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BINDING OF MEAT PIECES INTO SECTIONED AND FORMED BEEF STEAKS

The University of Nebraska - Lincoln PH.D. 1980

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BINDING OF MEAT PIECES INTO SECTIONED AND FORMED BEEF STEAKS

by

Alden M. Booren

A DISSERTATION

Presented to the Faculty of
The Graduate College in the University of Nebraska
In Partial Fulfillment of Requirements
For the Degree of Doctor of Philosophy

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Under the Supervision of Professor Roger W. Mandigo

Lincoln, Nebraska
May, 1980

TITLE

BINDING OF MEAT PIECES INTO SECTIONED AND FORMED BEEF STEAKS

BY

Alden M. Booren

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INTRODUCTION

During the 1970's, meat researchers developed new processing systems which utilize low-cost trimmings and difficult to merchandise wholesale cuts into roast or steak-like products. These systems are of interest to the meat industry because of increased consumer demands for more uniform, economical and high quality steaks from the meat animal. Historically, fresh meat can be processed into sausage using various salts, spices, mechanical actions, and thermal treatments. These processed meats have an appearance and consistency of intact muscle. Initial attempts to retain fresh meat flavor and color resulted in the development of meat loaves or rolls. These products have minimal amounts of salts and spices while mechanical action and thermal treatments are maximized.

Development of new equipment which increased the processor's ability to mechanically disrupt fresh meat tissue and manipulate it into desirable shapes led to the concept of "flaked and formed" or restructured steaks. These restructured steaks are low-cost, uniform, completely edible, and resemble a fresh intact muscle in flavor, color and textural properties. They contain small amounts of salts and can be produced with no additives if so desired. These new products have been well received by the steak consuming public, particularly in the Hotel, Restaurant and Institutional (HRI) industry.

Developments during the same time period include massaging and tumbling techniques used for cured, canned meat production in Europe. This created a meat product made up of large meat pieces bonded into a single meat mass using only proteins inherent to the muscle system. The technique involves using abrasion and impact energy to damage muscle tissue which releases various sticky protein fractions termed exudates. Upon heating the exudate undergoes changes

resulting in binding of the pieces into an intact section. This "sectioned and formed" product has flavor and color similar to intact cured meat tissue. It also is closer in textural properties to intact muscle than any other processed meat product. Consumer acceptance of these processed products must be rated among the highest of technological developments in the processed meat industry.

The success of these techniques has stimulated interest in creating a fresh steak by binding larger muscle pieces with an exudate of muscle origin. This steak should resemble intact fresh muscle in flavor, color and textural properties. Huffman and Cordray (1979) have restructured fresh pork pieces into acceptable chops using equal portions of 1–2 mm slices and 2–3 cm chunks. The thin slices increase surface area to enhance exudate extraction. These researchers acknowledged a less desirable color development during processing when compared to intact pork loins. Booren et al. (1979) demonstrated that 2–3 cm fresh beef pieces could be restructured into beef steaks using short mixing periods and 0.5% salt. Dalton (1979) substantiated this observation using pork pieces, and when comparing these chops to intact pork chops found the overall acceptability of the sectioned and formed chops to be superior. Solomon (1979) was able to restructure even larger pieces of enzymatically tenderized beef into acceptable steaks by adding crude myosin which was extracted from a second meat source.

In order to improve the method of restructuring meat pieces into fresh beef steaks and to relate the mechanisms of binding these pieces, three studies were initiated. The first study was designed to fulfill the following objectives:

1) Evaluate mixing time for optimum steak production.
2) Evaluate basic muscle types used for steak production.
3) Determine changes in color and rancidity during production and storage.

The second study had the following objectives:

1) Determine the effect of mixing time and muscle type on binding of meat pieces.
2) Evaluate and quantitate the specific proteins at the bond area.

The final study was designed to fulfill two objectives:

1) Determine the effect of vacuum processing on steak production and the proteins at the bond area.
2) Determine the effect of vacuum processing on color and rancidity during production and storage.

