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Effects of Massaging Minced Batter on the Physical, Chemical, and Sensory Characteristics of Low-Fat, High Added Water Bologna

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ABSTRACT

A high-fat bologna was formulated to contain 30%fat/10% added water (AW). Three low-fat treatments were formulated to contain 10%fat/30%AW. Lean and fat trim for the low-fat treatments (2, 3, and 4) were combined and minced before massaging intermittently (10 min on/20 min off) for 0, 2.5 and 5.0 h, respectively. Massaging improved (P<0.05) sensory cohesiveness scores and decreased particle definition. However, the high-fat control was the most cohesive, firmest and least juicy (P<0.05). Instron Texture Profile Analysis indicated that massaging increased cohesiveness (P<0.05) and tended to increase springiness. There were no differences (P>0.05) in hardness or fracturability among the low-fat treatments. The high-fat bologna was the hardest, least cohesive, and least springy (P<0.05).
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1.0 INTRODUCTION

The "40 percent" sausage rule allows for the substitution of added water (AW) for fat (≤30%) up to a combined total of 40% (USDA, 1988). However, low-fat high AW products that optimize this rule have been found to result in problems associated with texture and excessive purge during storage (Claus et al., 1990). Low-fat frankfurters were found to be firmer and less juicy (Rongey and Bratzler, 1966; Hand et al., 1987; Marquez et al., 1989; Park et al., 1989). Rust and Olson (1988) report that when the fat content of a meat product is reduced below 15%, the quality of the product changes significantly, especially in texture. When fat is reduced and replaced with AW, the critical issue in production is water binding rather than fat binding (Rust and Olson, 1988). In order to produce acceptable products that take full advantage of the "40 percent" sausage rule, new processes and improved technology must be created (Rust and Olson, 1988).

Physical manipulation such as massaging may help improve water binding in low-fat, high AW products by increasing protein-protein and protein-water interactions. Massaging has been reported to reduce processing time; improve tenderness; increase uniformity in color, texture, and fat distribution; and improve the binding in sectioned and formed meat products (Siegel et al., 1978a;1978b).
Claus et al. (1990) investigated the effects of massaging on a batter-type system and concluded that the benefits of massaging were not as evident when applied to sausage processing. However, they suggested that mincing after massaging may have disrupted the bonds formed during massaging and prevented the full advantages of massaging from being recognized.

The water-binding and textural problems of low-fat, high AW bologna can be approached in several ways. Acton and Saffle (1969) found that adding prerigor meat to sausage increased the amount of protein that could be extracted by 48% over postrigor. Bentley et al. (1988) reported that loaves made from hot boned fat exhibited a higher cook yield and released less fat and moisture. They attributed this to the ability of prerigor materials to bind water and fat. Comer et al. (1986) investigated the effects of fillers and meat ingredients in comminuted meat products. These researchers reported that all fillers in the study except skim milk increased textural firmness. They concluded that fillers may make a significant contribution to the stability and textural firmness of wieners. The advantage of massaging, however, is that this technique would allow the processor to produce an acceptable low-fat, high AW product without added ingredients or fillers that might increase costs. Also, added ingredients that are unfamiliar to
consumers are not always well accepted. No matter what approach is taken, an understanding of protein functionality in a meat system and processing techniques for comminuted products is essential. This study begins with a review of the literature to investigate the interaction between proteins and water, fat, and other proteins in a meat system, processing technologies for low-fat, high AW bologna, the effect of fat level and water level on sensory properties of low-fat, high AW bologna, and analysis of texture and color of meat products. This review is followed by a study performed on low-fat, high added water bologna to investigate the effects of massaging the minced batter.

The objectives of this study were to determine the effect of massaging the minced batter on the physical, chemical, and sensory characteristics of the final product.
2.0 REVIEW OF LITERATURE

2.1 PROTEIN FUNCTIONALITY IN COMMUNTED MEAT FORMULATIONS

Functionality of proteins within a meat system can determine the physical structure and sensory characteristics of the final product. There are three main types of protein interactions: protein-water, protein-fat, and protein-protein. Acton and Dick (1984) described these major functional properties as: water-binding ability, fat stabilization or emulsification, and protein gelation. These three properties occur during the sequence of steps in the formation of a comminuted meat batter and the following heat processing to form the final product (Acton et al., 1983). These properties are interrelated and can be affected by environmental conditions surrounding the system throughout the process (Acton et al., 1983). Some of these environmental conditions include salt concentration, batter pH, and temperature throughout the process (Swift and Sulzbacher, 1963; Acton et al., 1983).

Functional properties of meat constituents are known to be of importance for raw meat materials which are manufactured into "processed meat products" (Acton and Dick, 1984). Different functional properties are important to different meat products (Whiting, 1988). Water binding is important in bone-in hams, but not in fermented-dried sausage. Also, the proteins in frankfurters must bind water
and fat and form a firm elastic gel (Whiting, 1988). An understanding of protein functionality is essential to the development of a low-fat comminuted product that is similar to conventional products. Differences from conventional products in textural characteristics such as hardness, cohesiveness and fracturability, and in the protein structure are the main problems of low-fat products (Rust and Olson, 1988; Claus et al., 1990; Park et al., 1990). Understanding, controlling and modifying protein functionality, becomes even more important to processors when the development of low-fat products is considered (Smith, 1988).

2.11 Protein-Water Interactions

Protein-water interactions or water holding capacity (WHC) is defined as the ability of meat to retain its water during the application of external forces such as heating, grinding, or pressing (Judge et al., 1975). WHC affects the physical properties of meat such as color, texture, firmness, and juiciness. WHC is especially important in further processed products where the correct protein/water ratio is required for palatability and adequate yield of the finished product (Judge et al., 1975).

There are three types of proteins in a muscle fiber: myofibrillar, sarcoplasmic, and stromal. Myofibrillar
proteins are salt soluble and consist mainly of actin and myosin. Studies show that the myofibrillar proteins, particularly myosin, are the most important proteins in relation to binding properties within the meat formulation (Fukasawa et al., 1961a; Saffle, 1968; Samejima et al., 1969; Schut, 1976; Siegel et al., 1978a; Siegel et al., 1978b; Acton et al., 1981).

There are three forms of water in skeletal muscle: bound water, restricted water, and free or bulk water (Acton et al., 1983). It is the restricted water and free water that is of concern in relation to comminuted meats. The quantity of restricted water can vary and is affected by the:

1) ionization and charge density of the protein which is increased through salt addition and tissue pH which is more alkaline from the isoelectric point, 2) extent of physical disruption of tissue to enhance protein extraction and to create a more proteinaceous surface and capillary pore area, and 3) distance between water location and the protein surface (Acton et al., 1983).

Free water has no restrictions and is basically the water added during processing (Acton et al., 1983). The objective is to extract enough myofibrillar protein to bind the muscle tissue bulk water and the added process water (Acton et al.,
1983). This is especially important in low-fat products where high levels of water are added to replace fat in the system and WHC becomes more important than fat binding (Rust and Olson, 1988).

The addition of salt during mixing enhances protein hydration (Acton et al., 1983). Comminution disrupts the structure of the meat and releases myofibrillar proteins which help bind water (Marquez et al., 1989). Extraction of myofibrillar proteins in the presence of salt increases WHC (Acton et al., 1983). Hamm (1975) and Trout and Schmidt (1986) also found that reducing NaCl levels lowers WHC. Whiting (1984) found that when salt levels were decreased, the water binding ability failed first followed by decreased gelation and fat binding ability. Batters with 2.5% salt were more stable than those with 1.5% salt (Whiting, 1984).

WHC is influenced by ultimate pH and rate of pH decline postmortem (Fennema, 1990). Hamm (1975) found that adding sodium chloride causes a shift to lower pH values for minimum WHC. Hamm and Deatherage (1960) found that minimum hydration is near the isoelectric point of muscle (pH 5.5) and that by heating meats with higher or lower pH values than the isoelectric point results in greater WHC. At pH values less than 4.5 there is an increase in positive charges in the myofilaments and at pH values greater than 7.0 there is an increase in negative charges of the
myofilaments which causes a repulsion between actin and myosin and retention of WHC (Hamm and Deatherage, 1960). This repulsion results in an increase in myofibrillar volume and WHC (Price and Schweigert, 1987). Thomsen and Zeuthen (1988) found a tendency toward increased WHC with increased pH.

Temperature has an effect on WHC. Hamm and Deatherage (1960) studied the changes in hydration of muscle during cooking of meat and found that the greatest decrease of WHC occurs between 40°C and 50°C. Heating causes denaturation of proteins which results in decreased WHC (Zayas, 1985). However, the amount of WHC of cooked meats is related to the pH level during cooking. By heating meats with the pH above or below the isoelectric point, the resulting cooked meat will have a higher WHC (Hamm and Deatherage, 1960).

Increased temperatures during chopping cause an increase in protein-protein interaction and increased water separation upon cooking (Deng et al., 1981). Marquez et al. (1989) also found less water binding in beef frankfurters when protein-protein interactions increased. Protein-protein interactions will occur at temperatures between 15°C and 21°C (Acton and Dick, 1984). Thus, it is important to keep chopping and mixing temperatures below this zone in order to establish water-binding and fat encapsulation (Acton and Dick, 1984).
Rust and Olson (1988) recommended the addition of phosphates to high added water products to reduce purge. Alkaline phosphates improve water binding by increasing ionic strength (Bendall, 1954; Trout and Schmidt, 1984) and pH (Knipe et al., 1985; Rust and Olson, 1988). Knipe et al. (1985) found that higher phosphate levels significantly increased WHC. Fukasawa et al. (1961b) studied the cause of increased binding by the addition of phosphates and found that more protein was extracted upon addition of phosphates. Rongey and Bratzler (1966) found that phosphates gave the highest yields compared to other binders in the study.

