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Effects of processing method and non-meat binding ingredients on batter stability, yield and texture of frankfurters

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ABSTRACT

The effects of processing method and added non-meat ingredients on the processing yield, batter stability, and texture profile of frankfurters were investigated. Five ingredient treatments (control, sodium alginate, iota carrageenan, transglutaminase, and pork collagen) of frankfurters were produced using three different processing methods (coarse grinding, chopping in a bowl chopper and passing through an emulsion mill). Emulsion stability (water separation, fat separation and total liquid separation) was measured on the resulting batter. Processing yield was measured after cooking and chilling the frankfurters. A texture profile analysis (TPA) of the finished frankfurters was also conducted with a focus on the TPA characteristics of hardness, cohesiveness, and chewiness. Control treatments produced by different methods showed significantly ($P < 0.05$) different levels of processing yield with the emulsion mill producing the highest, followed by bowl chopper and then coarse grinding. Coarse ground treatments showed the most negative impact of processing method on processing yield and texture characteristics. The addition of transglutaminase showed a positive effect on TPA characteristics chewiness and cohesiveness, and did not affect processing yield. Consequently, a difference between frankfurters produced with different methods was observed, and a means to offset those differences through ingredient formulation was demonstrated.

CHAPTER 1. GENERAL INTRODUCTION

For many years, frankfurters have been a staple in the diet of United States citizens. While the specific origin of the hot dog is clouded in numerous claims of invention, the fact remains that Americans have, and will, continue to consume vast quantities of this popular processed meat product. To consumers, frankfurters represent a low cost, high protein, convenient food that is readily available to augment, or take center stage in, summer barbeques and school lunch menus. In recent years, variations on the typical frankfurter have emerged. Reduced fat and reduced sodium formulations have appealed to the health-conscious consumer. At the other end of the spectrum, the addition of savory flavoring ingredients such as bacon, cheese and a variety of other flavorful ingredients, have appealed to many consumers as an indulgent comfort food. Frankfurter formulations run the gamut from low cost; consisting primarily of raw meat ingredients such as mechanically deboned poultry meat to high-end specialty products such as natural, organic, and kosher all-beef franks. For meat processors, frankfurters are a means to utilize portions of meat that are unsuitable for retail in other forms. As with any low cost finished product, meat producers must rely on a high volume of efficient production to offset a low retail price point. To that end, numerous combinations of processing methods and adjunct ingredients are available to the modern processor. While past studies have focused on the effects of non-meat binding ingredients on the characteristics of emulsion-style products produced using a single final comminution method, there has been very little research that has examined the processing methods role in the properties of the end product. The objectives of this study were: (a) to determine the effect of meat batter production method on the batter stability, processing yield, and texture of frankfurters and (b) to investigate the effects of non-meat binding ingredients commonly used in processed meat products in combination with production methods on the batter stability, processing yield, and texture of frankfurters. This thesis is organized into four chapters. Chapter one provides a general introduction. Chapter two provides a review of the literature focused on topics related to frankfurter production and binding ingredients. Chapter three consists of a complete manuscript and chapter four provides general conclusions for the thesis as a whole.

CHAPTER 2. REVIEW OF LITERATURE

Finely Comminuted Meat Batters

A finely comminuted meat batter (FCMB) is an intricate mixture of lean meat, fat, water, salt, seasonings, and other non-meat ingredients. To fully understand the complexity of FCMBs, it is important to define and describe the components and interactions that take place throughout the process of creation of the finished product.

Meat Ingredients

The lean portion of the FCMB formulation is significant because it is the source of most of the functional proteins required for product stability. Lean muscle is comprised of approximately 20% protein (Huff-Lonergan and Lonergan, 2005). Myofibrillar proteins make up approximately 65-70% of the total protein fraction in meat (Offer and Trinick, 1983). Of the myofibrillar proteins, actin, myosin, and actomyosin represent the proteins of most value in processed meat products (Mandigo, 2004). These salt soluble proteins eventually form the protein gel matrix structure and interfacial protein films (IPF) which surround the fat globules in FCMBs (Gillett et al., 1977).

Fat provides flavor, texture, and juiciness to processed meat products (Keeton, 1994). The species of origin and anatomical location within species can greatly affect the quality attributes of the fat. In addition to having different flavor profiles, the level of saturation of fat from different sources can vary greatly. In FCMBs, individual fat cells are broken down during comminution. Depending on the level and type of comminution, fat particles can vary greatly in size. Fat particles in a batter produced in bowl chopper or emulsion mill can be as small as 1µm and range up in size to 50 µm (Xiong, 2010).

Non-Meat Ingredients

At slaughter, fresh meat consists of approximately 75% water. A portion of this water is lost during chilling, fabrication, and storage (Offer and Trinick, 1983). In processed meat products, native water is often supplemented with added water to provide a solvent for solubilized proteins and non-meat ingredients (Sebranek, 2009). Added water levels in FCMBs generally range between 10-35% of the overall formulation (Claus et al., 1990; Keeton, 1994)

Salt (sodium chloride) has been used since ancient times for the preservation of meat (Romans et al., 2001). Today, salt remains one of the most important and widely used ingredients in processed meat products (Desmond, 2006). In addition to enhancing the flavor of products, salt also serves many functional roles. At concentrations of 0.8 to 1M, salt serves to solubilize myofibrillar proteins in meat by causing them to swell (Offer and Trinick, 1983). The interactions of these meat proteins after solubilization are critical to forming the gelled protein matrix, which affects the water holding ability of processed meat. An added functional role that salt serves in processed meat products is that it acts as a microbial control by reducing the amount of free water available for microbial processes (Tobin et al., 2012).

Alkaline phosphates are often added to processed meat products to enhance the water holding ability and increase processing yields. By raising the pH of the meat, more protein surface charges are produced which enhances protein extraction (Xiong, 2010). Due to their ability to dissociate the actomyosin complex, sodium pyrophosphate and tripolyphosphate are very effective at maximizing myofibrillar protein extraction in the presence of salt (Xiong, 2005). The addition of phosphates is limited to 0.5% of the product weight (USDA, 1995). The most commonly used phosphate compounds in emulsion-style products, either by themselves or in some combination are: sodium pyrophosphate, sodium tripolyphosphate and sodium hexametaphosphate (Xiong, 2010).

The addition of sodium nitrite serves numerous functions in the production of frankfurters. Nitrite plays a significant role in producing the stable, cured meat color and flavors that are associated with cured meats. While the creation of cured meat flavor remains a subject of uncertainty, the process by which cured meat color is produced has been well described. Cured meat color is developed when nitrite is converted to nitric oxide. The nitric oxide then reacts with the sarcoplasmic protein, myoglobin, in the lean meat tissue to form nitric oxide myoglobin. Upon thermal processing, the nitric oxide myoglobin is converted to nitrosylhemochrome which gives the product a distinct pink color (Sebranek, 2009).

Applying mechanical action during the comminution of meat can lead to varying amounts of air being incorporated into the product. These air bubbles can become coated with a protein film in much the same way as the fat particles. Air in FCMBs can be viewed as either a positive or a negative inclusion. Girard et al. (1990) described a “sponge structure,” which positively affected the yield of cooked frankfurters by delaying the draining of water and fat brought on by thermal processing. Air bubbles can also be intentionally included to provide a plumping effect as the air expands inside the sausage during cooking by the consumer. These small air bubbles may also contribute to a positive mouthfeel by providing a less rubbery texture (Xiong, 2010). In most manufacturing systems, processes are put in place to reduce the quantity and size of air bubbles in the finished product. This is accomplished by pulling a vacuum around the product at one or several steps in the process, i.e., blending, chopping and stuffing. In addition to large voids in the finished product being reduced or eliminated, shelf life can be extended by reducing internal surface area and thereby slowing the negative effects of oxygen exposure in the product.

