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The effects of sodium tripolyphosphate on preblended pork sausages

Casey B. Frye
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The effects of sodium tripolyphosphate on preblend pork sausages

Frye, Casey B., Ph.D.

Iowa State University, 1990
The effects of sodium tripolyphosphate on preblended pork sausages

by

Casey B. Frye

A Dissertation Submitted to the
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LITERATURE REVIEW

Introduction

The maximum use of raw materials in meat processing is becoming more critical as profit margins decrease, government regulations increase and consumers become more critical of the composition and quality of sausage products. The functional properties of raw materials are extremely important to sausage products, as they ultimately dictate final product characteristics. The functional properties are essentially determined by three main interactions: protein-protein, protein-water and protein-lipid. This review will focus on the mechanisms of these interactions plus the various factors that influence them. An understanding of the basic mechanisms involved and factors which influence these interactions is vital for possible manipulation of these interactions in processed meat products.

Functional properties of muscle proteins can be greatly influenced by inorganic phosphates. Some phosphates have a greater influence on these properties than others, and the conditions of their use will be reviewed.

Preblending raw materials for sausage manufacture is an attempt to manipulate these protein interactions and to control product composition. The mechanisms, advantages and disadvantages of preblending also will be discussed.
Raw Material Functionality

Raw material functionality describes any physicochemical properties that affect the processing and behavior of proteins in food systems as judged by the quality attributes of the final products. These functional properties reflect complex interactions among the composition, structure, conformation, and physicochemical properties of the proteins, other food components and the conditions in which these are associated or measured (Kinsella, 1976). The major functional interactions occurring in processed meat products have been defined as protein-protein, protein-water and protein-lipid interactions (Acton et al., 1983; Acton and Dick, 1984, 1985). These interactions can be attributed to the initial raw meat materials and their inherent functional properties of protein gelling, water-binding and fat emulsifying.

It is generally agreed that myofibrillar proteins, especially acton and myosin, are the primary proteins which stabilize processed meat products. The protein, myosin, is characterized by a high proportion of basic and acidic amino acids, making it a highly charged molecule. The isoelectric pH of myosin is about 5.4. The native structure of the molecule has been described as a double stranded alpha-helical (coiled-coil) rod with two globular heads at one end. The head region, where light molecular weight chains are located, project laterally from the long axis of the filament. When myosin is subjected to proteolytic action (trypsin and chymotrypsin), it is split into two fractions that
differ in molecular weight; light meromyosin (LLM; 150,000 mw) and heavy meromyosin (HMM; 350,000 mw). Other proteolytic methods (treatment with papain) can further subdivide the HMM fragment into S-1 (globular) and S-2 (fibrous) segments.

There are many other proteins that exist in the myofiber but are trivial in their quantity and contribution to meat processing functionality.

**Protein-Protein Interactions**

**Protein interaction definitions** The association of proteins have been described and discussed using various, confusing terminologies. Hermansson (1979) classified and defined protein-protein mechanisms as aggregation, association, precipitation and/or flocculation. Schmidt (1981) reported that a complex interrelationship exists between association-dissociation, precipitation, coagulation and gelatin reactions of protein systems. Acton and Dick (1984) used protein aggregation as a general term to describe many types of protein-protein interactions, but stated definite differences between coagulation and gelation. To help clarify the terminologies used in describing protein-protein interactions, the terms will be defined as follows:

*association* - refers to changes at the molecular level such as monomer-dimer reactions characterized by weak bonds at specific binding sites (Hermansson, 1979).
aggregation - a general collective term for protein-protein interactions which generally involve the formation of higher molecular weight complexes from association reactions (Schmidt, 1981).

flocculation - a precipitation from solution in the form of fleecy masses. Random aggregation that is entirely a colloidal phenomenon where the interaction between protein molecules is determined by balances between electrostatic repulsive forces and Van der Waal's attraction (Hermansson, 1979).

precipitation - random aggregation that occurs as a result of neutralization of repulsive forces within a solution (Hermansson, 1979).

gelation - association of cross-linking of randomly dispersed polymer chains in solution to form a three-dimensional continuous network which immobilizes the liquid in the interstitial structures and resists flow under pressure (Glicksman, 1982).

coagulation - random protein-protein interaction of denatured protein molecules which does not lead to an ordered structural assembly of the final aggregate (Acton and Dick, 1984).

