550)
Phosphate	0.0135	6.13	0.30		
Total	2.007747	911.5171			

	45% Addition			**MC I 0.4% / HPMC I 0.6 %**	
	lbs	g	45%	ppm	
Water	1.85	839.90			
Salt	0.08	36.32	1.80		
Nitrite	0.000782	0.35		156.14	('156)
Sugar	0.012	5.45	0.27		
Erythorbate	0.001261	0.57		251.84	('550)
Phosphate	0.0135	6.13	0.30		
MC I	0.01781	8.09	0.400		
HPMC I	0.0267	12.12	0.600		
Total	2.002052	908.9316			

	45% Addition			**MC I 0.4% / KC 0.6%**	
	lbs	g	45%	ppm	
Water	1.85	839.90			
Salt	0.08	36.32	1.80		
Nitrite	0.000782	0.35		156.14	('156)
Sugar	0.012	5.45	0.27		
Erythorbate	0.001261	0.57		251.84	('550)
Phosphate	0.0135	6.13	0.30		
MC I	0.01781	8.09	0.400		
KC	0.0267	12.12	0.600		
Total	2.002052	908.9316			

	45% Addition			HPMC I 0.6% / KC 0.6%	
	lbs	g	45%	ppm	
Water	1.84	835.36			
Salt	0.08	36.32	1.80		
Nitrite	0.000781	0.35		156.15	('156)
Sugar	0.012	5.45	0.27		
Erythorbate	0.00126	0.57		251.88	('550)
Phosphate	0.0135	6.13	0.30		
HPMC I	0.0267	12.12	0.600		
KC	0.0267	12.12	0.600		
Total	2.000941	908.4273			

	45% Addition			MC I 0.4%/HPMC I 0.6%/KC 0.6%	
	lbs	g	45%	ppm	
Water	1.825	828.55			
Salt	0.08	36.32	1.80		
Nitrite	0.000782	0.36		156.13	('156)
Sugar	0.012	5.45	0.27		
Erythorbate	0.001262	0.57		251.85	('550)
Phosphate	0.0135	6.13	0.30		
MC I	0.01781	8.09	0.400		
HPMC I	0.0267	12.12	0.600		
KC	0.0267	12.12	0.600		
Total	2.003754	909.70			

MC and HPMC combination Brine Manufacture:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to 946.4 mL glass jar.

2. Add Brifisol 512 sodium phosphate (BK Giulini Corporation, Simi Valley, CA).

3. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all phosphate is added).

4. During phosphate mixing time, place MC I (A4M)and HPMC I (F4M) (The Dow Chemical Company, Midland, MI) in a beaker with the salt and sugar. Mix well by hand to fully disperse MC and HPMC.

5. Add MC I and HPMC I mixture, mix with drill mixer for 10 minutes (begin timing mixing once all mixture is fully added).

6. Repeat steps for each MC and HPMC brine (n=1).

KC with MC I and/or HPMC I Brine Manufacture:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to 946.4 mL glass jar.

2. Add Brifisol 512 sodium phosphate (BK Giulini Corporation, Simi Valley, CA).

3. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all phosphate is added).

4. Add salt and mix for 2 minutes (begin timing once all of salt is added).

5. During phosphate mixing time, place MC I (A4M) and/or HPMC I (F4M) (The Dow Chemical Company, Midland, MI), KC (Gelcarin ME 6910, FMC BioPolymer, Princeton, NJ) and sugar in beaker, mix thoroughly by hand.

6. Add MC and/or HPMC and KC mixture, mix with drill mixer for 10 minutes (begin timing mixing once all mixture is fully added).

7. Repeat steps for each combination brine (n=3).

Control Brine Manufacturing:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to 946.4 mL glass jar.

2. Add Brifisol 512 sodium phosphate (BK Giulini Corporation, Simi Valley, CA).

3. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all phosphate is added).

4. Add salt and mix for 2 minutes (begin timing once all of salt is added).

5. Add sugar and mix for 2 more minutes (begin timing once all sugar is added).

7. Repeat steps for each control brine (n=1).

Nitrite and Erythorbate Addition:

1. 12-16 hours after initial brine manufacturing.