REVIEW OF LITERATURE

BINDING PROTEINS

Throughout history recipes are available telling how to prepare meat products composed of meat pieces which adhere together after heating. The adhering of meat pieces, whether they are large or microscopic, is termed binding. Binding has been loosely used by many researchers, but generally involves water, fat and proteins in a muscle system. The role of proteins has been shown to be of primary importance when any form of binding is considered (Swift et al., 1961; Vadehra and Baker, 1970).

Proteins of Meat Origin

Lawrie (1966) stated that muscle proteins can be divided into three fractions: a) myofibrillar, b) sarcoplasmic, and c) connective tissue. The roles of these proteins in binding has been of great interest to the meat scientist. The connective tissue proteins or stromal proteins are insoluble in strong salt solutions and undergo changes which are undesirable when considering heat initiated binding of meat. Sarcoplasmic and myofibrillar proteins are soluble in 0.1 to 0.2M and 0.6M salt solutions respectively. They also account for nearly 90% of the protein available in meat tissue (Vadehra and Baker, 1970). Because of these properties, these protein fractions have been studied extensively with respect to heat initiated binding of red meats.

Fukazawa et al. (1961b) demonstrated that the sarcoplasmic proteins did not appreciably affect the binding qualities of sausage. This was done in a model system where various protein fractions were extracted from muscle and evaluated using tensile strength measurements as a binding value. Swift et al. (1961) studied

the capacity of fat uptake by these protein fractions. Fat uptake is of primary importance in emulsion products. By observing sedimentation patterns obtained from ultracentrifugal analysis of purified fractions and by observing photomicrographs of the emulsions, it was concluded that the salt soluble proteins or myofibrillar proteins were responsible for fat binding and subsequent particle binding in emulsion products. The sarcoplasmic proteins were found to exhibit no measurable binding properties unless salt was added. Salt addition enhanced sarcoplasmic binding. The myofibrillar protein fraction was found to have superior binding properties. Acton (1972b) clearly substantiated these results by measuring the salt soluble protein quantities during thermal treatment of poultry meat loaves. He found that myofibrillar protein extractability decreased as processing temperatures and binding strength increased. Limiting viscosity numbers increased with heating of the myofibrillar fraction. A conformational change in protein structure was related to this observation.

Recent studies have dealt with binding of large meat pieces. Sarcoplasmic protein was found to be a poor binder of meat pieces, but its presence was found to enhance the binding abilities of the myofibrillar proteins at low salt levels (Macfarlane et al., 1977). Both subjective and objective measures indicated sarcoplasmic proteins were poor binders when added to meat pieces being restructured to steakettes (Ford et al., 1978). Siegel and Schmidt (1979b) measured the binding ability of these protein fractions between large pieces using tensile strength measurements. Their results indicate increased binding for myofibrillar fractions.

The myofibrillar proteins are primarily myosin, tropomyosin, actin, m-protein and alpha actinin. Fukazawa et al. (1961a) provide electron microscopy

evidence indicating that actin and tropomyosin do not influence binding quality of sausage in a model system. Myosin in fibrils was found to have the greatest effect on binding. Myosin was demonstrated to contain the binding qualities when extracted from the fibril (Fukazawa et al., 1961c). Free myosin or myosin in the form of actomyosin was considered to play a major role in sausage binding. No close relation was found between the yield of extractable protein and binding quality of the sausage the protein was subsequently added to.

Swift (1965) postulated that the binding qualities of myosin and actomyosin may be due to the alpha-helical content of myosin. Hamm (1966) reported that the helical portions of the protein unravel during heating to a random form. These random forms produce cross-links both of ionic and hydrogen bonds. This cross-link formation is thought to be the basis of heat initiated binding (Vadehra and Baker, 1970). Acton (1972b) reported that binding began at approximately 40°C and reached a maximum at 82°C. This is similar to temperatures at which structural changes in intact myofibrils occur (Hamm 1966). Yasui et al. (1979) confirmed these observations using pure myosin gels and evaluating them with scanning electron microscopy, nuclear magnetic resonance and a gel shear modulus. They concluded that the "sol" to "gel" state occurs in the temperature range 40° to 80°C, the morphological state varies due to conditions, and water mobility is restricted by the bond formation. Ishioroshi et al. (1979) reported two transition temperatures where myosin undergoes conformational changes. These temperatures are similar to the range where the bond is formed. Siegel and Schmidt (1979a) demonstrated that binding ability of myosin between meat pieces increased over this same 40° to 80°C temperature range.