Myofibrillar proteins that would be consumed by IPF formation around air bubbles may be better utilized to stabilize the protein gel matrix (Tantikarnjathep et al., 1983). Tantikarnjathep et al. (1983) found that the use of vacuum during the chopping process in a bowl chopper had a positive effect on emulsion stability and cured color development in frankfurters. These improvements were only significant, however, when vacuum was applied throughout the entire process.

Emulsion Theory

References to FCMBs as “meat emulsions,” and “emulsion-style” products are numerous in the literature (Borchert et al., 1967; Gillett et al., 1977; Mandigo, 2004; Prabhu et al., 2004; Allais, 2010). The emulsion theory of FCMBs is based on the fact that batters have similar properties and characteristics of oil-in-water emulsions (Brown and Toledo, 1975). In a classic oil-in-water emulsion, there are two immiscible phases: a continuous phase (water) and a discontinuous phase (oil). The oil droplets are coated with an interfacial film made up of surfactant molecules or surface-active proteins. These surfactants reduce surface tension and serve as emulsifiers to separate the two phases in a colloidal suspension (Dalgleish, 1997). In true meat emulsions, sub-cellular fat globules represent the discontinuous phase. These are dispersed in a continuous phase consisting of salt-soluble myofibrillar proteins, insoluble proteins, muscle fibers, and connective tissue in an aqueous solution (Mandigo, 2004). An interfacial protein film (IPF), consisting mainly of myosin, is formed around the fat globules and serves as an emulsifier (Gordon et al., 1992). The formation of the IPF involves the heavy meromyosin heads of myosin molecules orienting towards the hydrophobic surface of the fat globules, and the light meromyosin tails orienting towards the aqueous phase (Mandigo, 2004).

The formation of the IPF is an energy-driven process that reduces the amount of free energy in the system, thereby stabilizing it (Gordon et al., 1992; Mandigo, 2004; Xiong, 2010).

Using a scanning electron microscope, Jones and Mandigo (1982) were able to observe the interfacial layer of protein surrounding fat globules in cooked frankfurters. Based on the parameters of the study, they found that the final batter chopping temperature significantly influenced the structure of the protein matrices which coated the fat globules. Lower final chopping temperatures produced a thinner, more elastic protein film. As the final chopping temperature increased, so did the thickness and rigidity of the film. The increase in thickness and rigidity of the film appeared to negatively affect the ability of the film to expand with the fat during thermal processing. Small holes were observed in some of the protein films. It was concluded that these holes, or weak points, acted as pressure release areas, permitting melted fat to escape the larger globules. Rather than coalescing to form another fat globule, the small fat droplets which escaped the larger fat globules were entrapped by the surrounding emulsion matrix.

Physical Entrapment Theory

According to the physical entrapment theory, fat cells remain relatively intact at a cellular level and are surrounded by an intricate matrix made up of swollen and solubilized myofibrillar proteins and insoluble stromal proteins. In addition to suspending the fat globules, the matrix also acts to immobilize free water in the system and retain moisture during thermal processing (Aberle et al., 2001).

In research conducted by Huber and Regenstein (1988), muscle from chicken breasts was exhaustively washed to eliminate soluble protein. The muscle fibers were then used to create a stable “emulsion” despite the lack of sufficient proteins to create an IPF around oil droplets. The authors concluded that this was evidence of an insoluble protein matrix, which entrapped the oil droplets, and therefore could be a significant contributor to batter stability.

It is generally accepted that varying combinations of both theories can take place in the production of successful FCMBs. Processing techniques, ingredient quality, and specific formulations can vary greatly between producers. This makes the relative importance of either batter forming process to the quality and stability of the final product unclear (Aberle et al., 2001). Using scanning electron microscopy, Theno and Schmidt (1978) showed large variations in the microstructures of three different commercial pork and beef frankfurters. Images of two of the products showed little to no evidence of the properties of a true emulsion, and contained large, uneven fat globules and whole muscle fibers. Images of the third product seemed to show features of a finely structured protein matrix and encapsulated fat droplets, properties of a true emulsion. The authors concluded that true meat emulsions do exist, but were not required for an acceptable product.

Production of Finely Comminuted Meat Batters

The process of creating FCMBs generally starts with the fragmentation of chilled lean meat trimmings. During lean fragmentation, salt is added to the meat at a concentration of approximately 4.5% of the lean meat weight. The myofibrillar proteins are solubilized by swelling in the presence of chloride ions. The native water in the meat is supplemented by adding water at this step in the process. Swelling and protein extraction is maximized at temperatures below 3°C. For this reason, a portion of the water may be added as ice. The latent heat of ice allows the batter to remain at a lower temperature for a longer duration despite the heat of friction created by mechanical processing. The water serves to further enhance the solubilisation of extracted proteins into a slurry, which is made up primarily of sarcoplasmic proteins, solubilized myofibrillar proteins and non-soluble stromal proteins. Structuration of the batter occurs when fat trim is added to the mixture. At this point, as mechanical action is continually applied, the temperature of the batter increases. Batter production processes are generally designed to target a specific final end-point chopping temperature or a specific change in temperature during each step of the process. Successful production of FCMBs creates a product in which the fat particles are so finely divided that the fat, even at close to 30% of the product batch, is not visible to the naked eye.

Processing Methods

In FCMB production, there are generally two main goals of mechanical processing: particle reduction and protein extraction. As the surface area of the lean muscle fibers is increased through particle size reduction, protein extraction becomes more efficient. As discussed earlier, one of the primary functions of solubilized myofibrillar proteins is to adequately coat the surfaces of fat globules and still be present in sufficient quantities to form a gel matrix. During comminution, fat particles are also reduced in size. The resulting increase in fat surface area requires more proteins to form the IPF, but at the same time more hydrophilic portions of the proteins are exposed to the continuous phase. In the time required for these interactions to take place, homogenization of the batter occurs. Numerous methods of producing FCMBs have existed over the years, but today, three main processing techniques endure.

Coarse Grind

Coarse ground frankfurters begin with raw meat materials being ground to an intermediate particle size. Grinders (mincers) are the most widely used type of equipment for particle reduction in meat processing. The raw meat is moved through a tube to a grinder plate which consists of a flat surface containing holes of uniform size. As the meat is pressed through the plate, a rotating set of knives shears the meat. Particle size and length is therefore regulated by the size of the holes in the plate and the number of knife arms on the knife assembly (Rust, 2004). In some larger systems, multiple plate and knife configurations with sequentially smaller holes can be included on a single shaft. This allows for a significant particle size reduction in a single pass which eliminates the need to regrind (Barbut, 2015a). The ground meat is then mixed with non-meat ingredients including water, salt, sodium phosphates, various seasoning ingredients and a curing agent before being reground to a smaller size and stuffed into a casing. Fat particles in coarse ground products are clearly visible to the naked eye, thus these products differ significantly in appearance from that of the FCMBs. While falling short of being finely comminuted to the point of being considered a classic emulsion-style (FCMB) product, coarse ground frankfurters represent a means for small to very small meat processors to access the market with a limited investment in capital equipment.

Bowl Chopper

Chopping, or finely mincing the raw meat materials in a bowl chopper consists of continuously passing reduced-particle sized fragments past numerous, rapidly spinning knives in order to create a finely comminuted batter. The number of knives (3-15), knife speed (up to 8000 rpm) and bowl speed (15-30 rpm) can be adjusted independently by the operator in order to control the rate at which comminution occurs (Barbut, 2015a). Modern bowl choppers are capable of producing large batches of batter of high technological quality. Bowl choppers are often fitted with a vacuum hood in order to reduce the amount of air that is incorporated into the batter during chopping. Industrial bowl choppers are currently available that can accommodate volumes of up to 1200L. It has been noted, however, that further increasing equipment sizes, may result in reduced batter quality and increased energy consumption (Weiss et al., 2010). Due to the necessity of having a skilled operator to run the equipment and qualify the state of the batter up to its final chopping point, the bowl chopper has fallen out of favor as the premier processing equipment in many large-scale processing settings in the United States.