2. Mix with 4-blade mixing head: 2-blades perpendicular (2.54 cm across) to shaft and 2 blades parallel to shaft (1.27 cm equidistant from shaft) attached to a drill (SKIL, S-B Power Tool Co., Chicago, IL). Mix for 5 minutes until MC or HPMC is well blended (begin timing once all is added).

3. Add sodium nitrite (J.T. Baker, Phillipsburg, NJ) then sodium erythorbate (Butcher and Packer Supply Co., Detroit, MI) and mix for an additional minute.

4. Repeat for each treatment (n=5)

APPENDIX 4: Programmed Water Bath Procedure

Water Bath Procedure:

1. PolyScience programmable water bath was turned on and program was initiated 30 minutes before sample entry; allowing water bath to achieve 4.0°C to simulate temperature of actual samples.

2. Hydrocolloid water solution, brine solution or meat samples were then placed into water bath at 4°C, thermally processed from stages 2-6, and cooled in stage 7 to simulate the shower cycle.

3. Remove samples from water bath and analyze as necessary.

4. This processes was repeated three times for each repetition as only 18 samples (n=6) could be thermally processed at one time.

Programming PolyScience Circulator with Digital Controller Bath: (Model 9510, PolyScience, Niles, IL)

1. To begin entering program, press FCN then #5. Select what program number you want to name the program (1 or 2).

2. Upon number selection you will see the word transferring. Select #1= display, edit and write a program. This will then allow you to enter temperatures and time points. Press enter after each item.

3. Up to 10 temperature/time steps can and must be entered. Repeat last step until you reach step 10.

4. After passing all 10 steps enter number of cycles you wish the water bath to go through (1-999 times).

5. At end of program select soak or power off when done. Selecting soak allows for water bath to hold at final constant temperature entered indefinitely.

6. Select #1 or 2 to store your new program.

7. Water bath is now programmed and ready to conduct process.

APPENDIX 5: Viscometer Calibration and Viscosity Determination

Calibration Procedure:

1. Turn power on to Brookfield Viscometer (Model DV-II, Brookfield Engineering laboratories, Stoughton, MA). Set speed dial to 12, and turn motor on.
2. Press auto zero. Display will start blinking.
3. When blinking stops turn motor off. Do not turn off power switch.
4. Press SPDL then enter spindle number (01...07). Example: spindle 3 = 03.
5. Press desired unit button (%, cPs, SS). Centipoise (cPs) was used.
6. Viscometer is now calibrated.

Viscosity Reading Procedure:

1. Place selected spindle slowly into brine/solution at a 45° angle. Look for air bubbles under spindle. If air bubbles are present, remove spindle and try again.
2. Attach spindle to viscometer, not allowing spindle to come out of sample.
3. Adjust spindle height. Solution should be level with notched ring around spindle neck.
4. Turn motor on.
5. Allow reading to equilibrate and record measurement.
6. Turn off motor, but do not turn off power to viscometer. If power is shut off re-calibrate viscometer.
7. Detach spindle, clean with distilled water, and dry with paper towel.
8. Repeat as necessary.

APPENDIX 6: TA-HD*i* Gel Strength Settings

Texture Analyzer:	TA-HD*i* Texture Analyzer Texture Technologies Corporation, Scarsdale, NY
TA-HD*i* Settings:	
Mode:	Measure Force in Compression
Option:	Return to Start
Pre-Test Speed:	5.0 mm/s
Test Speed:	0.20 mm/s
Post-Test Speed:	10 mm/s
Pre-Travel Distance:	51.0 mm/s
Compression Distance:	8 mm
Trigger Type:	Return
Data Acquisition Rate:	200 pps
Attachment/Accessory:	-TA-10; 12.7mm AOAC acrylic cylinder, 35mm tall -5 kg load cell -TA-90; Heavy duty platform