The effect of myosin and its ability to bind meat pieces and fat has been a subject studied by many groups. Macfarlane et al. (1977) found myosin to be

superior to actomyosin at low salt concentrations (below 1.0M). At higher concentrations binding of actomyosin was similar to myosin. The best binding ability was found in a mixture of myosin and sarcoplasmic proteins with no salt present. Myosin was found to have the highest binding ability in beef steakettes when analyzed both subjectively and objectively (Ford et al., 1978). When studying emulsion capacity, myosin is most rapidly solubilized and forms thick, creamy emulsions (Galluzzo and Regenstein, 1978a). Alone, actomyosin performs like myosin, and when dissociated, actin and myosin act independently. The actin contributes very little to good emulsion formation. Timed emulsification tests yielded similar results for actomyosin. Myosin was reported to be a superior emulsifier (Galluzzo and Regenstein, 1978b). When observing the exudate formed during massaging of cured hams, Siegel et al. (1978a) found actin and myosin extraction to be a prerequisite for good binding quality. The binding ability of myosin in a model system of meat pieces was superior to any other combination of muscle proteins (Siegel and Schmidt, 1979a). When the mole ratios of myosin to actin were compared under similar conditions, a higher ratio was positively correlated with better binding. These researchers concluded that ionic interactions are also involved in heat mediated binding. Turner et al. (1979) demonstrated that myosin binds better than actomyosin and that the rate of extraction does not change the myosin binding ability.

Proteins of Non-Meat Origin

The role of binding in meat pieces by proteins is as complex as the myofibrillar proteins in muscle tissue. To complete a discussion of binding proteins, proteins of non-meat origin must be considered. The property of acting like "glue" to hold meat pieces together has been recently explored by many. A

protein with the necessary binding qualities would contribute simplicity to the complex system of muscle tissue. Such a protein could be added to the system and basic guidelines governing extraction of the naturally occurring binding proteins could be eliminated. For a non-meat protein to be totally effective, it must have binding properties similar to myosin.

Dried milk solids and gelatin were found to increase binding of ground chicken (Froning, 1966). They were not as effective as naturally occurring proteins when extracted with appropriate salt and phosphate. Moore et al. (1976) compared the binding effects of delactosed whey, soy isolate and textured soy in cured beef rolls. The results were similar to the observations of Froning (1966). The delactosed whey was superior to other non-meat proteins compared, but it had only two-thirds the binding ability of myofibrillar proteins extracted with 1% salt and 0.25% phosphate. The proteins with the lowest inherent levels of salt and phosphate performed most poorly. Soy isolate was evaluated in turkey rolls (Kardouche et al., 1978). As the level of isolate increased to 3%, flavor, tenderness, texture, and acceptability scores increased. Shear values decreased. Soy isolate was found to form gels in water and emulsify fat (Hawley and Tuley, 1977). By injecting soy isolate into a ham product and massaging, yield and sliceability of the intact muscle increased. Siegel et al. (1979a) stated that the extracted mycfibrillar proteins in this system enhance the intrinsic function of the soy isolates. Reciprocally, the soy isolate enhances the extractability of the myofibrillar proteins by binding water. Binding between meat proteins and soy isolate was shown to occur, and molecular interactions were concluded to be responsible.

Plasma proteins can be thought of as proteins of muscle origin. However, they can also be isolated from the blood and added to a processed meat at a higher

level than that at which they naturally occur. Seideman et al. (1979) found that plasma protein isolate improved the texture, palatability and cohesiveness of ground beef. When added to ground beef extended with textured soy protein, it was reported to negate some of the undesirable effects of the textured soy proteins. These results varied from brand to brand of textured soy protein. When added to an emulsion product at a 1% level, it increased the strength of the outer skin and decreased fineness, mushiness and tendency to crumble (Terrell et al., 1979). Overextension (5%) caused a tough, rubbery, crumbly product.