Emulsion Mill

Emulsion mills were originally developed as a supplemental method of processing batters once mixing and comminution were achieved in a bowl chopper. Technical advances in emulsification equipment in recent years have led to machines that are able to convert pre-mixed blends of coarsely ground meat and non-meat ingredients into a FCMB. Emulsion mills have the advantage of producing a consistent final product in a continuous process (Rust, 2004; Weiss et al., 2010).

Several different designs of emulsion mills exist. Mills featuring a plate and knife system operate similarly to plate and knife-style grinders, albeit at much higher speeds. In the more common system, a pre-blended, coarsely ground batter is passed through a series of rapidly rotating knives and plates in a closed system. As the size of the holes decreases with each successive plate, the number of knife arms are increased to reduce particle size. The meat is moved through the system with either a mechanical or vacuum pump. In systems that utilize a vacuum pump, the amount of air bubbles in the final product are reduced (Rust, 2004; Weiss et al., 2010). A variation on this design replaces the knives with counter-rotating plates. This design reduces metal-to-metal contact and therefore also reduces surface wear on the plates and amount of energy consumed (Weiss et al., 2010) A third type of emulsion mill configuration consists of an impeller driven design which forces the meat past a stator-rotor knife system. The resulting product quality is a function of the quantity and geometry of the cutting surfaces. This design also alleviates metal-to-metal contact and extends equipment life (Rust, 2004; Weiss et al., 2010).

Often, emulsion mills are controlled by a computer, which can adjust the settings of the various knives and plates in the equipment to determine the final particle size and end-point batter temperature. Pressure of the product while in the equipment can also be adjusted automatically to alter the temperature rise and final temperature of the batter. The need for highly trained and experienced operators is thereby greatly diminished. Emulsifiers are able to pump the finished batter directly into filling equipment, thus simplifying the design of process flow (Weiss et al., 2010).

Preblending

Preblending is the process of grinding and mixing meat and non-meat ingredients several hours or days prior to further processing. Production of preblends allows processors to control inventory and quality control to a greater extent. Functionally, preblending allows time for swelling and solubilisation of myofibrillar proteins (Aberle et al., 2001). Hand et al. (1987) found that preblending low-salt, low-fat frankfurter formulations produced a very acceptable finished product with texture characteristics similar to frankfurters formulated with higher, more traditional levels of salt and fat. Preblending is especially effective when the formulated salt and water are added to the lean fraction of the meat block and mechanical action is applied prior to the addition of the fat. Preblending is optimized at 12-24 hours prior to final comminution (Barbut, 2015a)

Ingredients

Adjunct ingredients have long been used to enhance or supplement the technological quality of raw meat materials used in processed meats. The science and technology of the current era have afforded meat processors a distinct advantage over past generations. Product formulations have, over the course of time, arisen from the necessity to preserve highly perishable meat products for as long as possible between harvest occasions. In recent years, consumers have trended towards healthier products (Desmond, 2006). The relatively high amount of sodium and fat per portion size intrinsic to processed meats has forced meat processors to consider reduced sodium and reduced fat formulations of their products (Ruusunen and Puolanne, 2005). Upon reduction or elimination of fat and salt in processed meat formulations, myriad defects in the finished product can result (Hand et al., 1987; Marquez et al., 1989; Claus et al., 1990). Through the incorporation of specific novel ingredients, these defects can be reduced or eliminated.

Sodium Alginate

Sodium alginate (SA) is a non-starch hydrocolloid that gels in the presence of multivalent ions to form a heat stable gel (Lamkey, 2009). Alginate is derived from brown seaweed (Barbut, 2015b). The stems of the seaweed contain a higher proportion of guluronic acid while the leaves of the plant contain a higher fraction mannuronic acid. In the production of alginate, these acids are converted to their salt forms as mannuronate (M) and guluronate (G) (Lamkey, 2009). When linked together in one of the three block combinations (MM, MG/GM, and GG), "the proportion, distribution and length of these blocks determine the chemical and physical properties of the molecules" (Lamkey, 2009). The strongest gels are formed when high levels of GG blocks are present, due to their length and their reactivity with calcium. Calcium is the most commonly used cation to induce gelation of alginate based on its availability and safety (Lamkey, 2009). While alginate has been investigated for many processed meat applications, there appears to be little published research on the use of SA in emulsion-style products as a means to improve meat batter stability, increase processing yield, or to modify texture.

Iota Carrageenan

Carrageenan (CG) is a linear sulfated polysaccharide derived from several types of red algae species (Ayadi et al., 2009). Three major types of CG are commercially available for use as a food ingredient. These are designated as kappa, iota and lambda carrageenans. These classes of CG are defined by their degree of sulfation and the location of the sulfate groups on the galactose dimer (Černíková et al., 2008). Functionally, the three types of carrageenans differ in their gelling properties. Kappa carrageenan (KC) is characterized by its ability to form strong and brittle gels. Gels formed by Iota carrageenan (IC) are comparatively less strong and more elastic. These gels formed by IC and KC are thermoreversible. Lambda carrageenans do not gel, and are used primarily in food products other than meat as a thickening agent. Of the three types of carrageenan, IC is particularly well suited for use in finely comminuted meat batters (Foegeding and Ramsey, 1987).

Candogan and Kolsarici (2003) demonstrated that a combination of IC (1/3) and KC (2/3) increased the emulsion stability, processing yield and hardness of low fat (3%) frankfurters. Increases improved with higher additions of carrageenan from 0.3% to 0.7%. Concentrations of 0.5% and 0.7% showed characteristics similar to the high fat (17%) control.

DeFreitas et al. (1997) concluded that there were no obvious molecular interactions between meat proteins and carrageenan. This conclusion supported earlier research by Bernal et al. (1987) that found while moisture retention was increased in meat emulsions containing carrageenan, it was accomplished by binding water in the interstitial spaces of the gel network rather than direct interactions with proteins.

Microscopic observations made by Ayadi et al. (2009) in turkey meat batter emulsions showed that carrageenan had a negative effect on emulsion stability. In this study, the size of oil droplets increased with higher levels of carrageenan in the formulation. The authors stated that higher concentrations of carrageenan were responsible for the high degree of coalescence and appearance of large oil droplets. In this same study, the authors stated that despite carrageenan's detriment to emulsion stability, water holding capacity and texture were improved. These positive effects were attributed to the formation of a carrageenan gel network ancillary to the protein gel network.

Transglutaminase

Transglutaminase (TG) is an enzyme which catalyzes an acyl transfer reaction between amino acid residues of lysine and glutamine (Kuraishi et al., 1997). The resulting covalent bond creates a new, polymerized protein structure. Commercial TG preparations are available which contain enzyme that has been produced by culture and fermentation of the bacteria

Streptoverticillium mobaraense (Ando et al., 1989). The enzyme activity of TG is temperature dependent. Maximum activity is realized at approximately 55° C with an active range between 0-65°C. At temperatures below 55°C, TG is still active, albeit with a lowered rate of reaction as temperatures decrease. At temperatures above 65°C, the enzyme begins to denature with complete denaturation occurring between 70-75°C. For this reason, a short holding step for products with TG as a binder may be required prior to some cook cycles. In regards to pH, TG reacts optimally between pH 6-7 with a range of pH 4-9 (Payne, 2009; Hong et al., 2012).

In a patent submitted by Milkowski and Sosnicki (1999) a process is described by which pale, soft, and exudative (PSE) pork and turkey are treated with a brine solution containing TG. In the description of the invention the authors note the enzymes ability to cross-link proteins in meat despite poor myofibrillar protein extraction usually associated with meat displaying PSE characteristics. While there is mention of treatment of PSE meat prior to further processing, no description of FCMB products are discussed. This is of interest primarily because in reduced sodium FCMB formulations, less salt is available to solubilize myofibrillar proteins. Since TG acts on individual amino acids, a gel network consisting of polymerized proteins can be formed even when salt concentration, and therefore solubilized protein, is reduced.