APPENDIX 7: 2-Cycle Compression Settings for Meat Model

Texture Analyzer:	TA-HD*i* Texture Analyzer Texture Technologies Corporation, Scarsdale, NY
TA-HD*i* Settings:	
Test Mode:	TPA
Option:	Return to Start
Pre-Test Speed:	2.00 mm/s
Test Speed:	1.67 mm/s
Post-Test Speed:	1.67 mm/s
Pre-Travel Distance:	24.5 mm
Compression Distance:	sample size x 0.25
% Compression:	Compressed to 25% of original height (75% compression)
Trigger Type:	Return
Data Acquisition Rate:	200 pps
Attachment/Accessory:	-TA-30; 75mm aluminum plate, 10mm tall -5 kg load cell -TA-90; Heavy duty platform

APPENDIX 8: Proximate Composition

AOAC. 2000. Meat and meat products. In P. Cunniff (Ed.), Official methods of analysis of AOAC International. 1-23p. Washington, DC: AOAC International.

Sample Preparation (modified from section 983.18 Meat and Meat Products)

1. Section meat into very small (<1 cm squares) pieces. If already frozen, smash samples with a hammer to decrease size of sample for ease of grinding.

2. Add sample to Tekmar grinders (Tekmar Co, Cincinnati, OH) filling grinding chamber half full.

3. Then add dry ice to fill up chamber.

4. Grind 2 to 3 minutes using Tekmar grinder (Tekmar Co, Cincinnati, OH) until sample is ground into a fine powder. It may be necessary to stop in the middle of grinding and stir the sample up for uniform grinding.

5. Transfer finely ground powder to labeled whirl pack bags. Loosely close bag so that dry ice can evaporate and dissipate. This takes about 2 days. Place in freezer immediately to prevent melting of powder.

Moisture Analysis

6. Place a medium weigh boat on scale and zero. This is to keep the scale clean. Add paper labeled with sample ID and paperclip. Record the weight then tare the scale.

7. Add 2 grams ($\pm$ .03g) of thoroughly mixed sample to the paper. Once desired weight is reached record weight and fold over top. Secure by folding and tucking top. Place flat on tray. Do all samples in triplicate. Do not stack samples on tray. This will hinder the drying process.

8. Once tray is full, place in drying oven set at 100°C for 20 - 24 hours.

9. After drying, place samples using latex gloves or tongs in dessicator to cool completely before weighing. Once cool, weigh samples and record. This is your final weight for moisture and your initial weight for fat analysis. Use the following formula to determine the percent moisture in your samples:

$$\text{Moisture (\%)} = \frac{\text{wet sample wt.} - \text{dry sample wt.}}{\text{wet sample wt.}} \times 100$$

Fat Analysis Using Soxhlet Ether Extraction

10. Take samples from moisture analysis and place in extraction tubes. Make sure that all the samples are below the level where the ether drains off (curved glass on outside of tube).

11. Add petroleum ether to clean boiling flasks until about ¾ full. Add 2 to 3 glass beads as a boiling aid.

12. Connect the extraction flask to the boiling flask and Soxhlet apparatus. Place parafilm on the joint. Mount both to the condensing units on top of extraction flasks using parafilm around joint.

13. Turn on condensing water so it runs at a steady stream.

14. Set Rheostats on high and run for 24 hours.

15. Place ether soaked samples onto a tray in a hood for 2 hours to allow ether to dissipate.

16. Place samples in drying oven for 5 to 10 min to remove any possible moisture then place in dessicator for 1/2 hour to cool.

17. Weigh and record the weight of the samples. Calculate fat on wet basis with the following equation:

$$\text{Fat (\%)} = \frac{\text{dry sample wt.} - \text{extracted sample wt.}}{\text{wet sample wt.}} \times 100$$

Protein Analysis

1. Weigh out approximately 1 gram of powdered meat into the tared crucible. Write the weight and sample ID on the side of the crucible with pencil.

2. After weighing out samples, dry for 18 to 20 hours in the drying oven at 100°C. This removes moisture that can cause internal malfunctions with the Leco Protein Analyzer. Do not reweigh samples. Enter wet weight into computer.

Procedures for the LECO FP 2000 Nitrogen Analyzer

1. Open valves completely on oxygen, helium and compressed air tanks. Make sure tanks have adequate levels of gas (gauge should read >100psi) and that the pressure out of the tanks are set at 40 psi.