Siegel et al. (1979b) compared the binding abilities of selected non-meat proteins using model systems, gelation and electron microscopy. They demonstrated that all non-meat proteins were inferior to reported binding values of myosin or actomyosin. When ranked from highest to lowest binding ability, Siegel et al. (1979b) stated that the rank of proteins were wheat gluten, egg white, corn gluten, calcium reduced dried skim milk, bovine blood plasma, isolated soy protein and sodium caseinate. Bovine plasma protein was superior when no salt or phosphate was added. The ability of non-meat protein to bind meat pieces was related to its ability to interact with myosin during heating.

ADDITIVES AND FACTORS INFLUENCING BIND

It is widely accepted that the salt soluble proteins play a major role in binding meat pieces. Formulation methods for products utilizing heat initiated binding are very explicit and follow a repeatable step by step pattern. This is most likely due to the fact that myofibrillar proteins must be extracted within the system before effective binding will occur. Extractability of the salt soluble proteins from lean muscle is controlled by many factors. These factors or conditions can be divided into four basic groups.

Salt Addition

Salt is the basic additive for all processed meats. The three major protein fractions are separated by their salt solubility. Extraction yields of salt soluble proteins are influenced linearly by salt concentration in the aqueous phase up to about 10% (Bard, 1965). Beyond this concentration protein solubility decreases due to a salting out effect. One point must be emphasized: binding ability of myofibrillar protein is constant regardless of yield. Increased yields will not mean enhanced binding when equal amounts of proteins are considered (Fukazawa et al., 1961c).

The mechanism of action of salt on myofibrillar protein extractability was clearly demonstrated by Schnell et al. (1970). In general, there was a linear increase for binding as salt concentration increased. Cookout decreased about 60% with a 2% sodium chloride addition. The cookout fraction was analyzed for nucleic acid content. Nucleic acids were found to increase by a factor of 20 with salt addition. The amount of total nucleic acids was concluded to be a result of the osmotic effect of salt causing cell disruption and a release of intercellular materials (i.e., myofibrillar protein).

Salt increases water holding capacity of muscle tissue. This is due to the increase in the ionic strength of the media and subsequent interaction of salt ions and protein ions occurring in meat in the raw state (Shults and Wierbicki, 1973).

The relationship between salt and binding is clear when meat pieces are bound in the form of a meat roll. Pepper and Schmidt (1975) found that salt addition increased cook yield and binding strength when cooked to 68°C. Similar results have been reported for binding strength of ham rolls using 0, 0.5, 1.0 and 2.0% salt (Reynolds et al., 1978).

When studying the effect of salt on a flaked, cured pork product, Neer and Mandigo (1977) found a linear effect of increasing cook yield due to salt addition. Shear force was interpreted as a measure of binding ability and yielded linear effects due to salt addition. Schwartz (1975) indicated that a low level of salt (0.75%) effectively improved eating characteristics of flaked and formed chops. However, higher salt levels increased the rate of oxidative rancidity development. Salt addition at the 0.75% level has been found to increase ease of cutting, overall acceptability and tenderness of flaked and formed beef steaks (Cross and Stanfield, 1976).

When sectioned and formed ham was produced, breaking force increased due to salt addition (Siegel et al., 1978b). A 1% salt level gave the best cooking yield. If the myofibrillar proteins of the exudate are separated by molecular weight, salt addition contributed very little to differences between individual proteins. When the microstructure of the exudate and the binding junctions are observed, both solubilized proteins and fragments from fiber disruption are present. After heating, junctions exhibited good bind characteristics and emulsion-like areas when formulations contained 2% salt (Theno et al., 1978a,c). The ultrastructure of the muscle tissue indicated fiber disruption and, after long massaging treatment, a loss of normal structural integrity (Theno et al., 1978b).