Meats used in the formulation of comminuted products vary in composition and in their ability to bind water (Rongey and Bratzler, 1966). In this study, it was found that low-fat and low-binding meats produced the lowest yields. WHC affects the final cook yields of comminuted products. Rust and Olson (1988) found that fresh meat protein will have a better water-binding capacity than frozen meat. Slow freezing causes a small but significant decrease in WHC (Deatherage and Hamm, 1960). Deatherage and Hamm (1960) also found that the WHC of some meats increased upon freezing and thawing. This observation was explained by the idea that if tiny ice crystals formed without destroying cell walls, there would be a loosening of charged water binding groups on the protein. Miller et al. (1980)
found that comminuted products made from frozen meat lost the ability to retain moisture.

2.12 Protein-Fat Interaction

Comminuted meat products are sometimes referred to as emulsions (Jones, 1984). An emulsion is defined as a mixture of two immiscible liquids, one of which is dispersed in the form of small droplets or globules in the other liquid (Judge et al., 1975). Many authors have found that meat systems do not follow this definition of a true emulsion and find it more appropriate to use the term meat batter (Swasdee et al., 1982; Acton et al., 1983). However, Theno and Schmidt (1978) studied the microstructure of three commercial frankfurters and found that one brand had a very finely structured matrix similar to a true emulsion. They concluded that true meat emulsions do exist, but that a true meat emulsion is not necessary to produce an acceptable product.

Unlike a true emulsion where fat and water are dispersed within one another, the protein and fat in a meat product interact by forming a protein membrane which surrounds the fat particles (Acton et al., 1983). Jones (1984) describes this as the interfacial protein film and suggests that the characteristics of this membrane must be considered as one of the factors affecting emulsion
stability of comminuted meat products. The other factors affecting emulsion stability are: pH (Schut, 1976), ionic strength, physical characteristics of the fat source, protein-protein interactions, and processing conditions (Hansen, 1960; Swift et al., 1961; Carpentar and Saffle, 1964; Townsend et al., 1968; Morrison et al., 1971; Schut, 1976).

The interfacial protein film is formed when protein molecules arrange themselves at the junction between fat and water (Jones, 1984). The hydrophobic side chains of the protein molecules are attracted to the fat phase while the hydrophilic side chains are attracted to the water phase (Jones, 1984). This membrane surrounds the fat droplets while at the same time protein-protein and protein-water interactions are occurring (Acton et al., 1983). These combinations work together to form a gel which surrounds the protein encapsulated fat to form a stable meat system (Jones, 1984). Lee et al. (1981) describes a meat system as a gel-type emulsion where fat is dispersed uniformly and confined within a protein gel matrix. Helmer and Saffle (1963) and Swasdee et al. (1982) describe the fat globules as entrapped by a lattice of protein filaments and not completely surrounded by a protein membrane.

It seems that the salt soluble proteins, myosin and actomyosin, are most important in the formation of this
membrane (Hansen, 1960). However, Swift et al. (1961) reports that both water and salt soluble proteins are capable of increasing emulsion stability. They found that salt soluble proteins were more efficient and were utilized more completely during emulsification. Also, the membranes formed by water soluble proteins were not as thick as those formed by salt soluble proteins.

The presence of salt in the system is important because salt solubilizes myofibrillar proteins which denature on the surface of lipid particles and help to form a stable emulsion (Whiting, 1984). However, Whiting (1984) found that of all the protein interactions, fat emulsification was affected the least by reduced salt levels. Ockerman and Wu (1990) found that salt levels increased pH which in turn increased the emulsion capacity in pork sausage. Salt was also found to increase the efficiency of water soluble proteins to stabilize emulsions (Swift et al., 1961; Swift and Sulzbacher, 1963). Swift and Sulzbacher (1963) suggested that NaCl unfolds the structure of water soluble proteins which increased their ability to surround fat globules. Sofos (1983) reported that a 2.5% salt level resulted in emulsions of acceptable yield. As the salt level was reduced, total fluid losses and separated fat during thermal processing increased. These results differ

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from Trout and Schmidt (1986) who found that reducing NaCl had no effect on fat binding.

Jones (1984) reported that gel strength of the batter matrix is probably the most important factor affecting protein-lipid interaction. Gel strength is affected by pH and ionic strength (Jones, 1984). Swift and Sulzbacher (1963) found that generally, emulsion capacity increased with increasing pH. Knipe et al. (1985) found that phosphates increased the pH and produced stable emulsions. Seman et al. (1980) found that fat released and total cookout in the emulsion stability test was significantly higher for low ionic strength (IS) treatments than high IS treatments. Also, the addition of 0.13% tripotassium phosphate increased the emulsion stability of low IS products to a level close to that of high IS treatments. They attributed this improvement to an increase in the pH of the meat. Saffle and Galbreath (1964) concluded that if the pH of sausage emulsions could be increased, fat emulsification would increase.

Temperature has an effect on both the protein and the lipid components of processed meats. Heat denatures the proteins and causes them to form a lattice-like structure or membrane that prevents the fat, which liquifies upon heating, from moving freely throughout the system and
forming pools within the product or fat caps on the surface (Jones, 1984).

Final chopping temperatures of approximately 10°C-18°C seem to result in more acceptable batters (Hansen, 1960; Brown and Toledo, 1975; Ockerman and Wu, 1990). Toledo et al. (1977) reported the maximum level of fat stabilization to be 15°C-21°C. Hansen (1960) found that when the temperature rises excessively during chopping, the protein matrix denatures and fat separation can occur during cooking. Swasdee et al. (1982) reported that heating causes more changes in structure than the chopping itself. Lee et al. (1981) and Whiting (1984) found that emulsion stability decreased with elevated chopping temperatures. Helmer and Saffle (1963) suggested that the breakdown occurring at high chopping temperatures may be attributed to bringing the fat globules in contact with each other. Allen and Foegeding (1981) reported that some increase in temperature during chopping is desirable for fat dispersion, but an excessive temperature rise may result in the inability of the protein matrix to prevent fat from coalescing.

Swift et al. (1968); Allen and Foegeding (1981); and Jones (1984) agree that the characteristics of the fat such as fatty acid composition which determines the melting point, affect the stability of emulsified meat products. The fat of different species will have a variation in
composition which will affect emulsion stability (Allen and Foegeding, 1981). Townsend et al. (1971) reported that at 18°C a phase change occurs in pork fat which coincides with a loss in emulsion stability. Swift et al. (1968) found that oily fats can produce stable emulsions if the rate of addition is controlled. Trout and Schmidt (1986) and Hand et al. (1987) reported that fat level had no significant effect on emulsion stability. Results from Seman et al. (1980) indicate that emulsion stability is a good indicator of the textural characteristics of the final product. Jones (1984) reported the interaction of protein and lipids to be affected by: 1) the presence of an interfacial protein membrane which surrounds lipid particles; 2) the gel strength of the batter matrix and 3) physical characteristics of the fat.

2.13 Protein-Protein Interactions

Protein-protein interactions or gelation occurs during heat processing and is mostly responsible for the structure and texture of comminuted meat products (Acton et al., 1983; Acton and Dick, 1984). Protein-protein functionality determines the fat binding (Deng et al., 1981; Acton and Dick, 1984) and water binding ability (Trout and Schmidt, 1984; Marquez et al., 1989). Gelation more than other types
of protein interactions is responsible for the stability of the meat system (Lee et al., 1981; Comer et al., 1986).

Gelation depends mostly on the myofibrillar proteins, particularly myosin and actomyosin (Samejima et al., 1969; Nakayama and Sato, 1971; Macfarlane et al., 1977; Acton et al., 1983; Acton and Dick, 1984). Samejima et al. (1969) found that actin had no effect on gelation until it was combined with myosin. They also found that it is the whole myosin molecule which influences gelation. More research is needed on the effect of other proteins, but some studies reveal that the regulatory proteins of thick and thin filaments do not affect gelation significantly (Acton et al. 1983; Acton and Dick, 1984). Sarcoplasmic proteins only increased the binding strength of myosin when no salt was added, and the binding strength of sarcoplasmic proteins alone was too low to measure (Macfarlane et al., 1977).

Protein-protein interactions are often referred to as aggregation (Acton and Dick, 1984). There are two types of protein aggregations: coagulation, which is the random interaction of denatured proteins, and gelation, which is the orderly interaction of denatured or native proteins (Acton and Dick, 1984). The orderly interaction of gelation leads to the well-ordered three dimensional protein matrix characteristic of comminuted products (Acton and Dick, 1984).
The formation of the protein matrix occurs in two stages based on the involvement of a distinct region of the myosin molecule and the temperature range during heating (Samejima et al., 1981; Acton and Dick, 1984). The first stage occurs between 30°C to 50°C and involves myosin head to head aggregation while the second stage occurs at temperatures greater than 50°C and involves the crosslinking of the helical rod portion of myosin (Acton and Dick, 1984). It is the second stage that gives the gel its strength (Acton and Dick, 1984). Processed meats are usually heated to an internal temperature of 70°C and would cross both of these temperature zones. The protein network chemically binds and physically traps fat (Acton and Dick, 1984).