2. Press escape on upper left hand corner of touch screen until "front panel" comes up and then press it. On right hand side of screen a section labeled "analysis gas" can be found. Push the "on" button to turn gasses on to the machine. Check to see that your furnace temperature is 1050°F (located on left part of screen).

3. Wait about 5 minutes for all gasses to equilibrate then start your leak tests. Press escape from the front panel located in upper left corner. A screen with several icons will appear. Press "maintenance". This will bring up helium leak test, combustion leak test and ballast leak test icons. Press the helium leak test. If it passes move onto the combustion leak test. Once finished, start running blanks. Run a ballast test as it is part of the combustion system.

4. Run several air blanks through to purge the system. To do this escape from the "maintenance" section and push the "analyze" icon. On the bottom of the screen you will see several commands. Push "select ID code". Toggle the highlighted line using the arrows to blanks. Then push exit on bottom. Then push manual weight. This will bring up a touch screen with 0.2000000 on it. Push the enter button at least 10 times to bring up 10 rows of 0.20000. Then push analyze. The machine will run through these ten samples. Numbers should come down to about <.030% protein.

5. Once blanks are at an acceptable number, run 4 to 5 EDTA samples (approximately 0.5g) to verify machine is operating properly.

6. Weigh EDTA samples out in the ceramic boats and write the weight on the side in pencil (at least three decimal places).

7. Select "manual weight" and put your weight into the machine pushing enter after each entry. Once weights are entered, push analyze. Follow the directions on the touch screen. Push your first sample into the chamber about one half inch so the door doesn't catch the boat. Push okay on the screen when it asks you place your sample in the chamber. The next message will tell you to wait because the system is purging. Then the machine will then tell you to push the boat into the chamber. The machine will combust and analyze the sample in approximately 3 minutes.

8. Analyze samples as described in step 7.

APPENDIX 9: Study II Brine Formulation and Procedures

Brine Formulations:

	45% Addition			MC I 0.4% / KC 0.6%	
	lbs	g	45%	ppm	
Water	23.1	10487.40			
Salt	1.0	454.00	1.80		
Nitrite	0.009758	4.43		156.15	('156)
Sugar	0.15	68.10	0.27		
Erythorbate	0.01572	7.14		251.56	('550)
Phosphate	0.165	74.91	0.30		
MC I	0.2223	100.92	0.400		
KC	0.333	151.18	0.600		
Total	24.99578	11348.08			

	45% Addition			HPMC 0.6% / KC 0.6%	
	lbs	g	45%	ppm	
Water	23	10442.00			
Salt	0.999	453.55	1.80		
Nitrite	0.009763	4.43		156.17	('156)
Sugar	0.15	68.10	0.27		
Erythorbate	0.015726	7.14		251.56	('550)
Phosphate	0.165	74.91	0.30		
HPMC I	0.3332	151.27	0.600		
KC	0.3332	151.27	0.600		
Total	25.00589	11352.67			

	45% Addition		MC I 0.4%/HPMC I 0.6%/KC 0.6%		
	lbs	g	45%	ppm	
Water	23	10442.00			
Salt	1.01	458.54	1.80		
Nitrite	0.009858	4.48		156.15	('156)
Sugar	0.15	68.10	0.27		
Erythorbate	0.015882	7.21		251.56	('550)
Phosphate	0.17	77.18	0.30		
MC I	0.2245	101.92	0.400		
HPMC I	0.3365	152.77	0.600		
KC	0.3365	152.77	0.600		
Total	25.25324	11464.97			

	45% Addition				Control
	lbs	g	45%	ppm	
Water	24	10896.00			
Salt	1.015	460.81	1.80		
Nitrite	0.0099	4.49		156.15	('156)
Sugar	0.15	68.10	0.27		
Erythorbate	0.01595	7.24		251.57	('550)
Phosphate	0.17	77.18	0.30		
Total	25.36085	11513.83			

	45% Addition				KC 0.6%
	lbs	g	45%	ppm	
Water	23.5	10669.00			
Salt	1.005	456.27	1.80		
Nitrite	0.009833	4.46		156.16	('156)
Sugar	0.15	68.10	0.27		
Erythorbate	0.01584	7.19		251.56	('550)
Phosphate	0.17	77.18	0.30		
KC	0.336	152.54	0.600		
Total	25.18667	11434.75			

KC with MC and/or HPMC Brine Manufacture:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to white plastic bucket.