When salt was added at a 0.5% level to produce a sectioned and formed pork chop, Dalton (1979) observed increased tensile strength of the muscle bond. Salt treatments were rated more tender and flavorful. Salt was found to play an important role in development of desirable chemical, physical and organoleptic properties of sectioned and formed chops. Huffman and Cordray (1979) substantiated these observations when restructuring with thin slices and lean

cubes. Salt has been shown to increase binding of meat pieces in a model system at levels greater than 0.4% (Macfarlane et al., 1977).

Phosphate Addition

There are four theories explaining the role of phosphate on meat (Solomon, 1979): 1) the interaction of phosphate ions with protein ions, 2) a shift in pH, 3) cation chelating abilities, and 4) binding interactions with myosin. The role of phosphate in meat binding has been studied extensively. Phosphate added to an extracting solution increased extractable protein and increased viscosity (Fukazawa et al., 1961c). This effect depended upon type of phosphate used, with pyrophosphate highest, hexametaphosphate lowest and tripolyphosphate intermediate. Very low levels of tripolyphosphate (0.066% added) attained by soaking in a 6% solution, were found to increase binding of meat pieces using tear strength and cooking losses as indicators (Froning, 1965). Schults and Wierbicki (1973) found that phosphates increased water holding capacity, decreased meat shrinkage, increased swelling, and increased pH when added to ground meat tissue at a 0.3% level.

Phosphates up to a 2% addition increased binding of poultry rolls (Froning, 1966). Flavor was found to be significantly altered by all levels of polyphosphates. Schnell et al. (1970) found that when used with salt, phosphate levels above 0.5% were not qualitatively different from higher levels. These observations were confirmed by Gillett et al. (1978). Pepper and Schmidt (1975) reported increased binding strength when phosphates were added with salt in beef rolls. Surface area of the muscle tissue had no effect on binding or cook yield.

In flaked and formed pork products, Schwartz (1975) reported that phosphate incorporation yielded better texture and an overall superior product. A 0.125%

level of sodium tripolyphosphate was recommended. Neer and Mandigo (1977) confirmed these observations for cured restructured pork and also noted a linear increase in flavor strength with phosphate addition. They noted the benefits of phosphates in terms of antioxidant effect and color improvement.

In sectioned and formed ham products, phosphate addition increased salt migration (Krause et al., 1978a), increased binding strength and decreased cooking losses (Siegel et al., 1978b). Phosphate increased clouds of solubilized protein in the exudate at the bond area (Theno et al., 1978a). After heat treatment, the bond area was composed of more aligned areas (Theno et al., 1978c), which was reported as an indication of enhanced binding. Phosphate was demonstrated to have the greatest effect on relative percentages of actin, myosin and tropomyosin in exudate extracted from the meat surface (Siegel et al., 1978a). This observation is confirmed by data provided by Turner et al., (1979) for myosin. When phosphate was added to sectioned and formed fresh pork chops, there was a significant decrease in cooking loss (Huffman and Cordray, 1979). However, no advantage was demonstrated in bind evaluation using the Instron tensile measurement.

Energy

The definition of energy for this discussion will include energy of processing or energy input to the meat system before the heat initiated binding phenomenon. Under this broad definition, comminution, mixing, tumbling or massaging, ultrasonics, pressure, vacuum and temperature can be considered input energy into a specific meat system.

The level of comminution or particle size was studied by Acton (1972a) who found an increase in protein extraction and bind strength with decreasing particle

size. The structure of the finished product became finer with closer knitting as comminution method increased cell disruption and breakage. Cutting muscle across the fiber grain resulted in 49% more extracted protein. Chesney et al. (1978) demonstrated that flaked meat had more cohesiveness than ground meat. Meat flaked through a 12.7 mm head had less cohesiveness than flakes from 6.9 or 3.0 mm heads. Popenhagen and Mandigo (1978) recommended a mixture (50:50) of small flakes and large flakes of different temperatures for producing a higher quality restructured steak.