In FCMBs, TG is generally added to the lean meat portion at the same time as the salt. The salt-induced solubilisation and extraction of the myofibrillar proteins is enhanced by the mechanical action of the equipment and provides ample substrate for the enzyme to act. The protein cross-links that result provide further stabilization to the batter by strengthening the protein gel matrix (Ramírez-Suárez and Xiong, 2003). The main benefit of TG in FCMBs is texture improvement/modification (Sun and Arntfield, 2011). Usage amount can range from 0.025-0.30% of the formulation with lower sodium levels necessitating a higher amount of enzyme (Payne, 2009). It has been observed that usage levels above a certain threshold may reduce the processing yield in some products unless a suitable hydrocolloid, such as konjac flour, is incorporated simultaneously with the TG (Chin et.al. 2009).

Collagen

Collagen is a stromal protein that constitutes approximately 25-30% of total body protein in mammals. In the mammalian body, collagen is a major component of various structures. Skin, bone, teeth, connective tissue and blood vessels are all primarily composed of collagen. Collagen molecules are rod-shaped and are stabilized by various intra- and intermolecular cross-links that become more stable as the living animal ages. As the animal matures, the ability of collagen molecules to form multiple cross-links increases, thus resulting in a decrease of the tenderness of lean muscle tissue (Tarté, 2009).

Varying levels of collagen exist in processed meat products based on the anatomical source of meat used as raw material. Since frankfurters and other FCMB products are generally produced with lean trim that is unable to be sold as retail cuts, the amount of collagen present can be significant. In addition to the collagen present as part of the meat block, isolated and refined collagen can be added to formulations in order to alter the texture and processing characteristics of FCMB products (Schilling et al., 2003; Tarté, 2009).

In a study by Doerscher et al. (2004), the effects of pork collagen on the gelling properties of purified pork myofibrillar protein gels was examined. The authors found that despite the use of highly purified myofibrillar proteins, specific protein-protein interactions could not be observed. Additionally, when pork collagen was added at levels above 20% in the system, it was shown to have detrimental effects on the rate of heat-set gel formation. The authors concluded that in a model system, the ratio of 90:10, myofibrillar protein to pork collagen was optimum for texture improvement and increased water holding capacity.

Prabhu et al. (2004) found that the addition of refined pork collagen significantly increased the processing yield of pork and chicken frankfurters when added at levels above 1% of the formulation. In this study, it was also shown that purge in the finished product was significantly reduced after both 4 and 8 weeks of refrigerated storage. The authors attributed these findings to the absorption and binding of water by collagen in the gelled protein matrix. Additionally, it has been shown that similar levels of added refined pork collagen can help to improve texture and yields in frankfurters formulated with high (>60%) amounts of mechanically deboned poultry meat (Pereira et al., 2011).

Summary

Comminution methods and processes used to create meat batters can vary greatly between individual processors. While past studies have focused on the effects of non-meat binding ingredients on the characteristics of emulsion-style products produced using a single final comminution method, there has been very little research that has examined the processing methods role in the properties of the end product with specific non-meat binding ingredients taken in to consideration. The difference in particle size and level of soluble protein extraction between similarly formulated products processed by different equipment may lead to varying levels of batter stability, processing yield, and texture characteristics in the final products. Given the characteristics and benefits of the non-meat binding ingredients discussed herein, and their widespread use in the meat industry in similar products, similar benefits may be realized when these ingredients are used in frankfurter formulations, but the relative effects of the ingredients when used in the various comminution opttons are not clear.

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CHAPTER 3. EFFECTS OF PROCESSING METHOD AND NON-MEAT BINDING INGREDIENTS ON BATTER STABILIY, YIELD AND TEXTURE OF FRANKFURTERS

A manuscript prepared for submission to *Meat and Muscle Biology*

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Abstract

The effects of processing method and added non-meat ingredients on the processing yield, batter stability, and texture profile of frankfurters were investigated. Five ingredient treatments (control, sodium alginate, iota carrageenan, transglutaminase, and pork collagen) of frankfurters were produced using three different processing methods (coarse grinding, chopping in a bowl chopper and passing through an emulsion mill). Emulsion stability (water separation, fat separation and total liquid separation) was measured on the resulting batter. Processing yield was measured after cooking and chilling the frankfurters. A texture profile analysis (TPA) of the finished frankfurters was also conducted with a focus on the TPA characteristics of hardness, cohesiveness, and chewiness. Control treatments produced by different methods showed significantly ($P < 0.05$) different levels of processing yield with the emulsion mill producing the

highest, followed by bowl chopper and then coarse grinding. Coarse ground treatments showed the most negative impact of processing method on processing yield and texture characteristics. The addition of transglutaminase showed a positive effect on TPA characteristics chewiness and cohesiveness, and did not affect processing yield. Consequently, a difference between frankfurters produced with different methods was observed, and a means to offset those differences through ingredient formulation was demonstrated.

Key words: meat batter stability, non-meat binders, transglutaminase, carrageenan, collagen

Introduction

Frankfurters (cooked and cured meat sausages) are one of the most popular convenience food items in the world. Various raw meat material, seasonings, casing options, and processing techniques provide myriad choices for today's consumers. Currently, the most common processing methods for achieving a homogenous, reduced particle size, meat batter mixture for frankfurters are coarse grinding using a grinder/mincer, chopping in a bowl chopper, or passing through an emulsion mill. These different methods produce batters of varying meat particle size and technological quality. These different methods were examined to determine their impact on batter stability, processing yield, and texture characteristics.

Non-meat binding ingredients are often used to increase yield and modify sensory characteristics of processed meat products. Sodium alginate (SA) is a non-starch hydrocolloid that gels in the presence of multivalent ions to form a heat stable gel (Lamkey, 2009). While alginate has been investigated for many processed meat applications, there appears to be little published research on the use of SA in emulsion-style products as a means to improve meat batter stability, increase processing yield, or to modify texture. Carrageenan (CG) is a linear sulfated polysaccharide derived from several types of red algae species (Ayadi et al., 2009). The gelling properties of CG and its impact on moisture retention and texture improvements in finely comminuted processed meat products have been well described (Candogan and Kolsarici, 2003; Ayadi et al., 2009). There is, however, a lack of agreement on the impact of CG on meat batter stability. Transglutaminase (TG) is an enzyme which catalyzes an acyl transfer reaction between amino acid residues of lysine and glutamine (Kuraishi et al., 1997). The resulting covalent bond creates a new, polymerized protein structure which may greatly improve the texture characteristics of processed meat products, especially those formulated with reduced sodium and therefore having less solubilized myofibrillar protein. Varying levels of collagen exist in processed meat products based on the anatomical source of meat used as raw material. Since frankfurters and other finely comminuted products are generally produced with lean trim that is unable to be sold as retail cuts, the amount of collagen present can be significant. In addition to the collagen present as part of the meat block, isolated and refined collagen can be added to formulations in order to alter the texture and processing characteristics of FCMB products (Schilling et al., 2003; Tarté, 2009). Prabhu et al. (2004) found that the addition of refined pork collagen significantly increased the processing yield of pork and chicken frankfurters when added at levels above 1% of the formulation. The authors attributed these findings to the absorption and binding of water by collagen in the gelled protein matrix.

Thus, the objective of this study was to evaluate the impact of these non-meat binding agents on the performance of the different processing methods typically used to form comminuted meat batters for the production of frankfurters.