2. Add Brifisol 512 sodium phosphate (BK Giulini Corporation, Simi Valley, CA).

3. Mix with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm for 2 minutes until phosphate is dissolved (begin timing once all phosphate is added).

4. Add salt and mix for 2 minutes with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm (begin timing once all of salt is added).

5. During phosphate mixing time, place MC I (A4M) and/or HPMC I (F4M) (The Dow Chemical Company, Midland, MI), KC (Gelcarin ME 6910, FMC BioPolymer, Princeton, NJ) and sugar in beaker, mix thoroughly by hand. .

6. Add MC I and/or HPMC I and KC mixture, mix with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1500 rpm for 10 minutes (begin timing mixing once all mixture is fully added).

7. Repeat steps for each KC with MC or HPMC combination brine (n=4).

Control Brine Manufacturing:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to plastic bucket.

2. Add Brifisol 512 sodium phosphate (BK Giulini Corporation, Simi Valley, CA).

3. Mix with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm for 2 minutes until phosphate is dissolved (begin timing once all phosphate is added).

4. Add salt and mix for 2 minutes with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm (begin timing once all of salt is added).

5. Add sugar and mix for 2 more minutes with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm (begin timing once all sugar is added).

7. Repeat steps for each control brine (n=1).

KC Brine Manufacturing:

1. Add appropriate amount of chilled water (< 4.4°C) according to treatment from above table to plastic bucket.

2. Add Brifisol 512 sodium phosphate (BK Giulini Corporation, Simi Valley, CA).

3. Mix with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm for 2 minutes until phosphate is dissolved (begin timing once all phosphate is added).

4. Add salt and mix for 2 minutes with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm (begin timing once all of salt is added).

5. Add KC (Gelcarin ME 6910, FMC BioPolymer, Princeton, NJ) and mix for 3 more minutes with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm (begin timing once all KC is fully added).

6. Add sugar and mix for 2 more minutes with Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm (begin timing once all sugar is added).

7. Repeat steps for each KC brine (n=1).

Nitrite and Erythorbate Addition:

1. 12-16 hours after initial brine manufacturing.

2. Mix brine for 1 minute using Rotostat mixer (Model 80XP63SS, Admix Inc., Londonderry, NH) modified by MSU at 1200 rpm.

3. Add sodium nitrite (J.T. Baker, Phillipsburg, NJ) then sodium erythorbate (Butcher and Packer Supply Co., Detroit, MI) and mix for 1 additional minute with Rotostat mixer (Model 80XP63SS, Admix Inc., Londondery, NH) modified by MSU at 1200 rpm.

4. Repeat for each treatment (n=5)

APPENDIX 10: Storage Lighting Determination and Conversion Procedure

Procedure:

1. Measure size of sliced restructured ham storage cooler. Cooler length and width were measured 18.583 ft x 16.417 ft (566.41 cm x 500.39 cm).

2. Measure amount of light being emitted by lighting in Foot Candles (FC). A Triple Range Light Meter (Model 217, General Electric Lighting, Cleveland, OH) was used to determine Foot Candle reading. FC=80

3. Lumen conversion equation is shown below:

Luminous Flux (Lumen) Conversion:

Square feet = 18.583ft x 16.417 ft = 305.083 sq. feet

$$1\ FC = \frac{1\ \text{lumen}}{\text{sq. foot}}$$

$$80\ FC = \frac{\text{"x" lumens}}{305.083\ \text{square ft.}}$$

X= 24, 407 Lumens

APPENDIX 11: Cook Yield Determination

Cook Yield Procedure:

1. Restructured ham treatments were stuffed into11.4 cm x 76.2 cm fibrous, un-stuck, clipped casings.

2. Stuffed chubs were weighed per treatment raw as a group, recorded, and placed on smoke truck, one treatment per smoke stick, per row.

3. Place smoke truck with stuffed chubs in smoke house and were cooked to 70°C showered with cold water to 54.4°C.

4. Remove smoke truck from smokehouse following showering process and allow ham to equilibrate to 37.8°C at 20°C prior to weighing.