Protein-protein interactions are affected by pH, salt concentrations, temperature and time (Acton and Dick, 1984). The protein network is structurally dependent on pH, and gel rigidity of myosin is optimum at pH 6.0 (Acton et al., 1983). At a pH near the isoelectric point of meat, hydration or water binding decreased due to the tightening of the protein network which reduced the availability of binding sites (Hamm and Deatherage, 1960; Deng et al., 1981). Siegel and Schmidt (1979) found that pH had no significant effect on the binding ability of myosin, but attributed this to the buffering effect of the muscle surfaces on the myosin binders. The myosin binders were
allowed to equilibrate with the muscle before the binding ability was measured (Siegel and Schmidt, 1979). Deng et al. (1976) found that decreasing pH caused the rate and maximum extent of protein-protein interaction to increase. The optimum pH for actomyosin is 5.0 which is lower than for myosin at pH 6.0 (Acton et al., 1981). The difference in optimum pH for gelation is most likely due to the different methods used to measure gel strength rather than in the respective gelation behavior of the two proteins (Acton et al., 1981).

Salt (Whiting, 1984) and phosphates increase the gelation of myosin (Siegel and Schmidt, 1979; Acton et al., 1983). Increasing the salt concentration increases the amount of protein that can be extracted and become available for binding (Gillett et al., 1977). Swift and Ellis (1957) found that phosphates and salt increased the relative binding of sausage materials as indicated by increased tensile strength and cohesion of meat in bologna samples. Whiting (1984) found that gel strength was the second attribute after water binding to fail when salt levels were decreased in a meat system. Results of Trout and Schmidt (1986) showed that salt played an important role in protein-protein interactions by increasing the temperature that proteins can be heated to before aggregation occurs. Aggregation causes shrinkage of the meat protein matrix.
which limits the amount of water that can be bound and reduces the strength of the forces which bind the water (Trout and Schmidt, 1986). WBA is improved by preventing aggregation at lower temperatures (Trout and Schmidt, 1986). Macfarlane et al. (1977) found that the binding strength of myosin leveled off as NaCl increased to 0.2 M NaCl while that of actomyosin increased over the range of 0.4 M to 1.4 M NaCl. Pepper and Schmidt (1975) found that treatments containing salt and phosphate produced greater binding strength and higher cook yields than treatments with only salt.

Increased temperature causes protein denaturation and increased protein-protein interaction (Deng et al., 1981). Hansen (1960) and Helmer and Saffle (1963) found that increased temperature during chopping caused the protein matrix to denature. Lee et al. (1981) found that as chopping temperature increased the protein matrix became less cohesive and lost elasticity. Nakayama and Sato (1971) found that the physical properties of chicken meat gels produced at a lower temperature were different from those properties of gels produced at a higher temperature. A slower heating rate results in a significantly greater gel strength than that at a higher rate (Camou et al., 1989).

Time allowed for extraction of proteins has an effect on gelation. Siegel et al. (1978b) reported that time is
required for extracted proteins to react with salt or phosphate and to allow orientation of molecules to maximize binding. Gillett et al. (1977) studied different mixing times and found that increasing the length of time that lean meat is blended increased the amount of protein that was solubilized by the salt solution.

Protein-protein interactions produce the matrix that determines the texture of comminuted meat products. Comer (1979) found that muscle proteins are essential for the production of a firm, springy structure characteristic of comminuted meat products, and that other proteins such as collagen, plasma, and cereal and vegetable proteins did not have these desirable characteristics. Haq et al. (1973) found that greater stability can be obtained by using a more efficient protein. Camou et al. (1989) reported that gel strength is directly proportional to the amount of protein in the solution, and protein concentration has a significant effect on gel strength. These results support those of Hamann (1987) who found that protein concentration affects the hardness of processed meat products.

2.2 PROCESSING TECHNOLOGIES FOR LOW-FAT, HIGH AW BOLOGNA

The "40 percent" sausage rule allows the substitution of added water for fat up to a combined total of 40% (USDA, 1988). However, the production of acceptable low-fat, high
added water products has created the need for new processing techniques and treatments (Rust and Olson, 1988). Rust and Olson (1988) report that the critical concern with this type of product is the water-binding rather than fat binding. Processing technologies such as preblending (Hand et al., 1987) and massaging (Siegel et al., 1978b) can affect the texture of meat products by improving the WHC.

Mechanical treatments such as massaging and tumbling enhance quality attributes and accelerate meat product manufacture (Addis and Schanus, 1979). Mechanical treatment is applied to most processed meat products and is essential for adequate binding (Price and Schweigert, 1987). There are many types of mechanical treatments such as mixing, massaging and tumbling (Siegel et al., 1978b). The mechanism by which mechanical treatment improves binding seems to be cell disruption and breakage which causes the release of myofibrillar proteins (Price and Schweigert, 1987). These extracted proteins then form a binding agent (Addis and Schanus, 1979).

Mixing stirs the meat pieces with paddles that have been designed so that they do not tear up the meat pieces (Price and Schweigert, 1987). Mixing is usually conducted for shorter periods with holding times in between (Price and Schweigert, 1987). Massaging uses frictional energy by rubbing the meat pieces together while tumbling is a more severe treatment which uses impact energy (Addis and
Schanus, 1979; Price and Schweigert, 1987). Tumbling occurs in a rotating drum with paddles where the meat generally drops 3 feet and strikes against the paddles (Addis and Schanus, 1979; Price and Schweigert, 1987). Some processors in Europe select the appropriate method based on the categorization of muscle tissue either as firm or soft. Firm tissues, such as beef, mutton, and turkey are impact tumbled while soft tissues, such as pork and chicken are massaged (Addis and Schanus, 1979).

Preblending is not a new procedure in sausage production (Shannon, 1983). This technology is used to maximize the extraction of salt soluble proteins and improve the eating quality and stability of sausage (Shannon, 1983). Preblending is defined as the grinding and mixing of raw materials several hours before batter production (Judge et al., 1989). This is usually done to allow time for proximate analysis of the raw materials, however, it has also been found to aid in the extraction of proteins (Judge et al., 1975). Preblending can consist of the addition of salt or other ingredients to the meat several hours before production (Hand et al., 1987). A lean pre-blend is most effective because the lean contains the salt soluble proteins which can be extracted with salt to improve water binding capacity (Rust and Olson, 1988).
2.21 Massaging

Tumbling or massaging is used to aid in the process of binding pieces of meat together and accelerating the distribution of cure ingredients in processed meats (Judge et al., 1989; Siegel et al., 1978b). Binding occurs due to a tacky exudate that forms on the surface of the meat pieces. It consists mainly of myofibrillar or salt soluble proteins which are known to increase binding (Siegel et al., 1978a; Siegel et al., 1978b).

Massaging is known to reduce processing time, improve tenderness, increase uniformity in color, texture and fat distribution, and improve the binding in ham rolls prepared with and without salt and phosphates (Siegel et al., 1978a; 1978b). Claus et al. (1990) investigated the effects of massaging a batter-type system and concluded that the benefits of massaging were not as evident when applied to sausage processing and suggested that further research must be done.

Different time periods of massaging have been studied. Siegel et al. (1978a; 1978b) investigated the effects of massaging excised muscles for 0, 1, 2, 4, 8, and 24 h. They found that exudate formation can be seen after 2 h of massaging, but the greatest benefit from this operation occurred after 8 h of continuous massaging. Cassidy et al. (1978) found that an 18 h intermittent schedule which had
the same amount of actual tumbling time as a 3 h schedule caused more changes in deep tissue. Their findings indicate that there is an advantage to allowing extra time for phosphate and salt to extract proteins. Gillett et al. (1981) found that a continuous 4 h massage of hams gave adequate bind and yield, yet longer periods of 16 to 20 h gave consistently higher yields. There was little increase in bind or yield from massaging more than 20 h. Ockerman and Wu (1990) investigated the effects of tumbling hot and cold boned ground meat to be used in comminuted products. Relative to emulsion capacity, there was no significant difference between tumbling 0 h and 24 h, but 12 h had a higher emulsion capacity than those tumbled 0 h or 24 h. Tumbling 0 h had a significantly lower percentage of free water and lower moisture loss than tumbling 12 h. Tumbling for 12 h gave lower values than those tumbled 24 h (Ockerman and Wu, 1990). Cook yield was not significantly affected by tumbling in this study.

Massaging improves water binding in section and formed products by incorporating salt and phosphate into the muscle cells and aiding in protein extraction (Siegel et al., 1978b). However, there was no improvement in bind, or reduction of cooking loss due to massaging in sausage type products (Claus et al., 1990; Ockerman and Wu, 1990). Ockerman and Wu (1990) found that tumbling for up to 12 h
improved emulsion capacity, but decreased emulsion capacity at 24 h. The effects of massaging on sausage type products should be further studied to find an appropriate time and method of massaging for this type of product. It appears that adequate massaging time is useful, but over massaging can be detrimental to the physical characteristics of sausage type products (Claus et al., 1990).

2.22 Preblending

According to Pearson and Tauber (1984) the main advantages of preblending are: 1) composition control of the batch through time for analysis of the meat and adjustment to a known fat content; 2) stabilization of the meat and control of spoilage through the addition of cure; 3) incorporation of hot-boned meat, where the maximum amount of salt soluble proteins can be extracted by the addition of the cure; 4) more efficient use of processing equipment as the meat can be curing while the equipment is used for other products; 5) reduction of rancidity by retarding oxidation.