Materials and Methods

Frozen raw meat materials consisting of 50% lean pork and 90% lean beef were obtained from the Iowa State University Meat Laboratory. The frozen meat was allowed to temper at 2.2°C for 3 days. Five treatments of frankfurters with a variety of non-meat binding agents were formulated. Each formulation was prepared by three different processing methods; as a coarse-ground batter, or as a finely comminuted batter using either an emulsion mill, or a bowl chopper. The non-meat binding agents included iota carrageenan (S-100, Ingredient Solutions, Inc., Waldo, ME), sodium alginate (WBS 203, Wenda Ingredients, Naperville, IL), transglutaminase (Activa® TI, (maltodextrin 99%, transglutaminase 1%), Ajinomoto North America, Inc., Ft. Lee, NJ), and a functional pork collagen ingredient in the form of dried pork stock (DPS, Essentia Protein Solutions, Ankeny, IA). The control treatment consisted of a standard Iowa State University frankfurter formulation including salt, spices (EJ-93-150-001, A.C. Legg, Calera, AL) and sodium nitrite, but without phosphates, and with the level of added sodium chloride reduced from 2% to 1.5% of the meat weight. This was done in order to weaken the emulsion stability to a degree that the adjunct ingredients could more effectively show signs of improving the stability of the batter. Raw meat materials were formulated to provide a fat content of approximately 30% in the finished frankfurters. Fat analyses of the raw meat materials were performed prior to formulation using an Anyl Ray fat analyzer (Kartridg Pak, Model 316-48, R.A. Jones & Co, Davenport, IA). Formulations for individual ingredient formulations are listed in Table 1.

Batter Production and Frankfurter Production

For each of the five ingredient formulations, production of the frankfurter batters was performed using three separate and independent batter preparation methods which included coarse grinding, chopping in a bowl chopper, or passing through an emulsion mill. For all treatments and preparation methods, the meat block, consisting of a lean beef portion and a fat pork portion, was first coarsely ground through a 12.7 mm grinder plate prior to creation of the batter.

For treatments containing sodium alginate (SA), a unique process was required because alginate does not form gels effectively in the presence of NaCl (Hong and Chin, 2010). In order to avoid the relatively high salt concentrations during blending, the day prior to batter production, the fat portion of the meat block was ground through a 12.7 mm grinder plate and mixed with half of the water included in the formulation. Simultaneously, the sodium alginate was also incorporated into the water/pork fat mixture. The resulting blend was flattened to a uniform thickness at the bottom of a storage lug and allowed to rest overnight (15 hours) in a cooler at 2° C. This produced a firm "sheet" of pork fat which was sliced into 25 mm cubes by hand prior to being incorporated into the batters.

For the production of the emulsion mill (EM) and coarse-ground (CG) treatments, the meat and non-meat ingredients were mixed into a homogenous pre-blend using a double action ribbon/paddle mixer (Leland Southwest, model 200DA70, Ft. Worth, TX) immediately prior to batter production. The production of the pre-blends was achieved as follows: The lean portion of the meat block was added to the mixer along with the salt and half of the water. Half of the weight of the water was in the form of ice in order to keep the temperature of the pre-blend low during mechanical processing. After mixing for two minutes, the fat portion of the meat block and the remaining non-meat ingredients (including the ice/water mixture) were added to the blend and allowed to mix for an additional 2 minutes.

In order to achieve the final coarse-ground (CG) batters, the pre-blend was passed through a 3.18 mm grinder plate using a table top grinder (Torrey, model M-22R, Houston, TX).

Prior to passing pre-blends through the emulsion mill (Stephan Microcut, Mundelein, IL), the mill was first chilled by passing 2 kg of ice through the hopper, knives, and discharge spout of the machine. This process was also performed between each treatment in order to return the contact surfaces of the mill to a consistent temperature.

For treatments processed in the bowl chopper (BC), the lean portion of the meat block was first added to the bowl chopper (Kilia, Vacuum-Cooking Bowl Cutter 30 Ltr. with 6 knives, Neumuenster, Germany) along with the salt and half of the ice/water mixture. The mixture was chopped at a knife speed of 5400 rpm and a bowl speed of 20 rpm until the mixture reached 5.5°C. The fat portion of the meat block was then added to the bowl chopper along with the remaining ice/water mixture and non-meat ingredients. When chopping the treatment containing the SA, the portion of ice/water mixture was reduced by half in order to compensate for water previously added to hydrate the SA while incorporating it into the fat portion of the meat block. This resulted in 25% of the overall ice/water mixture being added during lean chopping and 25% being added along with the fat portion. This resulted in a more rapid increase in temperature during chopping for the SA treatment and therefore a shorter chopping time. With all of the ingredients in the bowl chopper, the batter was chopped under vacuum at a knife speed of 5400 rpm and a bowl rotation speed of 20 rpm until the temperature of the batter reached a temperature of 13° C.

For all of the treatments, once the final comminution of batter was achieved, samples were collected for analysis of emulsion stability. The remaining batter was loaded into a vacuum filler (Risco, Model 4003-165, South Easton, MA), and stuffed in to size 26 (USA) peelable cellulose casings (Viscofan, 651795P 26x125 CF-FP, Lisle, IL). The sausages were linked, placed on sticks, weighed, and all treatments were placed on a single smoke truck for thermal processing. Thermal processing was accomplished using a Maurer, single-truck, batch oven (Maurer-Atmos, Reichenau, Germany) with attached natural smoke generator (Raucherzeuger Goliath II, Reichenau, Germany). The franks were cooked to an internal temperature of 70°C using the cook/natural smoke cycle shown in Table 2.

Upon completion of thermal processing, the sausages were removed from the oven and placed in a cooler at 0°C to chill overnight (15 hours).

Once chilled, the frankfurters were reweighed to determine smokehouse and stabilization yield (processing yield, PY). The cellulose casings were removed from the frankfurters using an automated peeler (Townsend Engineering, Model 2600, Des Moines, IA). The franks were then vacuum packaged in bags (Cryovac Sealed Air, 5x16 B2470 Standard, Charlotte, NC) at the rate of five links per pack in a single layer and stored under refrigeration (2°C) for approximately two weeks prior to being analyzed for texture.

Emulsion Stability Analysis

As previously described, samples of raw batter were collected immediately following the final mechanical steps of batter production, and evaluated using the Rongey method as described by Sebranek et al., (2001). A modified, open end syringe was used to collect an approximate 25 g sample from the batter. The sample was transferred to a Wierbicki tube containing a fritted glass disc, with care taken to minimize air bubbles. Samples were then cooked in a water bath (Shel Lab, model WP C95, Cornelius, OR) for 30 minutes at 71.1°C. Upon completion of cooking, samples were allowed to cool at ambient temperature for 3 minutes. The samples were then placed in a centrifuge (Lab Line, Inc., Model No. 61, Chicago, IL), and spun at low speed (10,000 rpm) for 5 minutes. After centrifugation, amounts of separated fat and water were measured. Percent water separation, percent fat separation, and percent total liquid separation were calculated using the following formulas:

% water separation = (ml water/sample weight) x 100

% fat separation = (ml fat/sample weight) x 100

% total liquid separation = % water separation + % fat separation

Three samples were analyzed from each ingredient x processing method treatment.

Texture Analysis

Texture analysis was conducted within approximately two weeks of packaging the frankfurters. Samples of each treatment were randomly selected from the packaged frankfurters. The franks were stored under refrigeration until just prior to analysis in order to reduce temperature variations. A 2.54 cm cross section was cut from the middle of individual, randomly selected frankfurters for analysis. Texture analysis was conducted using a TA-XT2i Texture Analyzer (Texture Technologies Corp., Algonquin, IL). The tests were performed using a 5.08 cm cylinder probe (model TA-25) to compress the sample along its vertical axis. The texture profile analysis (TPA) test was programmed with a trigger force of 5 g, a compression speed of 5 mm/sec, travel distance of 50%, and return speed of 5 mm/sec. Frankfurters samples were measured by a standard, 2 compression, TPA procedure with a focus on hardness, cohesiveness, and chewiness as the primary data of interest. Hardness was measured as the peak force of the first compression, cohesiveness was measured as the area of work during the second compression divided by the area of work in the first compression, and chewiness was calculated as gumminess multiplied by springiness (Bourne, 2002). Three samples of each ingredient x processing method treatment were tested.