5. Blot dry ham casings with clean towel, remove treatment chub groups from smoke truck and reweigh (37.8°C).

6. Percent cook yield was determined using the following calculation:

$$\% \text{ cook yield} = \frac{\text{Wt. of cooked chub treatment group}}{\text{Wt. of raw chub treatment group}} \times 100$$

APPENDIX 12: TBARS Analysis

Rhee, KS. 1978. Minimization of further lipid peroxidation in the destillation 2-thiobarbutiric acid test of fish and meat. J Food Sci 43:1776-1778.

Tarladigis, GG, Wats, BM, Younthan, MT, Dugan, L Jr. 1960. J Am Oil Chem 37:44-48.

Zipser, MW, Watts, BM. 1962. Lipid oxidation (TBA) methods. Food Technol 16(7):102.

1. TBA Reagent

Prepare the amount of TBA Reagent needed for your samples according to the table below:

Thiobarbituric Acid	Distilled Water	Total Vol. Water and Acid
1.4416 g	50 ml	500 ml
0.7208 g	25 ml	250 ml
0.5766 g	20 ml	200 ml
0.2883 g	10 ml	100 ml
0.1442 g	5 ml	50 ml

Dissolve the Thiobarbituric Acid (Eastman Organic Chemicals) in the distilled water and about 2/3 the total volume. Place flask in sonic cleaner (several minutes) and shake occasionally until TBA is dissolved. Allow reagent to come to room temperature then bring to volume. Store in cooler, may be kept for 2 days.

2. HCl Solution

Make volume as needed; 1:2, HCl : H_2O (v/v).

3. Antifoam (Thomas®, Swedeboro, NJ)

The use of antifoam may not be necessary depending on the product. Fish and egg require antifoam while poultry does not. In this study, antifoam was used.

4. Sulfanilamide Reagent (Cured Meat Only)

Dissolve 0.5 g Sulfanilamide and 20ml Conc. HCl in 100 ml volumetric flask. Bring to volume with distilled water. NOTE: Store in dark bottle, will discolor with age.

Procedure:

1. Assemble connecting tube (spouts) and graduated cylinders.

2. Turn on condenser water.

3. Add 10 g of diced sample to 100 ml plastic bottle containing 50 ml distilled water plus 10 ul antioxidant solution (Tenox 5 – food grade BHA+BHT).

4. Homogenize sample plus solution using Polytron mixer (PT-35, Kinematica, AG, Switzerland) on speed setting 4 for 1 minute (Homogenized samples can be held in cooler if needed).

5. Into 500 ml extraction flasks, add 4, 4 mm glass beads (Fisher Scientific, Pittsburgh, PA), homogenized meat sample, 2.5 ml HCl solution, 1.0 ml Sulfanilamide solution, 46.5 ml distilled water, and 2 sprays of antifoam (Note: total volume is 50 ml + 2.5 ml + 1.0ml + 46.5 ml = 100 ml).

6. Connect extraction flasks to distilling tubes and tighten heating mantles in place.

7. Turn powerstats to line voltage (setting 85) and heat flasks rapidly.

8. Distill and collect 50 ml of the distillate.

9. Transfer distillate to 50 ml centrifuge tubes, cap and hold in refrigerator for TBA reaction. (Can be held for 18 hours).

TBA Reaction / Spectrophotometric Determination:

10. Invert each test tube containing the 50 ml distillate and pipette 5 ml into each of 2 tubes labeled "A" and "B". Prepare 2 blanks by pipetting 5 ml distilled water into both tubes labeled "A" and "B".

11. Add 5 ml of TBA Reagent into each tube containing 5 ml of sample and into both blanks. Thoroughly mix each tube using Vortex mixer (American Scientific Products, McGaw Park, IL).

12. Turn water bath on 100° C.

13. Place tubes in test tube rack and immerse into boiling water bath (model 9510 PolyScience, Sorvall Co., Niles, IL) for 30 minutes.