Binding The binding among pieces of meat during cooking is a heat-induced phenomenon which involves protein-protein interactions, since raw meat pieces do not exhibit rigid binding to any significant extent (Asghar et al., 1985). However, final product binding properties depend on protein solubilization and extraction in the raw product. Several researchers have tried to explain the mechanism of binding meat pieces as a structural rearrangement of soluble proteins.
This rearrangement of solubilized meat proteins makes them more reactive for essential protein binding during heat treatment (Vadehra and Baker, 1970; Kotter and Fischer, 1975). Kotter and Fischer (1975) also postulated that a loosely ordered protein structure is built from previously dissolved protein.

This ordered structure has been examined at the binding junctions of processed meat products. Theno et al. (1978) illustrated the presence of aligned elements in the binding junction of sectioned and formed ham. Siegel and Schmidt (1979b) examined the ultrastructure of a crude myosin gel as affected by salt, phosphate, pH and temperature to determine the mechanism of binding of meat pieces. They concluded that the mechanism of binding between meat pieces involves the interaction of super-thick filaments, formed by intact heavy chains of extracted myosin and the heavy chain cores of myosin found within myofibers on or near the surface of meat pieces. Super-thick filament formation is possible at higher heating temperatures because heavy chains are freed from the parent molecule due to their salt solubility at lower heating temperatures (Siegel and Schmidt, 1979b).

Using model systems of purified muscle proteins, several researchers (Fukazawa et al., 1961a, b, c; Samejima et al., 1969; Nakayam and Sato, 1971a, b, c) have shown that myosin and actomyosin are the most essential of the myofibrillar proteins in developing binding properties. Macfarlane et al. (1977) studied the
binding properties of purified muscle proteins in relation to the binding of meat pieces. They found that the binding strength of myosin was superior to actomyosin at salt concentrations to 1 M. However, increased myosin concentration is not directly related to increased binding strength (Macfarlane et al., 1977; Siegel and Schmidt, 1979a; Booren et al., 1982). Siegel and Schmidt (1979a) reported that these results implicated the possibility of interactions in binding.

Macfarlane et al. (1977) reported that, without salt, the binding ability of myosin is enhanced by the addition of sarcoplasmic proteins. The ionic contributions of sarcoplasmic proteins added to myosin improved its binding power in a manner similar to salt. However, at increased salt concentrations, sarcoplasmic proteins exerted an unfavorable effect on the binding ability of myosin. They (Macfarlane et al., 1977) attributed this effect on the absorption of denatured sarcoplasmic proteins onto myofibrillar protein molecules, decreasing the available binding sites.

Thus, it seems that the mechanism involved in the binding of meat pieces is a complex one. The protein-protein interactions are a heat-induced phenomenon influenced by salt, ionic strength, protein type and protein quantity.
Gelation   As proteins are heated, they change from their native state, through denaturation, to a gelled state. It has become widely accepted that the gelation of muscle proteins is largely responsible for the physical and chemical stabilization of fat and water in comminuted red meat and poultry products and for binding between meat pieces in section and formed products. The characteristic texture of various processed meat products may also be a function of the properties of the protein matrix and its specific interactions with the continuous, aqueous phase and dispersed fat (Ziegler and Acton, 1984b). This network of protein fibers provides the structural rigidity found in manufactured meat products (Schmidt et al., 1981).

Gelation is the heat-induced formation of a three-dimensional protein matrix by myosin and actomyosin intermolecular interactions (Acton and Dick, 1984). The mechanism of gel formation is a complex one and is being further defined with current research. The mechanism may differ among proteins, most probably because of the type of molecular interactions that stabilize the gels of different protein systems (Schmidt et al., 1981). These interactions may consist of multiple hydrogen bonds (Boedtken and Doty, 1954; Eldridge and Ferry, 1954), sulfhydryl-disulfide linkages (Huggins et al., 1951), peptide bonds (Bello and Vinograd, 1958; Bello, 1965) or possibly electrostatic and hydrophobic interactions (Catsimpoolas and Meyer, 1970; Liu et al., 1982).
The general consensus for this interaction is that polypeptide chains crosslink to form five or six major binding regions per molecule during gelation (Asghar et al., 1985). Critical parameters important to the type of gel formed include temperature, pH, salt level and protein concentrations. These parameters change the degree of crosslinking by changing the quaternary structure of the protein or the charge distribution on the polymer molecules (Paul and Palmer, 1972). Paul and Palmer (1972) further stated that it is the flexibility of these polymeric molecules and the number of connections between them which determines the elastic-plastic nature of the gel structure. Asghar et al. (1985) suggested that salt bonds between amino and carboxyl groups of the side chains provide the main crosslinks without involving water dipoles. They further postulated that perhaps imide and carboxyl groups are involved in hydrogen bonding. Although formation of some disulfide bonds have also been suggested (Hamm and Hofmann, 1965), the existence of covalent bonds, which melt readily on heating, seems unlikely (Asghar et al. 1985).