Statistical Analysis

The experiment was independently replicated three times on separate production days for each replication over the course of a six-month period. Statistical analysis of the data was performed using PROC MIXED by Statistical Analysis System (SAS v9.4, Cary, NC). The fixed effects of the experimental design process, formulation and test replication were analyzed. Results were compared for differences among frankfurter treatments as well as for the differences between processing methods. Least squares means and standard errors are reported for each characteristic. Significance was determined at $P \leq 0.05$.

Results and Discussion

Processing yield (PY) measurements of frankfurter formulations using the emulsion mill, bowl chopper and coarse ground processing methods are presented in Table 3. The yields were affected significantly ($P < 0.05$) by each of the three different processing methods, with the emulsion mill resulting in greater yield than the coarse ground in all formulations and greater than the bowl chopper for the control and carrageenan (IC) formulations. The coarse ground products resulted in the lowest yield for all formulations except the IC. This can be attributed to the level of comminution and the increase in functional protein extraction and availability produced by the emulsion mill and the bowl chopper, and which serves to bind free water. No differences between the emulsion mill and bowl chopper methods were observed for frankfurters prepared with CO, sodium alginate (SA) or transglutaminase (TG). The CO, SA and TG formulations each resulted in similar processing yields for the emulsion mill and the bowl chopper while IC did not. Overall, this confirms that the processing method used for final comminution of the batter, particularly the fine comminution achieved by the emulsion mill and the bowl chopper, is an important determinant of the processing yield of frankfurters. This is a well-recognized effect of comminution on processing yield for these products. These results also show that adding certain adjunct ingredients has potential to reduce the differences between the processing methods, particularly the emulsion mill and bowl chopper. Table 4 displays the results for PY measurements for each of the different frankfurter formulations in the three processing methods. Of the frankfurters produced in the bowl chopper, only the SA formulation was significantly ($P < 0.05$) different for processing yield, and resulted in the highest yield compared to all other formulations processed with the bowl chopper. No significant differences ($P > 0.05$) occurred among the other formulations for the bowl chopper method. Coarse ground treatments containing SA and IC also showed a significant ($P < 0.05$) increase in processing yield when compared to all other formulations. Processing yield of frankfurter formulations IC, TG and SA produced in the emulsion mill were not significantly different ($P > 0.05$) than the control. However, the TG frankfurters had lower ($P < 0.05$) PY than the emulsion mill processed SA and IC frankfurters, but was not different ($P > 0.05$) from the control or CO frankfurters. This is consistent with previous observations where the incorporation of TG slightly reduced the yield of the finished product (Chin et.al. 2009). Of the four ingredient treatments, SA increased ($P < 0.05$) yield most consistently, among the different processing methods used. This may have been due to the preparation method necessary for SA as previously described, where a substantial amount of the added water was pre-blended with the SA ingredient and allowed to form a gel prior to being incorporated into the final batter. These results are supported by Hong and Chin (2010) who reported that SA improved the water binding ability of porcine myofibrillar gels and that TG enhanced gel strength but increased moisture loss from the gels. These authors also reported that combining SA and TG treatments was effective for improving both water retention and texture of the protein gels. Sadeghi-Mehr et.al. (2018) also compared SA and TG in porcine meat batters and reported increased water binding achieved by addition of SA to the batters.

Results for the effect of processing method on water separation in the emulsion stability analysis are shown in Table 5. All frankfurter formulation treatments processed in the bowl chopper, except the SA treatment, showed significantly less water separation compared to the other processing methods. Table 6 displays the results for the effect of frankfurter formulation on water separation from the emulsion stability analysis. Control frankfurters processed in the bowl chopper overall showed the greatest amount of water separation, but this was not statistically different ($P > 0.05$) from IC, TG or CO. The SA treatment was significantly ($P < 0.05$) lower than the control, producing the least amount of water separation. Coarse ground frankfurters showed the highest amount of water separation when formulated with CO and the lowest when formulated with IC and SA, respectively, while frankfurters produced in the emulsion mill also showed the lowest water separation values when formulated with sodium alginate. The IC and CO were intermediate for the amount of water separation while the TG and CO formulations were similar to the control.

The results for the effect of frankfurter processing method on fat separation during emulsion stability analysis are shown in Table 7. The amount of fat separation was relatively small in all cases, consequently differences were more difficult to detect. The bowl chopper generally resulted in less fat separation but this was significant only with the IC and TG formulations. The ground product generally results in the most fat separation but again was significant only for the CO and SA formulations. IC and TG treatments produced in the emulsion mill showed similar results to the same treatments produced by coarse grinding. Table 8 displays the effect of the frankfurter formulations on the fat separation component of emulsion stability analysis. Here again, the relatively small amount of fat separation that occurred in all cases makes any potential differences more difficult to detect. While SA resulted in significantly less ($P < 0.05$) fat separation than the other non-meat binding agents in the emulsion mill, it was not different than the control. These results suggest that formulation with non-meat binders has minimal effect on fat separation from meat batters as observed in the different processing methods used in this study.

Table 9 shows the effect of frankfurter processing method on the total liquid separation (TLS) observed during emulsion stability analysis. As might be expected from the results for water and fat separation in tables 5 and 7, differences in total liquid separation are similar to the values noted for water separation since water was the largest share of the total liquid measured. With the exception of the SA formulation produced in the emulsion mill, all other formulations including the control resulted in significantly less ($P < 0.05$) total liquid separation when produced in the bowl chopper compared to the other methods.

The results for the effect of frankfurter formulation on total liquid separation are shown in Table 10. Again, these results are similar to those observed for water separation shown in table 6. The SA treatment produced in the bowl chopper had lower ($P > 0.05$) TLS than the control but did not differ from the other formulations with added ingredients. The IC, TG, and CO treatments were similar ($P > 0.05$) to the control and to each other. In the coarse ground formulations, IC reduced ($P < 0.05$) the TLS when compared to the control while the CO resulted in greater ($P < 0.05$) TLS than any of the other ingredient treatments. Of the treatments prepared in the emulsion mill, the SA resulted in the least ($P < 0.05$) TLS of all the ingredients studied.

Results for the effect of processing method on texture profile analysis (TPA) component hardness are displayed in Table 11. The three processing methods were similar ($P > 0.05$) in hardness for the control formulation. Further, no significant differences ($P > 0.05$) between processing methods were observed for the frankfurters formulated with CO and TG. Coarse ground frankfurters formulated with either SA or IC were similar to each other but with less ($P < 0.05$) hardness than those produced in the emulsion mill. Frankfurters formulated with SA and IC and produced in the bowl chopper were not significantly different ($P > 0.05$) than those produced in the emulsion mill or that were coarse ground. Table 12 shows the results of the effect of frankfurter formulation on TPA hardness. No significant ($P > 0.05$) differences were seen between any of the formulations that were produced in the bowl chopper. The TG formulation, although not different from CO, was significantly ($P < 0.05$) harder than the control, SA or IC in the coarse ground frankfurters. The frankfurters produced in the emulsion mill with the CO formulation were similar to the control, but with the SA, IC and TG formulations, provided a significant ($P < 0.05$) increase in hardness. Huang and Clarke (2017) reported that TG and IC increased the hardness of a fish protein gel matrix over controls without these ingredients but did not observe similar effects for SA.

Results for the effect of processing method on the TPA component chewiness are displayed in Table 13. The ingredient formulations produced in the bowl chopper and in the emulsion mill, each produced statistically similar ($P > 0.05$) results. Values observed in all formulations produced by coarse grinding were significantly lower ($P < 0.05$) for chewiness than for batches produced in the emulsion mill or bowl chopper. This is likely due to the reduced protein extraction and subsequent adhesion between coarse ground particles resulting from the reduced mechanical action that occurs with coarse grinding in comparison to the protein gel matrix that results from finely comminuted meat mixtures. Table 14 shows results for the effect of frankfurter formulation on the TPA component chewiness. The TG formulation resulted in the highest ($P < 0.05$) value for chewiness in the coarse ground frankfurters, and also resulted in a trend toward greater numerical value for chewiness with the other processing methods, though this was not significantly ($P > 0.05$) different from the other ingredients, in most cases. In general, with formulations produced in the emulsion mill, the TG, SA, and IC treatments showed significant improvement in chewiness over the control. The protein crosslinking effect of TG appears to have had a greater impact on the loosely structured coarse ground particles than in the case of the finely comminuted products where the protein gel matrix is more predominant.