Hand et al. (1987) investigated the effects of preblending of frankfurter batters with different salt and fat levels on the color and texture of the final product. They found that preblending had minimal effects on color and texture. However, preblending did remove the differences due to saltiness between high fat and low fat franks at the
same salt level. Puolanne and Terrell (1983) found that the highest WBC was achieved when preblends containing 4.0% salt were used to make sausages with 1.5 or 2.0% salt. Sausages in this study made from preblends without salt had the lowest WBC.

In a study of frankfurter emulsions made from prerigor, preblended prerigor, postrigor, postrigor frozen, and preblended postrigor frozen meat, the percentage salt soluble protein and emulsification capacity were similar for prerigor and preblended prerigor treatments and significantly higher than the other treatments (Acton and Saffle, 1969). The preblended postrigor meat had a higher emulsifying capacity than the non-preblended fresh or frozen postrigor samples. Acton and Saffle (1969) also found that preblending decreased total bacterial counts and resulted in a more desirable color formation.

Froning and Janky (1971) found that preblending of mechanically deboned turkey meat used in sausage production improved the solubility of protein, thereby making it available for emulsification. In this study, the release of gel-water and solids decreased and cooking losses decreased. However, no significant differences in tensile strength of the emulsions were observed. They concluded that salt preblending in conjunction with pH adjustment may improve the emulsifying capacity of mechanically deboned meats.
Jantawat and Carpentar (1989) added mechanically deboned poultry meat to a 3:1 pork:beef smoked sausage and studied the effects of preblending. They found that preblending did not influence the cooked yield or the intensity and desirability of the products' color. Preblending did result in higher Instron firmness and chewiness scores, but sensory scores for these traits did not show any significant differences.

2.3 EFFECT OF COMPOSITION ON SENSORY PROPERTIES

2.3.1 Effect of Fat Content on Sensory Properties

Rust and Olson (1988) report that when the fat content of a meat product is reduced below 15%, the quality of the product changes significantly especially in texture. Low-fat franks were found to have texture problems such as increased firmness and decreased juiciness (Rongey and Bratzler, 1966; Hand et al., 1987; Marquez et al., 1989; Park et al., 1989). Lee et al. (1987) found that scores for firmness, elasticity and chewiness significantly decreased and mushiness increased as fat content rose from 16% to 32%. Data from Claus et al. (1989) confirm that elasticity and firmness decrease with increased fat level. Van et al. (1980) investigated the maximum allowable fat content in nonspecific meat products and found that loaves containing 30% fat rated higher in every sensory trait (appearance,
firmness, juiciness, flavor, and overall desirability) when compared to those containing 40% fat. Sofos and Allen (1977) reported that reducing the fat content from 30% to 10% by adding textured soy protein resulted in lower, but not significant, sensory texture scores in wiener-type products.

Ground beef patties with 16% fat were rated tougher than patties containing 24% and 28% fat (Cross et al., 1980). Also, patties with 16% fat were less juicy than patties with 20%, 24% or 28% fat.

Frankfurters with 12% fat received lower ratings for overall acceptability than 20% or 29% frankfurters, but were still in the acceptable range (Marquez et al., 1989). These investigators found that the 12% fat frankfurters received higher flavor scores than the other treatments. Therefore, low-fat franks can be produced that are acceptable to consumers (St. John et al., 1986; Marquez et al., 1989).

A product's sensory attributes are related to rheology (Payne and Rizvi, 1988). Payne and Rizvi (1988) observed an increase in apparent viscosity with an increase in fat (5%-25%), however, the results of Burge and Acton (1984) differed as apparent viscosity increased as fat level decreased (11%-26%). Claus et al. (1989) found that batter viscosity was lower for treatments with 15% or less fat and 25% or more AW than a control batter with 30% fat and 10%
AW. Also, increases in AW while the fat level remained constant resulted in a decrease in batter viscosity.

2.32 Effect of Water on Sensory Properties

The results of Ahmed et al. (1990) suggest that some of the physical and sensory properties associated with low-fat pork sausages may be improved by adding higher levels of AW. However, the 40% rule does not apply to fresh ground meat products and this study involved the addition of only 3% AW and 13% AW to three fat levels (15, 25 and 35%).

Not many studies are available to directly compare sensory data of high AW meat products (Claus et al., 1989). However, the following studies suggest that sensory scores are affected by high levels of AW. Bologna formulated with high AW levels within a certain fat level received higher juiciness scores and lower springiness scores (Claus et al., 1989). Claus et al. (1989) found that increases in AW resulted in a less rigid product structure as evidenced by a decrease in sensory firmness and cohesiveness. Uram et al. (1984) produced smoked sausage with two levels of added emulsion (0 and 10%) and three levels of AW (0, 10, and 20%) and found that sensory scores for tenderness and juiciness increased with increased AW, but the increase from 10% to 20% was not significant (P>0.05). Park et al. (1990) produced frankfurters with varying levels of AW and high-
oleic sunflower oil (HOSO). They found that the low-fat HOSO, high AW (13.6% fat/ 29.6% AW) product was similar in flavor, juiciness and overall desirability to the high pork fat, low AW treatment (28.8% fat/ 12.4% AW). They concluded that low-fat HOSO frankfurters with the maximum allowable level of AW can be produced without negatively affecting processing yield, texture, and sensory properties.

Although AW improves some sensory traits of low-fat products it generally causes greater purge in the package (Rust and Olson, 1988). Claus et al. (1989) also found that purge increased as levels of AW increased.

2.4 ANALYSIS OF PHYSICAL PROPERTIES

2.4.1 Texture Profile Analysis

An important aspect of food acceptability is texture (Bourne, 1978). Claus et al. (1989) found that texture was one of the main problems associated with low-fat high AW bologna. Texture can be analyzed using the texture profile method developed by Bourne (1978). These results can be correlated to sensory panel data (Montejano et al., 1985; Claus et al., 1989).

Seven textural parameters have been named by Szezesniak (1975) and described by Bourne (1978). Fracturability, first known as brittleness, is described as the force at the first significant peak or break in the curve. The peak
force of the first compression is called hardness. Cohesiveness is the area under the curve of the second compression divided by the area under the curve of the first compression. Springiness has been defined by Bourne (1978) as the height recovered by the food during the period between the end of the first bite and the start of the second bite. To determine springiness, Bourne (1978) uses the base width of the second compression while Montejano et al. (1985) uses a ratio of the base width of the second compression over the base width of the first compression. Adhesiveness is the negative force area for the first bite which is shown by the work needed to pull the compression disc away from the sample. Gumminess and chewiness are dependent on the other parameters. Gumminess is the product of hardness and cohesiveness. Chewiness is the product of gumminess and springiness.

Texture Profile Analysis (TPA) really began with the General Foods Texturometer (Bourne, 1978). However, the Instron Universal Testing machine was adapted by Bourne (1968;1974) to perform TPA. Each instrument is being used for TPA and has it's advantages and disadvantages (Bourne, 1978). The Texturometer is more like a human jaw, but it cannot be used to give true work functions (Bourne, 1978). The Instron gives work functions and can be calibrated in
pounds, kilograms, and Newtons, but does not imitate the human jaw as well as the Texturometer.

Instron TPA was conducted on frankfurters made with increased monounsaturated/saturated lipid ratio and 25% less fat than a control (St. John et al., 1986). Lite (22% fat) franks had greater values for gumminess and chewiness than the regular (28% fat) franks. Cohesiveness was not significantly affected.

Claus et al. (1989) also conducted Instron TPA on bologna samples made with different levels of fat and AW. Fracturability and hardness of bologna samples compressed 75% and 25% of sample height increased as the fat decreased within an AW level. Also, increases in AW within a fat level decreased fracturability and hardness. They did not find differences in springiness between treatments, and cohesiveness increased with increased fat, but was not affected by increases in AW.

Claus et al. (1990) used TPA on low-fat high AW massaged bologna. They found that massaging with all of the water and none of the fat resulted in greater hardness and fracturability values than non-preblended bologna. Massaging did not have a significant effect on springiness, cohesiveness, or total energy.
2.42 Color Analysis of Meat

Meat color can be measured by either visual evaluation or one of many different instruments (Hunt, 1980; Price and Schweigert, 1987). Both methods involve the chemistry of the meat pigment myoglobin (Hunt, 1980). This pigment is one of the most important contributors to meat color (Judge et al., 1989).

The normal colors of fresh meat can be illustrated by a color triangle of the three forms of myoglobin (Price and Schweigert, 1987). Oxymyoglobin is formed when meat is exposed to air and oxygen penetrates the tissue (Price and Schweigert, 1987). It is often referred to as the "bioom" of meats and has a bright cherry red color in beef. Reduced myoglobin is the unoxygogenated form of myoglobin which has a dark purple color (Price and Schweigert, 1987). At low partial pressure of oxygen the iron in the heme is oxidized from the ferrous (Fe$^{2+}$) to the ferric state (Fe$^{3+}$) and produces a brown color which is metmyoglobin.

In cured products, nitrate or nitrite is reduced to nitric oxide which reacts with reduced myoglobin to form nitric oxide myoglobin which gives the bright red color to cured meats before heat processing (Judge et al., 1989). This color is stabilized during the heating process which denatures the protein portion of the myoglobin and forms the pigment, nitrosyl hemochrome resulting in the bright pink
color of cured meats (Judge et al., 1989). Another possible path for the development of cured color would be the conversion of myoglobin and oxymyoglobin to metmyoglobin caused by nitrite which can serve as an oxidizing agent (Judge et al., 1989). Nitric oxide would then react with the heme portion of metmyoglobin and form nitric oxide metmyoglobin. This pigment must then be reduced to nitric oxide myoglobin either naturally in the tissue or by reductants incorporated in the cure. This pigment is then denatured by heat and forms nitrosyl hemochrome.