14. Turn Spectrophotometer (Lambda 20, Perkin Elmer, Norwalk, CT) to IDLE (must warm up 20 min.)

15. When the tubes are done heating in the water bath cool them in ice for at least 10 minutes.

16. Mix each test tube with sample for 10 seconds using Vortex mixer (American Scientific Products, McGaw Park, IL).

17. Transfer sample to disposable 4.5 ml cuvette (done in duplicates).

18. Turn Spec to ON: Manually adjust wave length to 538 nm for cured meat (read samples within 1 hour).

19. Convert % T to optical density and multiply by the constant 7.8 (7.6 for poultry) to convert to mg malonaldehyde/1000 g of sample, i.e. TBA Number.

APPENDIX 13: 2-Cycle Compression Settings

Texture Analyzer:	TA-HD*i* Texture Analyzer Texture Technologies Corporation, Scarsdale, NY
TA-HD*i* Settings:	
Test Mode:	TPA
Option:	Return to Start
Pre-Test Speed:	2.00 mm/s
Test Speed:	1.67 mm/s
Post-Test Speed:	1.67 mm/s
Pre-Travel Distance:	24.5 mm
Compression Distance:	3.13 mm
% Compression:	Compressed to 25% of original height (75% compression)
Trigger Type:	Return
Data Acquisition Rate:	200 pps
Attachment/Accessory:	-TA-30; 75mm aluminum plate, 10mm tall -5 kg load cell -TA-90; Heavy duty platform

APPENDIX 14: Kramer 5-Blade Shear Settings

Texture Analyzer:	TA-HD*i* Texture Analyzer Texture Technologies Corporation, Scarsdale, NY
TA-HD*i* Settings:	
Mode:	Measure Force in Compression
Option:	Return to Start
Pre-Test Speed:	10 mm/s
Test Speed:	1.67 mm/s
Post-Test Speed:	5.00 mm/s
Distance:	35.0 mm/s
Trigger Type:	Return
Data Acquisition Rate:	200 pps
Attachment/Accessory:	-5-bladed Kramer Shear Cell -50 kg load cell -TA-90; Heavy duty platform

APPENDIX 15: **Trained Sensory Panel Ballot**

Restructured Ham Descriptive Attribute Ballot

Name_____ Rep_____ Date_____

Sample	Hardness	Juiciness	Residue/mouth-coating	Intensity of off-flavor
Warm-up				

Hardness
8 Extremely Hard
7 Very Hard
6 Moderately Hard
5 Slightly Hard
4 Slightly Soft
3 Moderately Soft
2 Very Soft
1 Extremely Soft

Juiciness
8 Extremely Juicy
7 Very Juicy
6 Moderately Juicy
5 Slightly Juicy
4 Slightly Dry
3 Moderately Dry
2 Very Dry
1 Extremely Dry

Residue/mouth-coating
8 Abundant Residue/mouth-coating
7 Moderately Abundant Residue/mouth-coating
6 Slightly Abundant Residue/mouth-coating
5 Moderate Residue/mouth-coating
4 Slight Residue/mouth-coating
3 Traces Residue/mouth-coating
2 Practically None Residue/mouth-coating
1 No Residue/mouth-coating

Off-flavor Intensity
8 Abundant
7 Moderately Abdt
6 Slightly Abdt
5 Moderate
4 Slight
3 Traces
2 Practically None
1 None

APPENDIX 16: Trained Sensory Panel Treatment Randomization

Trained Sensory Panel serving order with random numbers:

Practice:
Trt 3 833
Trt 1 679
Trt 5 930
Trt 2 249
Trt 4 614

Rep 3:
Warm-up Trt 5
Trt 2 318
Trt 1 403
Trt 4 927
Trt 5 715
Trt 3 423

Rep 2:
Warm-up Trt 4
Trt 5 372
Trt 4 116
Trt 2 888
Trt 1 505
Trt 3 182

Rep 1:
Warm-up Trt 5
Trt 2 887
Trt 3 479
Trt 4 621
Trt 5 223
Trt 1 285

Treatment Key:
Treatment 1: 0.4% MC I / 0.6% KC
Treatment 2: 0.6% HPMC I/ 0.6% KC
Treatment 3: 0.4% MC I / 0.6% HPMC I / 0.6% KC
Treatment 4: Control
Treatment 5: 0.6% KC

APPENDIX 17: TA-HD*i* Texture Analyzer Calibration and Analysis Procedures

---

Calibration Procedure:

1. Turn texture analyzer (TA) on.

2. Log on to texture analyzer program on computer. Program found on computer desktop.

3. Turn TA key to the "run" position.

4. Clear deck of TA, removing all attachments and platform.

5. Attach calibration weight hanger attachment.

6. Turn TA key to machine configuration.

7. Press "ENT (enter)" to determine load cell weight.

8. Press " +/-" to acquire appropriate load cell weight.
   For example: 50 kg load cell will be indicated by "50" on screen.