The concept of a more loosely held product structure in the coarse ground products is supported by the TPA component cohesiveness results shown in Table 15. All formulations resulted in significantly ($P < 0.05$) less cohesiveness, while the bowl chopper and the emulsion mill were similar for all the formulations., with those processed by coarse grinding being significantly ($P < 0.05$) less cohesive, regardless of ingredient treatment. In table 16, the effect of frankfurter formulation on cohesiveness shows that the TG formulation produced in the bowl chopper resulted in a significant ($P < 0.05$) increase in cohesiveness compared to the other formulations, which did not differ from each other. In formulations produced by the coarse grind method, the addition of SA showed significantly ($P < 0.05$) more cohesiveness than the other formulations, while the other ingredients showed no significant ($P > 0.05$) differences from the control. In treatments produced in the emulsion mill, the SA and TG formulations increased ($P < 0.05$) the cohesiveness relative to the control. Thus, SA and TG have potential to impact product cohesiveness of meat batters but the impact is dependent on the processing method used.

Conclusions

The results of this study support the commonly held belief that a higher degree of comminution, specifically that achieved by processing meat batters in either an emulsion mill or bowl chopper, result in a higher degree of technological quality which translates to higher yield and a firm texture profile. When coarse grinding alone is used as the only method of comminution, processing yield is negatively impacted by reduced emulsion stability. Chewiness and cohesiveness are also negatively impacted in coarse ground formulations. Hardness is generally not affected by the processing method used, but is increased in coarse ground frankfurters formulated with TG. TG also seems to have a positive effect on chewiness and cohesiveness, due to the crosslinking of proteins, regardless of the processing method used. TG did not seem to negatively affect processing yield, but at the same time provided no increase in yield for any processing method. Frankfurters processed in the emulsion mill show the highest overall processing yield. Frankfurters produced in the bowl chopper generally show the highest emulsion stability in terms of total liquid separation. The correlation of emulsion stability and processing yield was not examined in this research. Future studies may benefit from a more detailed investigation of this correlation. There may also be benefits in combining TG, IC, and SA in formulations. The texture improvements provided by TG and IC combined with the water retention benefits of IC and SA may have potential to maximize yield and texture in frankfurters regardless of processing method.

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Tables

Table 1

Frankfurter Formulations

Ingredient	Control (lbs)	Sodium Alginate (lbs)	Iota Carrageenan (lbs)	Transglutaminase (lbs)	Pork Collagen (lbs)
	Formulation				
Beef Trim[1]	6.33	6.33	6.33	6.33	6.33
Pork Trim[2]	8.44	8.44	8.44	8.44	8.44
Ice/Water	4.40	4.40	4.40	4.40	4.40
Seasoning[3]	0.49	0.49	0.49	0.49	0.49
Salt	0.30	0.30	0.30	0.30	0.30
Curing Salt[4]	0.036	0.036	0.036	0.036	0.036
Sodium Alginate[5]	-	0.18	-	-	-
Iota Carrageenan[6]	-	-	0.10	-	-
Transglutaminase[7]	-	-	-	0.015	-
Pork Collagen[8]	-	-	-	-	0.05

[1]90% Lean, [2]50% Lean, [3]EJ-93-150-001-A.C. Legg, [4]6.25% $NaNO_2$, [5]WBS 203-Wenda Ingredients, [6]S100-ISI, [7]Activa TI-Ajinomoto North America, [8]DPS - Essentia

Table 2

Thermal Processing Schedule

Step	Step Time	Dry Bulb Temperature (°F)	Wet Bulb Temperature (°F)	% Relative Humidity	Internal Temperature (°F)	Main Blower	Exhaust Damper
Cook	00:10	110	100	70	-	Low	Auto
Cook	00:30	145	0	0	-	High	Auto
Smoke	01:00	145	138	82	-	High	Closed
Cook	00:30	155	0	0	-	High	Auto
Cook	00:30	180	140	36	-	High	Auto
Steam	00:01	180	180	100	160	High	Closed
Cold Shower	00:15	50	0	0	-	Off	Auto

Table 3

Least squares means for the effect of frankfurter processing method on processing yield (%)

	Formulation				
Process	Control	Pork Collagen	Iota Carrageenan	Sodium Alginate	Transglutaminase
Emulsion Mill	87.3[a]	86.4[a]	87.8[a]	87.5[a]	86.6[a]
Bowl Chopper	86.3[b]	86.1[a]	86.4[b]	87.6[a]	86.5[a]
Coarse Ground	85.0[c]	85.3[b]	86.4[b]	86.8[b]	85.1[b]
S.E.[d]	0.2	0.1	0.1	0.2	0.2

[a-c]Means in the same column with different letters are significantly different at $P < 0.05$
[d]Standard error of means

Table 4

Least squares means for the effect of frankfurter formulation on processing yield (%)

	Processing Method		
Formulation	Bowl Chopper	Coarse Ground	Emulsion Mill
Control	86.3[b]	85.0[b]	87.3[ab]
Sodium Alginate	87.6[a]	86.8[a]	87.5[a]
Iota Carrageenan	86.4[b]	86.4[a]	87.8[a]
Transglutaminase	86.5[b]	85.1[b]	86.6[bc]
Pork Collagen	86.1[b]	85.3[b]	86.4[c]
S.E.[d]	0.2	0.2	0.2

[a-c]Means in the same column with different letters are significantly different at $P < 0.05$
[d]Standard error of means

Table 5

Least squares means for the effect of frankfurter processing method on emulsion stability analysis - water separation (%)

	Formulation				
Process	Control	Pork Collagen	Iota Carrageenan	Sodium Alginate	Transglutaminase
Bowl Chopper	2.7^{b}	2.0^{c}	1.9^{b}	1.6^{b}	2.1^{b}
Coarse Ground	10.2^{a}	15.0^{a}	5.6^{a}	7.7^{a}	11.0^{a}
Emulsion Mill	9.1^{a}	8.4^{b}	6.7^{a}	2.3^{b}	10.1^{a}
S.E.[c]	0.8	0.5	0.5	0.5	0.6

[a-b]Means in the same column with different letters are significantly different at $P < 0.05$
[c]Standard error of means

Table 6

Least squares mean for the effect of frankfurter formulation on emulsion stability analysis - water separation (%)

	Processing Method		
Formulation	Bowl Chopper	Coarse Ground	Emulsion Mill
Control	2.7^{a}	10.2^{b}	9.1^{a}
Sodium Alginate	1.6^{b}	7.7^{c}	2.3^{c}
Iota Carrageenan	1.9^{ab}	5.6^{c}	6.7^{b}
Transglutaminase	2.1^{ab}	11.0^{b}	10.1^{a}
Pork Collagen	2.0^{ab}	15.0^{a}	8.4^{ab}
S.E.[d]	0.3	0.6	0.5

[a-c]Means in the same column with different letters are significantly different at $P < 0.05$
[d]Standard error of means

Table 7

Least squares means for the effect of frankfurter processing method on emulsion stability analysis - fat separation (%)

	Formulation				
Process	Control	Pork Collagen	Iota Carrageenan	Sodium Alginate	Transglutaminase
Bowl Chopper	0.5^{b}	0.5^{b}	0.5^{b}	0.4^{b}	0.5^{b}
Coarse Ground	1.8^{a}	2.3^{a}	1.3^{a}	1.8^{a}	1.2^{a}
Emulsion Mill	1.2^{ab}	1.3^{b}	1.4^{a}	0.5^{b}	1.7^{a}
S.E.^{c}	0.2	0.3	0.2	0.3	0.2