An important method of color evaluation is by the human eye. The color seen by the human eye is a result of several factors (Judge et al., 1989). There are three attributes of color known as hue, value, and chroma. Judge et al. (1989) describes hue as that which is normally thought of as a color—yellow, red, blue, green. Value is an indication of the lightness or brightness of color and chroma is the saturation that describes the intensity of a color relative to the amount of white light that is mixed with it (Judge et al., 1989). Meat color is the total impression seen by the eye and is influenced by the meat pigments, the viewing conditions, the structure and texture of the meat and the differences in each individual's perception (Judge et al., 1989).
There are several types of instruments that give a physical description of how the meat color is perceived (Hunt, 1980). These systems such as the Hunter, Munsell and Minolta Chromameter are useful in establishing color standards or precise descriptions of color in terms of hue, value and chroma (Hunt, 1980). These systems do not give information on myoglobin content (Hunt, 1980).

Information on myoglobin content and how a treatment may affect pigment stability can be obtained by reflectance and transmission spectrophotometry (Hunt, 1980). False results can easily be produced by transmission spectrophotometry because extraction techniques used to prepare the sample can change the color or state of the pigment (Hunt, 1980). Reflectance spectrophotometry involves the mathematical manipulation of data from selected wavelengths. Absorbance values are converted to reflectance where \( R_a = 2 - \log R \) and these values are often converted to \( K/S \) values (Hunt, 1980). \( K/S \) values are obtained from the Kubelka-Munk equation which allows reflectance data to be more quantitative by adjusting for the light scattering and absorption properties of the sample (Hunt, 1980).
3.0 CHAPTER ONE

3.1 INTRODUCTION

The "40 percent" sausage rule allows for the substitution of added water (AW) for fat (≤30%) up to a combined total of 40% (USDA, 1988). However, low-fat, high AW products that maximize this rule have been found to result in problems associated with texture and excessive purge during storage (Claus et al., 1990). Rust and Olson (1988) report that when the fat content of a meat product is reduced below 15%, the quality of the product changes significantly, especially in texture. When the fat is reduced and replaced with AW, the critical issue in production is water binding rather than fat binding (Rust and Olson, 1988).

Physical manipulation such as massaging may help improve water binding in low-fat, high AW products by increasing protein-protein and protein-water interactions. Massaging is known to reduce processing time, improve tenderness, increase uniformity in color, texture, and fat distribution, and improve the binding in sectioned and formed meat products (Siegel et al., 1978a; 1978b). Claus et al. (1990) investigated the effects of massaging on a batter-type system and concluded that the benefits of massaging were not as evident when applied to sausage processing. However, Claus et al. (1990) suggested that
mincing after massaging may have disrupted the bonds formed
during massaging and prevented the full advantages of
massaging from being recognized.

The objectives of this study were to determine the
effect of massaging the minced batter on the physical,
chemical, and sensory characteristics of the final product.

3.2 MATERIALS AND METHODS

Product manufacture

Vacuum packaged fresh beef cow knuckles (Quadriceps
femoris complex) were trimmed of subcutaneous and
intermuscular fat, proportioned into three replications,
vacuum packaged and stored at -20°C prior to sausage
manufacture. Frozen commercial beef trim was proportioned
into three replications, vacuum packaged and stored at -20°C
until production. Prior to sausage manufacture, the frozen
knuckles were thawed for 45 h at 1°C, ground (9.5 mm plate)
and mixed 2 min (Leland Meat Mixing Machine, Model #100-DA).
Beef trim was ground frozen (19 mm plate), mixed 2 min, and
reground (9.5 mm plate). Lean and fat sources were sampled
and analyzed for moisture (AOAC, 1990) and fat (Foss-let
Rapid Fat Analyzer, A/S N Foss Electric, Denmark). Protein
content was determined by difference.

All treatments were formulated using the Least Cost
Formulator™ developed by Least Cost Formulations Ltd.
Inc., Virginia Beach, Va. Each batch was approximately 9 kg, however, this weight was increased slightly for massaged batches, to compensate for the batter characterization samples removed during massaging. This enabled each treatment to be approximately the same average size throughout production. Treatment 1, the high-fat control, was formulated to contain 30% fat and 10% added-water (AW). Treatments 2, 3, and 4 were formulated to contain 10% fat and 30% AW. After mincing, treatments 3 and 4 were massaged (Hobart bowl mixer, Model A-200) for 2.5, and 5 h, respectively. A massage cycle consisted of 10 min on and 20 min off each 30 min for a total of 20 min massage per h.

On the production day, coarse ground lean and fat sources were reground (3.2 mm plate). All treatments were processed in a 1°C cooler. The lean was mixed (Hobart bowl mixer, Model A-200) for 2 min with salt (2.3% of finished weight), a third of the water, and 15% ingredient solutions to provide sodium tripolyphosphate (0.5% meat block, Rhône-Poulenc Basic Chemicals Co., Chicago, Ill.), sodium erythorbate (550 ppm meat block) and sodium nitrite (156 ppm). The fat and remaining water were added and mixed 2 min. Treatments 3 and 4 were minced (1.7 mm plate, Griffith Mince Master®, Model GL-86) and massaged for 2.5 and 5.0 h, respectively. After massaging, 0.5% Heller's bologna seasoning (Heller Co., Bedford Park, Ill.) and 2% sugar
(based on the weight of batter left in the bowl after massaging) were added and mixed 2 min. For treatments 1 and 2, all ingredients were added and mixed 6 min before mincing. A vacuum was pulled on all batters using a Inauen Maschinen AG vacuum packager (Model VC 999-01) to remove air pockets. The batters were stuffed (Koch Piston Stuffer, Model E251) into 7 cm regular, fibrous, pre-stuck casings (Viskase™ Corp.) to an average weight of 1.5 kg. Stuffed products were weighed and heat processed in an Alkar Smokehouse (Model 2160 A-T) to an internal temperature of 67°C. The following smokehouse cycle was used:

<table>
<thead>
<tr>
<th>Time</th>
<th>Dry-bulb(°C)</th>
<th>Wet-bulb(°C)</th>
<th>Smoke</th>
<th>RH%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 h</td>
<td>62.8</td>
<td>17.8</td>
<td>off</td>
<td>--</td>
</tr>
<tr>
<td>1 h</td>
<td>71.1</td>
<td>48.9</td>
<td>on</td>
<td>30.5</td>
</tr>
<tr>
<td>1 h</td>
<td>76.7</td>
<td>65.6</td>
<td>off</td>
<td>59.0</td>
</tr>
<tr>
<td>to finish</td>
<td>85.0</td>
<td>79.4</td>
<td>off</td>
<td>79.0</td>
</tr>
</tbody>
</table>

Internal temperatures were measured using thermocouples and an electronic temperature recorder (Omega Digital Thermometer, Model 2160 A-T).

**Batter Characterization**

Samples from treatment 3 and 4 were taken immediately after mincing and then after each 10 min cycle of massaging for batter characterization and temperature measurement. Approximately 10 g of batter and 50 ml of distilled water were placed in a plastic stomacher bag and stomached (Tekmar...
Co., Model ST0-400) 2 min for pH measurement using a Corning pH meter (Model 240). Batter viscosity was measured using a Brookfield Dial Reading Viscometer (Model RVF, Brookfield Engineering Laboratories, Inc., Stoughton, Mass.). Three repeated measurements were taken using a number 7 spindle at 10 rpm.

Thermal emulsion stability (TES) was tested by stuffing 15-20 g of batter into open-ended glass tubes (18 cm x 2 cm diameter). One end was plugged with a rubber stopper and the other end was covered with aluminum foil. The tubes were placed in a 70°C water bath until the internal temperature reached 70°C as determined by thermocouples centrally placed in the tubes and an electronic temperature recorder (Omega digital thermometer). The difference in the weight of the sample before and after cooking was used to calculate percentage cook loss. One sample each from treatments 1 and 2 was taken after mincing and analyzed for batter characterization.

**Cook Yield and Purge Accumulation During Storage**

Each chub (10 total) was weighed prior to heat processing and then cooked and chilled 60 h at 1°C and reweighed. Cook yield was determined by calculating the percentage difference between before and after weights.
Cooked product was cut into 4 mm thick slices and stored under three vacuum levels to determine the effects on purge accumulation. Five slices were weighed and placed in moisture impermeable Cryovac™ bags (#B550 T 6.5 x 12, Cryovac, Duncan, S. Caro.). Duplicate samples were packaged under high vacuum (87.78 kPa), low vacuum (30.38 kPa) and 100% CO₂ gas (no vacuum). Packages were stored 30 days in a 6°C enclosed display cooler. At the end of the storage period the packages were opened and drained. The slices were blotted dry and reweighed. Purge was calculated as the percent difference between before and after weights.