**Heat induced gelation** For muscle proteins during processing, thermal energy is the single, essential driving force in protein transition from the native state to the denatured state (Acton and Dick, 1984). For myosin and the actomyosin complex, this transition is a continuous process of native protein structural changes involving secondary, tertiary and/or quaternary structure. Hydrogen
bonding, hydrophobic interactions and electrostatic linkages are changed during transition to the denatured state (Fennema, 1976).

Thermal energy input into a protein system is supplied to drive the denatured reaction at a given rate through a particular path of bond breaking and possible changed bond reformation in the new structure (Acton and Dick, 1984). This results in definite conformational changes present in the denatured protein state. While electrostatic and hydrogen bonding increases with conformational change, there is a greater tendency for more interchain hydrophobic interaction to occur (Acton and Dick, 1984).

The changes involved in heat-induced gelation divide themselves into three temperature ranges: below 30°C, 30° to 50°C, and over 50°C. Obviously, the temperature range is a continuum with changes occurring in each range that ultimately affect upon changes with other ranges and final gelation properties.

**Temperatures below 30°C** By mechanical shearing of intact muscle cells, addition of water and salt, and through means of dispersive actions, a suspension of macroparticles exists in a continuous, aqueous phase (Acton and Dick, 1984). The term "sol" can be applied to the aqueous phase of macromolecular, hydrated, myofibrillar protein. A sol-to-gel transformation occurs in ground meat tissue by continuous energy input (temperature) during heat processing (Acton and Dick, 1984). The sol transformation of
myofibrillar proteins to the gelled state results in formation of the ultimate three-dimensional interlinked protein network (Acton and Dick, 1984). This protein network physically (because of capillarity) and chemically (because of noncovalent bonding) stabilizes water and physically or structurally restrains dispersed fat (Acton and Dick, 1984).

Work by Burgarella et al. (1985) showed that the gelation of minced fish sols were characterized by three distinct thermal transitions. They thought that these transitions probably related to the onset of paste thickening because of protein-protein interactions at 10-15°C; "setting" of the paste into the translucent cohesive gel near 40°C; and thermal gelation of the proteins into a firm opaque gel at temperatures above 50°C.

The "setting" of fish muscle proteins at temperatures below that at which rapid aggregation occurs (about 40°C) may be viewed as a process where partly denatured proteins begin to interact noncovalently to form a fine elastic network. Setting below 40°C, before heating to 60°-80°C, allows slow "ordering" of the protein molecules and results in the formation of gels with greater firmness and cohesiveness (Lanier et al., 1982). Acton et al. (1981) stated that it is generally recognized that in prolonged, refrigerated storage of myosin and actomyosin, filamentous particles are gradually formed at temperatures as low as 0°C.
Lee and Toledo (1976) theorized that gel-setting behavior of fish surimi was temperature dependent. At a fast heating rate, a tight cohesive network with a small number of large aggregates was formed. The cohesiveness and integrity of the gel network were inversely correlated with the amount of expressible fluid: the greater the cohesiveness of the gel network, the less expressible fluid it released upon compression. This seems to support the suggestion of Hermansson (1978) that the denaturation of proteins before aggregation results in a finer gel structure, exhibiting greater elasticity than if random aggregation occurs simultaneously or before denaturation.

Lanier et al. (1982) stated that the phenomenon of setting in surimi probably proceeds at very low temperatures and may be synonymous with the protein-protein interactions which lead to loss of product functionality during frozen storage. They examined the development of textural strength resulting from low temperature setting of chopped surimi batters containing 2% salt (NaCl) over several hours. The textural development was most apparent at 20° and 30°C, while barely detectable at 0° and 10°C. The protein molecules evidently began to form a gel network even at temperatures as low as 0°C during a few hours, which may become texturally evident only upon coagulation of the protein at higher temperatures.

Although the effects of low temperatures on fish gels lead to definite ultrastructural changes, these effects or changes are not as
evident in studies with mammalian species. Several researchers have reported that the change in gelation strength for myosin solutions below 30°C is very small (Samejima et al., 1969; Ishioroshi et al., 1979, 1982; Yasui et al., 1979). Davey and Gilbert (1974) reported that extractability of myosin from myofibrils remained at a maximum (48% of the myofibrillar protein) with increasing temperatures to 30°C.