$^{a-b}$Means in the same column with different letters are significantly different at $P < 0.05$
^{c}Standard error of means

Table 8

Least squares means for the effect of frankfurter formulation on emulsion stability analysis – fat separation (%)

	Processing Method		
Formulation	Bowl Chopper	Coarse Ground	Emulsion Mill
Control	0.5^{a}	1.8^{ab}	1.2^{ab}
Sodium Alginate	0.4^{a}	1.8^{ab}	0.5^{b}
Iota Carrageenan	0.5^{a}	1.3^{ab}	1.4^{a}
Transglutaminase	0.4^{a}	1.2^{b}	1.7^{a}
Pork Collagen	0.5^{a}	2.3^{a}	1.3^{a}
S.E.^{c}	0.1	0.2	0.2

$^{a-b}$Means in the same column with different letters are significantly different at $P < 0.05$
^{c}Standard error of means

Table 9

Least squares means for the effect of frankfurter processing method on emulsion stability analysis – total liquid separation (%)

	Formulation				
Process	Control	Pork Collagen	Iota Carrageenan	Sodium Alginate	Transglutaminase
Bowl Chopper	3.2[b]	2.5[c]	2.4[b]	1.9[b]	2.6[b]
Coarse Ground	12.1[a]	17.3[a]	6.9[a]	9.6[a]	12.3[a]
Emulsion Mill	10.3[a]	9.7[b]	8.1[a]	2.8[b]	11.7[a]
S.E.[d]	0.9	0.7	0.6	0.8	0.8

[a-c]Means in the same column with different letters are significantly different at $P < 0.05$
[d]Standard error of means

Table 10

Least squares means for the effect of frankfurter formulation on emulsion stability analysis – total liquid separation (%)

	Processing Method		
Formulation	Bowl Chopper	Coarse Ground	Emulsion Mill
Control	3.2[a]	12.1[b]	10.3[ab]
Sodium Alginate	1.9[b]	9.6[bc]	2.8[c]
Iota Carrageenan	2.4[ab]	6.9[c]	8.1[b]
Transglutaminase	2.6[ab]	12.3[b]	11.7[a]
Pork Collagen	2.5[ab]	17.3[a]	9.7[ab]
S.E.[d]	0.3	0.8	0.6

[a-c]Means in the same column with different letters are significantly different at $P < 0.05$
[d]Standard error of means

Table 11

Least squares means for the effect of frankfurter processing method on TPA - hardness (g)

	Formulation				
Process	Control	Pork Collagen	Iota Carrageenan	Sodium Alginate	Transglutaminase
Bowl Chopper	11497^{a}	10969^{a}	12957^{ab}	11295^{ab}	13396^{a}
Coarse Ground	9817^{a}	11715^{a}	9755^{b}	10030^{b}	13829^{a}
Emulsion Mill	12180^{a}	12564^{a}	13549^{a}	13550^{a}	13548^{a}
S.E.^{c}	717.65	802.62	1006.53	784.13	314.1

$^{a-b}$Means in the same column with different letters are significantly different at $P < 0.05$
^{c}Standard error of means

Table 12

Least squares means for the effect of frankfurter formulation on TPA - hardness (g)

	Processing Method		
Formulation	Bowl Chopper	Coarse Ground	Emulsion Mill
Control	11497^{a}	9817^{b}	12180^{b}
Sodium Alginate	11295^{a}	10030^{b}	13550^{a}
Iota Carrageenan	12957^{a}	9755^{b}	13549^{a}
Transglutaminase	13396^{a}	13829^{a}	13548^{a}
Pork Collagen	10969^{a}	11715^{ab}	12564^{b}
S.E.^{c}	890.42	918.17	187.34

$^{a-b}$Means in the same column with different letters are significantly different at $P < 0.05$
^{c}Standard error of means

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Table 13

Least squares means for the effect of frankfurter processing method on TPA - chewiness

	Formulation				
Process	Control	Pork Collagen	Iota Carrageenan	Sodium Alginate	Transglutaminase
Bowl Chopper	6223.72[a]	5971.40[a]	7026.28[a]	6174.44[a]	8043.20[a]
Coarse Ground	3526.50[b]	4124.31[b]	3305.93[b]	2423.50[b]	5854.47[b]
Emulsion Mill	6035.15[a]	6434.11[a]	6907.90[a]	7218.53[a]	7442.34[a]
S.E.[c]	306.68	460.38	358.92	438.35	280.57

[a-b]Means in the same column with different letters are significantly different at $P < 0.05$
[c]Standard error of means

Table 14

Least squares means for the effect of frankfurter formulation on TPA - chewiness

	Processing Method		
Formulation	Bowl Chopper	Coarse Ground	Emulsion Mill
Control	6223.72[ab]	3526.50[bc]	6035.15[c]
Sodium Alginate	6174.44[ab]	2423.50[c]	7218.53[a]
Iota Carrageenan	7026.28[ab]	3305.93[bc]	6907.90[ab]
Transglutaminase	8043.2[a]	5854.47[a]	7442.34[a]
Pork Collagen	5971.40[b]	4124.31[b]	6434.11[bc]
S.E.[d]	496.33	364.35	146.3

[a-c]Means in the same column with different letters are significantly different at $P < 0.05$
[d]Standard error of means

Table 15

Least squares means for the effect of frankfurter processing method on TPA – cohesiveness (%)

	Formulation				
Process	Control	Pork Collagen	Iota Carrageenan	Sodium Alginate	Transglutaminase
Bowl Chopper	64.41^{a}	64.90^{a}	64.18^{a}	64.87^{a}	68.93^{a}
Coarse Ground	46.38^{b}	44.60^{b}	41.07^{b}	31.38^{b}	51.88^{b}
Emulsion Mill	59.72^{a}	62.54^{a}	62.50^{a}	64.01^{a}	66.33^{a}
S.E.[c]	0.02	0.02	0.01	0.01	0.02

[a-b]Means in the same column with different letters are significantly different at $P < 0.05$
[c]Standard error of means

Table 16

Least squares means for the effect of frankfurter formulation on TPA – cohesiveness (%)

	Processing Method		
Formulation	Bowl Chopper	Coarse Ground	Emulsion Mill
Control	64.41^{b}	46.38^{ab}	59.72^{c}
Sodium Alginate	64.87^{b}	31.38^{c}	64.01^{ab}
Iota Carrageenan	64.18^{b}	41.07^{b}	62.50^{bc}
Transglutaminase	68.93^{a}	52.88^{a}	66.33^{a}
Pork Collagen	64.90^{b}	44.60^{ab}	62.54^{bc}
S.E.[d]	0.004	0.02	0.01

[a-c]Means in the same column with different letters are significantly different at $P < 0.05$
[d]Standard error of means

CHAPTER 4. GENERAL CONCLUSIONS

The results of this study support the commonly held belief that a higher degree of comminution, specifically that achieved by processing meat batters in either an emulsion mill or bowl chopper, result in a higher degree of technological quality which translates to higher yield and a desirable texture profile. When coarse grinding alone is used as the only method of comminution, processing yield is negatively impacted by reduced emulsion stability. Chewiness and cohesiveness are also negatively impacted in coarse ground formulations. Hardness is generally not affected by the processing method used, but is increased in coarse ground frankfurters formulated with TG. TG also seems to have a positive effect on chewiness and cohesiveness, due to the crosslinking of proteins, regardless of the processing method used. TG did not seem to negatively affect processing yield, but at the same time provided no increase in yield for any processing method. Frankfurters processed in the emulsion mill show the highest overall processing yield. Frankfurters produced in the bowl chopper generally show the highest emulsion stability in terms of total liquid separation. The correlation of emulsion stability and processing yield was not examined in this research. Future studies may benefit from a more detailed investigation of this correlation. There may also be benefits in combining TG, IC, and SA in formulations. The texture improvements provided by TG and IC combined with the water retention benefits of IC and SA may have potential to maximize yield and texture in frankfurters regardless of processing method.

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