**Texture Analysis**

Four chilled (4°C) slices (1.9 cm thick) per treatment were used for instrumental texture analysis. Four cores (2.5 cm diameter) per slice were taken for eight repeated measures of 75% compression and eight repeated measures of 50% compression. The procedures for Texture Profile Analysis (TPA) developed by Bourne (1978) and Montejano et al. (1985) were followed. Each core, for the 75% compression, was compressed 75% of the height to determine: cohesiveness (total energy, TE in kgf*m, of the second compression divided by TE of the first compression), hardness (kgf), and fracturability (height of first significant peak). Each core, for the 50% compression, was
compressed 50% of the height to determine springiness (base width of the second curve divided by the base width of the first curve * 100). An Instron Model 1011 (Instron Corp., Canton, Mass.) was programmed for a load range of 50 kg and a crosshead speed of 200 mm/min. The strip chart recorder was set at 2:1 (recorder:crosshead).

**Sensory and Color Evaluation**

An eight member trained sensory panel was used to analyze the textural characteristics of the bologna. Six training sessions were conducted to train the panelists for the desired traits using three different commercial brands of bologna and laboratory prepared samples following the general guidelines outlined in Larmond (1977). The panels were conducted in the Food Science and Technology Sensory Lab in individual booths using red lighting. A 1.5 cm thick wedge-shaped sample was served at room temperature. Apple slices and water were used to cleanse the palate between samples. The samples were coded with three digit numbers and served in random order to the panelists. The samples were evaluated for cohesiveness (extent to which sample was deformed before rupture); firmness (force required to bite through sample with incisors); saltiness (after 5-6 chews); juiciness (initial and prolonged presence of moisture during 6-8 chews). Scores were based on an eight point structured
scale for cohesiveness (1=extremely non-cohesive to 8=extremely cohesive), firmness (1=extremely soft to 8=extremely firm), juiciness (1=extremely dry to 8=extremely juicy), and saltiness (1=none to 8=extremely strong). Descriptive nomenclature for cohesiveness, firmness and juiciness was: extremely (1 and 8), very (2 and 7), moderately (3 and 6) and slightly (4 and 5).

Panelists visually evaluated vacuum packaged slices (0.5 cm thick) for particle definition using an eight point scale (1=none to 8=abundant).

Color evaluations were made by a trained seven member panel over a four week period. Training sessions were held to familiarize panelists with lightness and off-color traits of bologna products. Slices (.5 cm thick) from each treatment were vacuum packaged in Cryovac bags (#B550 T 6.5 X 12, Cryovac, Duncan, S. Caro.) labeled with three digit random codes, and displayed continuously in an enclosed display case at 10°C. The samples were placed 1000 Lux of light away from the light source (Philips Cool White, 30 W rapid start) as measured by an Extech Digital Light Meter.

Panelists evaluated the samples at week 0, 1, 2, 3, and 4 for the traits of lightness and off-color. Scores for each parameter were based on an eight point structured scale for lightness (1=extremely light red to 8=extremely dark red). Descriptive nomenclature for lightness was: very(2
and 7), moderately (3 and 6), and slightly (4 and 5). Off-color was scored as: 1=none, 2=practically none, 3=traces, 4=slight, 5=small, 6=slightly severe, 7=severe to 8=very severe.

**Chemical analysis**

All treatments were analyzed for moisture, fat and protein following AOAC (1990) procedures.

**Statistical Analysis**

Statistical analysis was performed using the Statistical Analysis System (SAS,1988). Chemical analysis, texture profile analysis, cooking loss, sensory and texture data from three replications were analyzed as a complete randomized block design. Purge accumulation and color evaluation were analyzed as split plot designs where the whole plot was four main treatments and the split plot was vacuum level and storage time, respectively. Treatment means at the final time and time means for batter characterization were analyzed as a completely randomized block design. Time means were also analyzed by regression analysis to describe trends over time. Means were separated using Fisher's LSD method. Simple correlations were done to compare selected variables.
3.3 RESULTS AND DISCUSSION

**Chemical Analysis**

Chemical analysis of the cooked low-fat treatments (Table 1) indicated that the average for fat (10.0%) was at the formulated target level and that for AW (29.1%) was within 0.9% of the formulated target. For the high-fat control, fat and AW were within 2.7% and 1.1% of the target levels, respectively.

**Cook Loss and Purge Accumulation**

The high-fat bologna had the lowest (P<0.05) cooking loss at 4.4% (Table 2). No differences (P>0.05) were found in cooking loss between the low-fat, high AW treatments. The average of the means for the low-fat treatments was 7.7%. These results agree with Claus et al. (1989) who reported low cook yields for low-fat treatments.

Purge accumulation was lowest (P<0.05) for the high-fat control (Table 2). Purge accumulation was higher (P<0.05) in the low-fat treatments compared to the high-fat treatment at all vacuum levels. Purge accumulation was affected by the vacuum level. The no vacuum package had the least amount (P<0.05) of purge accumulation for all treatments while the full vacuum packages tended to have the most purge. Purge accumulation in the partial vacuum packages was less (P<0.05) than the full vacuum packages for the high-fat control. For the low-fat treatments,
Table 1—Mean values for chemical analysis of cooked bologna

<table>
<thead>
<tr>
<th>Treat- ment (%)</th>
<th>Massage</th>
<th>Chemical analysis (%)</th>
<th>AW</th>
<th>40% rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 30/10</td>
<td>-</td>
<td>27.3(^a) 56.1(^a)</td>
<td>11.2</td>
<td>11.1(^a)</td>
</tr>
<tr>
<td>2 10/30</td>
<td>-</td>
<td>9.8(^b) 72.8(^b)</td>
<td>11.0</td>
<td>28.7(^b)</td>
</tr>
<tr>
<td>3 10/30</td>
<td>2.5 h</td>
<td>10.2(^b) 72.8(^b)</td>
<td>10.9</td>
<td>29.2(^b)</td>
</tr>
<tr>
<td>4 10/30</td>
<td>5.0 h</td>
<td>10.0(^b) 73.2(^b)</td>
<td>11.0</td>
<td>29.3(^b)</td>
</tr>
</tbody>
</table>

Standard Error  .27  .28  .13  .75  .58

\(^a\)\(^b\) Means within the same column with unlike superscripts are different (P<0.05).
\(^c\)AW=USDA added water=\%Moisture-4(\%Protein).
\(^d\)40% rule=\%Fat+\%AW.
Table 2-Means for cooking losses and purge accumulation of cooked bologna packaged at different vacuum levels

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percent Fat/AW&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Massage</th>
<th>Cooking Loss(%)</th>
<th>% Purge Accumulation&lt;sup&gt;e&lt;/sup&gt;</th>
<th>No Vac&lt;sup&gt;f&lt;/sup&gt;</th>
<th>Partial Vac</th>
<th>Full Vac</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30/10</td>
<td>-</td>
<td>4.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.6&lt;sup&gt;cZ&lt;/sup&gt;</td>
<td>3.4&lt;sup&gt;cY&lt;/sup&gt;</td>
<td>4.3&lt;sup&gt;cX&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10/30</td>
<td>-</td>
<td>7.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3&lt;sup&gt;bY&lt;/sup&gt;</td>
<td>7.2&lt;sup&gt;bX&lt;/sup&gt;</td>
<td>7.8&lt;sup&gt;bX&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10/30</td>
<td>2.5 h</td>
<td>7.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3&lt;sup&gt;bY&lt;/sup&gt;</td>
<td>8.1&lt;sup&gt;aX&lt;/sup&gt;</td>
<td>8.6&lt;sup&gt;aX&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10/30</td>
<td>5.0 h</td>
<td>7.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.3&lt;sup&gt;aY&lt;/sup&gt;</td>
<td>8.2&lt;sup&gt;aX&lt;/sup&gt;</td>
<td>8.8&lt;sup&gt;aX&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

Standard Error .10 .24 .24 .24

<sup>a-c</sup>Means within the same column with unlike superscripts are different (P<0.05).
<sup>d</sup>AW=USDA added water=%Moisture-4(%Protein).
<sup>e</sup>Purge Accumulation: Treatment * vacuum Level (P<0.05).
<sup>f</sup>No Vac=100% CO<sub>2</sub>; Partial Vac=30.38 kPa; Full Vac=87.78 kPa.
<sup>x-z</sup>Means within the same row that have different superscript letters are different (P<0.05).
the purge levels in the partial vacuum packages were higher (P<0.05) than the no vacuum but not different (P>0.05) than the full vacuum packages. These results differ from those of Claus et al. (1990) who found that low-fat bologna treatments produced by massaging with all of the AW, but none of the fat had less (P<0.05) purge than non-massaged low-fat treatments. Because the low-fat treatments in our study were massaged with all of the AW and fat, the fat may have interfered with the protein-protein and protein-water interactions resulting in a lower water binding capacity and more purge during storage. Our results agree with Rust and Olson (1988) who stated that a high vacuum may result in greater purge due to the constant pull on the product.