9. Turn TA key back to "run" position and then back to machine configure. This saves settings in TA.

10. Press calibrate key, then enter.

11. When TA screen reads appropriate weight put actual weight on TA weight hanger.
    For example: 50 kg load cell will utilize a 10,000 kg weight. 5 kg load cell utilizes a 2000 kg weight.

12. Press calibrate and when screen reads done switch TA key back to "run" position.

13. Remove weight from hanger but do not remove hanger.

14. Next, calibrate the computer.

15. Go to heading that reads "TA".

16. Calibrate for "force".

17. Press ok. The computer will then ask you to place weight on hanger.

18. Once weight is on hanger press "ok".

19. The computer will then say "calibration successful".

20. If this is not indicated or if calibration unsuccessful. Re-calibrate machine.

21. Remove weight and hanger from TA.

22. TA is now ready to analyze samples.

Analysis Procedure:

1. Once TA is calibrated analyses can begin.

2. Attach appropriate "attachment" to TA. For example: Kramer shear test attach 5-blade attachment to TA and from Gel hardness attach TA-10 attachment.

3. Create a personal file for data collection.

4. Open file with pre-determined settings for analysis. Settings can be seen in Appendices 6, 7 and 13.

5. Place sample in designated area.

6. Click on TA icon on computer screen. Select run test. Sample is then analyzed

7. Repeat steps 4-7 as necessary.

RECOMMENDATIONS FOR FUTURE RESEARCH

The results from this thesis have indicated future use of MC and/or HPMC with KC as a purge controller. When used singularly MC and HPMC significantly decreases cook yields. Yet, when MC is used in combination with KC there is a definite purge controlling effect shown by increased cook yield values and decreased storage day purge values. Although this research was successful defining MC with KC as a purge controller, future research needs to address consumer acceptability. Throughout Study II off-flavors were recognized by a trained panel in samples with MC or HPMC. Research focusing upon masking the MC and HPMC off-flavor intensity would be of great value to the processor and consumer. One potential solution would be the incorporation of savory flavorings or sweeteners into the meat model.

Despite the fact that this research focused upon restructured ham products, further research needs to investigate other brine addition options. Efforts should focus upon making these brines solutions pumpable through an automatic injector. This would allow the combination brine treatments to be injected into whole muscle meat products such as beef, chicken, and pork making them more appealing to the meat processor. One such research idea would be to inject MC with KC into prime rib or roast beef cuts to increase juiciness and tenderness of the final product.

Another potential research option would be to conduct a freeze/thaw study utilizing MC and HPMC in restructured meat products. Kappa carrageenan has been shown to decrease freeze/thaw purge, further research needs to investigate if the combination of MC and/or HPMC with KC can further decrease freeze/thaw purge

values. In conjunction with this study a shelf-life study should be conducted determining product life and microbial activity. This study could be particularly beneficial to determine microbial growth and activity with the addition of high amounts of water.

Study II results suggest the future research to determine if the addition of MC and/or HPMC with KC has potential synergistic or additive purge controlling effects. This study would have to be statistically organized to determine if the use of MC and/or HPMC do have these potential effects. This study would be beneficial as it would allow a researcher to branch into new areas with the utilization of MC and/or HPMC in processed meats.

In a final thought, the investigation of MC and/or HPMC with KC exposed new possibilities to produce high-moisture restructured ham products with little purge. However, the basis of this new brine solution technique to be used commercially is dependent upon cost. Cost determination is a research avenue that has to be confronted if it is to become a new staple in the meat processors brine arsenal. If we can offer this new technique as a cost effective purge controller it will be used in all segments of the meat industry.

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