Pepper and Schmidt (1975) indicated that mixing time had little effect upon binding strength of beef rolls. This may be due to the fact that high levels of salt and phosphate were used in this system. When salt and phosphate levels were lowered, beef rolls appeared to have higher breaking strengths. Belohlavy (1975) and Booren et al. (1979) have indicated that mechanical mixing up to 24 minutes increased cooking losses and binding strength in flaked meat and meat pieces respectively. Tumbling time and method (intermittent vs continuous) increased cellular disruption and decreased microstructure clarity (Cassidy et al., 1978). Intermittent tumbling maximized these effects. Binding as measured by sliceability was found to be maximized by longer (9 hr) intermittent tumbling periods (Krause et al., 1978b). Similar observations are documented for massaged hams (Siegel et al., 1978a,b; Theno et al., 1978b). The effect of massaging was probably most appropriately demonstrated by Siegel et al. (1979a) by injecting a curing solution containing soy isolate into hams. Before massaging, the soy isolate was observed only in perimysial spaces. After massage treatment it had penetrated into the endomysial spaces.

Ultrasonic treatment has been investigated as a possible mechanism to accelerate cellular disruption and enhance binding (Reynolds et al., 1978). Results

demonstrated that ultrasound caused changes in microstructure and increased binding strength. Ultrasound increased the potential for myofibrillar protein extraction, while no effect was shown for sarcoplasmic proteins.

Pressure has been found to solubilize proteins utilized in binding (Macfarlane and McKenzie, 1976). Their results indicate that pressure solubilizes all myofibrillar proteins equally. This effect involves more than a simple effect on solubility equilibrium. Pressurization of meat stuffed into membrane casings did not increase binding of meat rolls (Meydav et al., 1979).

The effect of vacuum processing has become the subject of recent research on binding. Rejt et al. (1978) found meat subjected to vacuum massage had less cooking loss and smaller changes in linear dimensions. Solomon (1979) substantiated this and also showed that cure penetration was improved and binding strength was significantly greater for vacuum treatments.

The effect of temperature is reported by Bard (1965). Maximum extraction of salt soluble proteins occurs at near -5°C and is quite similar for the 0°–30°C range. Steaks made from 2.2°C flakes were more cohesive, more acceptable and had less cooking loss than restructured steaks made from -5.6°C flakes (Popenhagen and Mandigo, 1978). However, restructured products made from a combination of the two temperatures (50:50) had the highest quality.

Rigor State

Rigor mortis is simply defined as the stiffening of muscle after death. This phenomenon is characterized by a buildup of lactic acid due to anaerobic glycolysis, the depletion of ATP and a permanent bond formation between the myofibrillar proteins actin and myosin. The development of rigor and the drop in pH due to lactic acid results in a sharp loss of water holding capacity (Hamm,

1978). Clearly, extraction of myofibrillar protein will be easier before permanent bond formation of actin and myosin occurs. In a system where extractable myofibrillar proteins are at a minimum, use of prerigor tissue should enhance binding properties due to increased ease of extraction of myofibrillar protein.

The effect of rigor mortis on extractability of myofibrillar proteins is considered an important functional property. Johnson and Henrickson (1970) found normal prerigor meat contains 69.9% more extractable salt soluble protein than normal postrigor meat. Low pH prerigor meat showed only a 7.3% advantage. This is most likely due to loss of solubility of sarcoplasmic proteins and subsequent coating of myofibrillar protein. The differences were shown using salt levels as low as 1%. Johnson and Henrickson (1970) also noted that if prerigor meat was salted and held for 48 hours, myofibrillar extractability remained high. When similar treatments were performed on postrigor tissue extractability decreased. Hamm (1978) showed that grinding, then salting prerigor meat enhanced binding qualities in processed meats. The binding ability of this tissue could be preserved by freeze dehydration. He postulated that prerigor salt addition caused a strong swelling and extraction of myofibrillar proteins thus preventing rigor bond formation.

It appears that the rigor condition does not enhance the binding ability of myofibrillar protein, but does increase protein volume due to increased extractability. The binding strengths of crude myosin from postrigor and prerigor beef were similar and agreed with previously reported data (Turner et al., 1979).

When prerigor and postrigor emulsion products were compared, Stilwell et al. (1978) found no differences in finished products. Similar results were found when binding strength in meat rolls was subjectively and objectively evaluated