**Batter Characterization**

Batter characteristics for each treatment at the final time period (time 0, 0, 6, 11 for treatment 1, 2, 3, 4, respectively) were compared (Table 3). The high-fat bologna was warmer (P<0.07) than the massaged treatments just before stuffing. Claus et al. (1989) reported higher temperatures for batters containing 15% or more fat and less than 20% AW. Thus, the higher temperature of the high-fat treatment may be due to its lower level of AW. Claus et al. (1990) reported that the high-fat control had the highest batter
Table 3-Means for characteristics of uncooked bologna batter just before stuffing

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percent Fat/WW&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Massage</th>
<th>Temperature (°C)</th>
<th>pH</th>
<th>Brookfield Viscosity (mPa s)</th>
<th>Thermal Emulsion Stability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>-</td>
<td>10.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.22</td>
<td>206400&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.1&lt;sup&gt;b&lt;/sup&gt;&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>10/30</td>
<td>-</td>
<td>6.7&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.17</td>
<td>60356&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19.4&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
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<td>10/30</td>
<td>2.5 h</td>
<td>6.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.20</td>
<td>88511&lt;sup&gt;b&lt;/sup&gt;</td>
<td>28.2&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
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<td>10/30</td>
<td>5.0 h</td>
<td>4.9&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>87422&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>5182.2</td>
<td>1.97</td>
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<sup>a-c</sup> Means within the same column with unlike superscripts are different (P<0.05). Temperature different at (P<0.07).
<sup>d</sup> AW=USDA added water=Moisture-4(% Protein).
<sup>c</sup> Thermal Emulsion Stability=weight of the plug of batter before cooking-weight of the plug after cooking/weight of the plug before cooking × 100.
temperature due to frictional forces created during the mincing of this batter. There were no differences (P>0.07) among the low-fat treatments. Although, the non-massaged low-fat treatment tended to be higher than the massaged treatments. The massaged treatments were processed longer in a 1°C cooler after mincing which may account for the lower temperature. Also, pH values among treatments were not different (P>0.05) as would be expected. Brookfield viscosity was highest (P<0.05) for the high-fat bologna. This observation agrees with the results of Payne and Rizvi (1988) who reported that apparent viscosity increased with an increase in fat. The lower viscosities for the low-fat treatments agree with the results of Haq et al. (1973) and Hamm (1975) who found that increased levels of water resulted in a decrease in viscosity. Hamm (1975) suggested that the increasing water content reduces the interaction between particle surfaces and lowers the viscosity of the liquid phase. The massaged low-fat treatments were higher (P<0.05) in the final viscosity than the non-massaged, low-fat treatment. This trend could be due to the decrease in temperature of these batters over time. Hamm (1975) suggested that rheological properties are influenced by temperature especially when dealing with fat. Hamm (1975) concluded that changes in the interaction between myosin and actin are one of the main factors influencing rheological
properties. Dissociation of actin and myosin by ATP or diphosphate causes an increase in viscosity (Hamm, 1975). Greater lengths of massaging in sectioned and formed products are required to incorporate salt and phosphate and aid in protein extraction and water binding (Siegel and Schmidt, 1978b) which would in turn increase the viscosity.

Batter characteristics for the massaged treatments were also analyzed for differences between times over the 5.0 h massage period. Temperature decreased rapidly until time 5 (50 min massage) and then continued to decrease but at a much slower rate. This can be described by a linear time effect (P<0.05) as determined by regression analysis (Figure 1). Time had no effect (P>0.05) on pH. Brookfield viscosity increased (P<0.05) from time 0 to time 2 but then tended to decrease over time of massage (Figure 2). There was a linear effect (P<0.05) on Brookfield viscosity as determined by regression analysis.
Figure 1-Changes in the temperature of uncooked, low-fat bologna batter over a 5.0 h intermittent (10 min on/20 min off) massage period. Time numbers (1-11) correspond to samples taken after each massaged cycle. Time 0 is the sample taken after mincing but before massaging began.
Figure 2-Changes in the viscosity of uncooked, low-fat bologna batter over a 5.0 h intermittent (10 min on/20 min off) massage period. Time numbers (1-11) correspond to samples taken after each massage cycle. Time 0 is the sample taken after mincing but before massaging began.
TES for total cook loss at the final times for each treatment were compared (Table 3). TES for the massaged treatments tended to be greater than the high-fat bologna. TES for the 5.0 h massage was higher (P<0.05) than both the high-fat and low-fat controls. Massaging increased (P<0.05) TES compared to the non-massaged bologna. Similar to the results for purge accumulation, the increased percentage cookout in massaged batters could have been due to the fact that the batters were massaged with all of the fat. However, the results of percentage cookout determined by TES did not agree with the results for smokehouse cooking loss which was not different among low-fat treatments. This may have been due to the method used to determine cookout for TES compared to the smokehouse process. The TES cooking method brought the sample up to 67°C in 30 min while the smokehouse process was a slow cook of over 4 h. Thermal processing and cooking rates can have an effect on the gelation of the bologna which may effect the cooking loss (Camou et al, 1989). These researchers concluded that a slower heating rate would result in a more complete gelation. Foegeding et al. (1986) suggested a slower cooking rate decreased moisture loss. Also, there was not a significant correlation between percent TES and cook loss. TES was not significantly correlated with moisture, fat,
Figure 3—Changes in total cook loss determined by thermal emulsion stability (TES%) for uncooked, low-fat bologna batter over a 5.0 h intermittent (10 min on/20 min off) massage period. Time numbers (1-11) correspond to samples taken at each massage cycle. Time 0 is the sample taken after mincing but before massaging began.
protein or AW, while smokehouse cooking loss was highly correlated with both moisture (r=0.99) and AW (r=0.98).

TES for total cook loss was also analyzed for changes over time during the 5.0 h massage period (Figure 3). These values tended to increase with time after time 4 (forty min of massage). This would indicate that the extended massaging after 2.5 h was not beneficial and that a massage time less than 2.5 h might result in the lowest TES values. The mean TES at time four for the massaged treatments (21.0%) was less than the mean for the high-fat bologna (24.1%). Regression analysis of the change in TES over time for the massaged treatment indicated that the linear trend was not significant, but the addition of a second order model was significant (P<0.02). The overall trend was quadratic as shown in Figure 3.

**Visual Color Evaluation**

The high-fat control had the most off-color (P<0.05) and was the lightest (P<0.05) colored bologna (Table 4). There were no significant differences among the low-fat treatments in either lightness or off-color, however, the massaged treatments tended to be darker red and have less off-color than the non-massaged treatment. Several researchers have reported that low-fat products are darker in color than
Table 4—Means for sensory evaluation of cooked bologna

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percent Fat/AW&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Massage</th>
<th>Sensory Score&lt;sup&gt;e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>5.3&lt;sup&gt;a&lt;/sup&gt; 6.3&lt;sup&gt;a&lt;/sup&gt; 4.2&lt;sup&gt;c&lt;/sup&gt; 5.0&lt;sup&gt;b&lt;/sup&gt; 3.8&lt;sup&gt;b&lt;/sup&gt; 4.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>10/30</td>
<td>-</td>
<td>3.7&lt;sup&gt;c&lt;/sup&gt; 4.0&lt;sup&gt;b&lt;/sup&gt; 5.6&lt;sup&gt;b&lt;/sup&gt; 6.3&lt;sup&gt;a&lt;/sup&gt; 5.9&lt;sup&gt;a&lt;/sup&gt; 3.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>10/30 2.5 h</td>
<td></td>
<td>4.6&lt;sup&gt;b&lt;/sup&gt; 3.9&lt;sup&gt;b&lt;/sup&gt; 6.0&lt;sup&gt;a&lt;/sup&gt; 3.3&lt;sup&gt;c&lt;/sup&gt; 6.2&lt;sup&gt;a&lt;/sup&gt; 2.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>10/30 5.0 h</td>
<td></td>
<td>4.4&lt;sup&gt;b&lt;/sup&gt; 3.9&lt;sup&gt;b&lt;/sup&gt; 5.8&lt;sup&gt;ab&lt;/sup&gt; 2.9&lt;sup&gt;c&lt;/sup&gt; 6.2&lt;sup&gt;a&lt;/sup&gt; 2.8&lt;sup&gt;b&lt;/sup&gt;</td>
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</tbody>
</table>

Standard Error

0.20 0.33 0.09 0.35 0.17 0.22

<sup>a-c</sup>Means within the same column that have unlike superscripts are different (P<0.05).

<sup>d</sup>AW=USDA added water=%Moisture-4(%Protein)

<sup>e</sup>Based on eight-point scale: 1=extremely non-cohesive, soft, dry, none (Particle Definition); 8=extremely cohesive, firm, juicy, abundant (Particle Definition); 1=extremely light red (Lightness); 8=extremely dark red (Lightness); 1=none (Off-color), 8=very severe (Off-color).
Table 5-Week means for visual color evaluation of cooked bologna

<table>
<thead>
<tr>
<th>Week</th>
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<th></th>
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</tr>
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<td>Off-color</td>
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</tr>
<tr>
<td>0</td>
<td>5.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.8&lt;sup&gt;b&lt;/sup&gt;</td>
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</tr>
<tr>
<td>4</td>
<td>5.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standard Error</td>
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<td>.24</td>
</tr>
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</table>

<sup>a-b</sup>Means within the same column with unlike superscripts are different (P<0.05).
<sup>c</sup>Based on eight-point scale: Lightness(1=extremely light red to 8=extremely dark red); Off-color(1=none to 8=very severe).
high-fat products (Rongey and Bratzler, 1966; Van et al., 1980; Hand et al., 1987; Claus et al., 1990).

The lightness of the bologna remained the same (P>0.05) throughout the 4 week storage period (Table 5). However, panelists rated off-color as more severe (P<0.05) at week 0 than during the remaining storage period. This may be explained by an off-colored ring that appeared in the low-fat treatments just after being vacuum packaged. The off-colored ring could have been caused by the incorporation of air during massaging. Although, each batter was evacuated by pulling a vacuum on the batter, some air pockets may have remained. The nitrosyl hemochrome compound that is formed after heat processing is very susceptible to light fading especially when meat cuts are displayed under light and exposed to oxygen (Judge et al., 1989). The light splits the nitric oxide from the heme of the myoglobin and the air in the package could have oxidized the nitric oxide and the heme group which would result in the brown color. As the oxygen is used up in the package the nitric oxide would be reduced and recombine with the heme to form the pink color. The ring disappeared by the next evaluation. Off-color tended to increase with time.
Sensory Evaluation

The high-fat control was the firmest and most cohesive (P<0.05), however the massaged low-fat treatments were more cohesive (P<0.05) than the non-massaged low-fat treatment (Table 4). The 5.0 h massaged treatment was not different (P<0.05) in cohesiveness from the 2.5 h massaged treatment. There were no significant differences in firmness among the low-fat treatments.

The results for firmness and cohesiveness agree with those of Claus et al. (1989, 1990). They reported that as the fat content of bologna was reduced and the AW level increased, the products became softer and less cohesive. Claus et al. (1989) suggested that protein content was responsible for sensory cohesiveness and firmness because of correlation values of r=0.82 and r=0.84, respectively. However, our results revealed high correlations of firmness and cohesiveness with fat content (r=0.92 and r=0.76, respectively). High negative correlations of AW with cohesiveness (r=-0.75) and firmness (r=-0.92) were also observed. Correlation of protein with cohesiveness was not significant. Correlation of protein with firmness was r=.64. This would support reports that low-fat frankfurters without high AW are firmer than high-fat frankfurters (Hand et al., 1987; Marquez et al., 1989).
The low-fat treatments were juicier (P<0.05) than the high-fat control. The 2.5 h massaged treatment tended to be more juicy than the 5.0 h massaged treatment and was significantly juicier than the non-massaged low-fat treatment. The 5.0 h massaged treatment was not different (P<0.05) in juiciness from the non-massaged low-fat treatment. As the fat content is decreased and the AW increased, products become more juicy (Claus et al., 1989). Uram et al. (1984) reported that increased levels of AW in smoked sausage resulted in a more juicy product. However, Park et al. (1990) reported that low-fat frankfurters made with high oleic sunflower oil were similar in juiciness to high-fat frankfurters. Lee and Patel (1984) reported that the sensory juiciness of frankfurters correlated well with expressible fluid. They reported that the intensity of juiciness correlated well with the amount of fat in the expressed fluid, but that the desirability of juiciness decreased as the amount of fat in the fluid became greater than the amount of water.

The non-massaged, low-fat treatment had the most abundant amount of particle definition (P<0.05). The massaged treatments had less particle definition (P<0.05) than all other treatments. Particle definition tended to decrease with the longer massaging period. Therefore, even though all treatments were minced through the same size
Figure 4—Treatment means for Instron texture profile analysis of bologna. Bars within the same plot with unlike letters are different (P<0.05). Numbers under the bars indicate treatment.
plate, massaging reduced particle definition in the finished product. There were no differences (P>0.05) in saltiness scores among the treatments.

**Texture Profile Analysis**

Instron texture profile analysis (Figure 4) indicated that low-fat treatments were more springy and cohesive (P<0.05) than the high-fat control. The low-fat massaged treatments were more cohesive (P<0.05) than the non-massaged, low-fat treatment. Massaging had no significant effect on springiness of the low-fat treatments. The high-fat control had higher hardness values (P<0.05) than the low-fat treatments and there were no differences in fracturability (P>0.05) among the treatments.

These results agree with those of Claus et al. (1990), except that they reported that massaging for 5.0 h had no significant effect on cohesiveness. This discrepancy may be because they used 50% compression to determine cohesiveness. Also, Claus et al. (1990) minced after massaging which may explain the discrepancy. The 2.5 h massaged treatment in our study tended to be more cohesive (Figure 4) than the 5.0 h massaged treatment. Claus et al. (1989) reported high correlations of protein with instrumental fracturability (r=0.76) and hardness (r=0.67). In this study, the correlation of protein to fracturability was r=0.62 (P<0.05)
and to hardness was not significant. Instead, high correlations of fat to fracturability ($r=0.79$) and hardness ($r=0.86$) were observed. This would support the results that hardness and fracturability increased with a increase in fat. Correlations of AW to fracturability ($r=-0.83$) and hardness ($r=-0.86$) were similar to those of Claus et al. (1989).

Correlations of instrumental texture traits and sensory texture traits are presented in Table 6. Sensory cohesiveness significantly correlated to instrumental hardness ($r=0.63$). Sensory firmness was significantly correlated to fracturability ($r=0.82$), cohesiveness ($r=-0.60$) and hardness ($r=0.79$). These results are similar to those found by Claus et al. (1989) and Montejano et al. (1985) except for cohesiveness which both researchers reported to positively correlate with sensory firmness.
Table 6—Correlation coefficients of sensory traits with TPA traits for cooked bologna

<table>
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<th>Sensory Traits</th>
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<tr>
<td></td>
<td>Cohesiveness</td>
<td>Firmness</td>
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</tr>
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<td>Springiness</td>
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<td>-.67*</td>
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<tr>
<td>Fracturability</td>
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<tr>
<td>Cohesiveness</td>
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<tr>
<td>Hardness</td>
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<td>.79**</td>
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*P<0.05  
**P<0.005
3.4 CONCLUSIONS

The main problems associated with low-fat, high AW products are excessive purge during storage and changes in textural characteristics compared to high-fat products. In this study, we investigated the effects of massaging on these problems and determined that massaging did not decrease purge accumulation. However, massaging did increase sensory cohesiveness scores and increase values for instrumental texture analysis. Massaging significantly decreased particle definition compared to the low-fat and high-fat controls. Decreased particle definition might be considered an improvement in the appearance of certain processed products. Massaging also tended to decrease off-color.

Although massaged treatments were formulated to contain only approximately 10% fat, massaging with all of the added fat trim might have interfered with the protein-water and protein-protein interactions occurring in the batter. This would result in minimal improvements in the water holding properties and hardness of the final product. Further research needs to be done to investigate the effects of massaging the minced lean and water before the fat is added.
REFERENCES


Appendix A—Correlation coefficients for experimental traits and chemical analysis of bologna

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*a*Number of observations used to calculate each coefficient was 12.

*P* < 0.05

**P** < 0.005

***P*** < 0.0001
Appendix B—Treatment means for Instron texture profile analysis of bologna. Bars within the same plot that have different letters are different (P<0.05). Numbers under the bars indicate treatment.
Appendix 1

Experimental Viscosity Measurements

Two other experimental viscosity measurements were used to characterize the batter. A plastic cone (4.5 cm diameter, 9.2 cm length) was attached to the end of a threaded rod (0.60 cm diameter and 224 g combined wt). The rod was guided through a piece of glass tubing attached vertically to a ring stand. The rod was marked so that the distance the cone traveled into the batter could be measured in centimeters. The tip of the cone was positioned just at the top of the batter with the zero mark on the rod at the end of the glass tubing. The cone was then pulled up 7.5 cm against the glass tubing and allowed to drop into the batter. As soon as the cone hit the batter it was stopped and a penetration distance was determined. The second procedure was a modified Brookfield reading in which a number 7 spindle was positioned in the batter up to the mark on the spindle. The spindle was twisted to 100, held for 5 s, and released for 15 s. At 15 s, the needle was stopped and a reading was taken.

Means for the spindle twist method for each treatment at the final time period were compared. Viscosity was highest (P<0.05) for the high-fat bologna. There were no differences (P>0.05) between the low-fat treatments. Spindle twist viscosity was also analyzed for differences between times. Time 2 and 3 had the highest (P<0.05) values for viscosity.
Differences between the other times were not significant. This method for measuring viscosity did not produce any results that could be used to better characterize the batter. There could be problems with strands of fat or collagen wrapping around the spindle and affecting the data.

Means for the cone drop method for each treatment at the final time period were compared. The high-fat bologna had the lowest (P<0.05) value which would correspond to a more viscous batter. The 2.5 h massaged bologna was not different (P>0.05) from the non-massaged treatment. The 5.0 h massaged bologna had the highest (P<0.05) value which would correspond to the least viscous. However, when the massaged treatments were analyzed for differences over the 5.0 h time period only time 11 was different (P<0.05). This observation suggests that treatment 4 was similar to the other low-fat treatments. It only looks that way when the final time periods are compared.

Also, this method was not consistent. The values over time went up and down. Regression analysis determined that there was neither a linear nor a quadratic effect. This would suggest a straight line. This does not compare to the results for Brookfield viscosity which showed a linear and a quadratic effect.
Appendix 2

$F_0$ values

Temperatures were tracked during the heating process in order to determine the differences in the heating rate of each treatment.

Internal temperatures were measured during thermal processing using thermocouples and an electronic temperature recorder (Omega Digital Thermometer, Model 2160 A-T). Temperatures were recorded every 10 min until an internal temperature of 67°C was reached and used in calculating the $F_0$ values of the heating portion of the curve.

No differences ($P>0.05$) were found among the $F_0$ values of each treatment. The low-fat treatments tended to be lower than the high-fat control. Thus, the low-fat treatments heated at a slower rate and did not receive the same heating process as the high-fat control. The variation in the data may suggest a smokehouse effect rather than a treatment effect. It is known that cooking rate and temperature affects the texture and water binding ability of cooked meat products (Trout and Schmidt, 1987). Further research should be investigated to standardize the smokehouse process and determine the differences in the heating rates of low-fat versus high-fat bologna. Understanding the thermal process may lead to improvements in the texture and water binding of low-fat bologna.
VITA

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