**Temperatures between 30° to 50°C** Several studies have shown at least two conformation transitions in myosin molecules or filaments exist during heating, one at 43-47°C and the other at 53-55°C (Samejima et al., 1969, 1976; Ishioroshi et al., 1979). The first transition temperature is thought to represent the aggregation of heavy meromyosin (HMM) S-1 heads of myosin (Yasui et al., 1968). This transition is possibly due to the alpha-helix to random coil transformation accompanied with the destruction of hydrogen bonds (Samejima et al., 1976). The helix-coil transition of light meromyosin (LMM) occurs about 30°C and is complete at 50°C (Yasui et al., 1973) with a marked decrease in solubility at 60°C (Samejima and Yasui, 1975). The transition occurring at 55°C is possibly the most critical because this is the temperature that myosin gels attain maximum bind (Yasui et al., 1982). This transition at 55°C is highly pH dependent and may be due to electrostatic forces (Samejima et al., 1976).

However, Wright et al. (1977) used differential scanning calorimetry and showed there were three distinct molecular regions of
myosin which accounted for its differing thermal stabilities. Samejima et al. (1983) stated that a major transition was at 52.5°C and two minor transitions were at 46 and 57°C. The major transition corresponded to the aggregation of HMM S-1 (15°C) and HMM S-2 (53°C) fragments of myosin. The major transitions at 46 and 57°C were shown to represent the changes from helix to coil in the myosin tail portion (i.e., LMM). Schmidt et al. (1981) attributed the differences in the number of transition temperatures to the differing levels of organization of the myosin molecules in the different samples.

Samejima and Wolfe (1976) suggested that heat-denaturation of the myosin rod results in local, irreversible, conformational changes involving aromatic amino acid residues. The aromatic amino acid residues (especially tryptophan) are exposed to the polar environment during heating and do not return to their original hydrophobic position upon cooling (Samejima et al., 1976, 1981; Asghar et al., 1985).

Acton and Dick (1984) stated that the stage between 30 and 50°C involves aggregation of the globular head regions of the molecule. This is an irreversible reaction; assuming, heating will be continuous with continuous temperature elevation of the system. Through studies with the HMM S-1 fraction, intact HMM segment and myosin, the aggregation is believed to be dependent on oxidation of sulfhydryl groups predominantly found in the globular head region (Samejima et al., 1981; Ishioroshi et al., 1982). Ishioroshi et al. (1980) reported that if a myosin molecule is treated to block sulfhydryls, an appreciable
reduction in the heat induced interaction of myosin was noted (as measured gel rigidity). This supports the role of sulfhydryl group involvement in head-to-head aggregation as one factor in protein-protein interactions. Liu et al. (1982) concluded, on the basis of ease of solubilization, that hydrophobic interactions were the predominant force in actomyosin aggregation of fish proteins below 50°C.

**Temperatures above 50°C** Yasui et al. (1979) summarized heat-induced gelation as: 1) the heat-induced gelation of myosin starts from 30°C and reaches a maximum at 60-70°C; 2) thermal transition from the "sol" to "gel" state is the reflection of structural unfolding of the proteins; 3) the network structure exists in the gels formed, though their morphological features differ depending on conditions of gelation; and 4) the water mobility in the gel is somehow restricted as compared to that in a solution.

Acton and Dick (1984) associated temperatures above 50°C with a structural change of the helical rod segment of myosin that culminates in network formation through cross linking between these segments. From gel rigidity data (Ishioroshi et al., 1982), LMM shows only a single transition at about 53°C. Ishioroshi et al. (1982) and Samejima et al. (1981) assumed at 55°C the myosin rod segment unfolds after head to head interactions occur during gelation at lower temperatures.
While the globular head interaction predominates in the 30 to 50°C range, there is also apparent early disruption of the alpha helix at the hinge region in moving from the coiled coil to a random coil type structure in the same lower temperature region (Acton and Dick, 1984). Further helical disruption of the tail portion requires a higher energy input, thus, these helical changes predominate in the later stage at temperatures above 50°C.

The coiled-coil to random-coil conformational change in the tail region is extremely important to aggregation occurring above 50°C temperature range (Acton and Dick, 1984). The exposure of hydrophobic residues, as detected in several studies (Shimada and Matsushita, 1981; Samejima et al., 1981; Ishioroshi et al., 1982) facilitates hydrophobic interactions and thus increases the potential for tail-to-tail crosslinking for creation of the gel framework. However, Foegeding et al. (1983) reported that myosin gels heated to 70°C were stabilized by noncovalent and disulfide bonds.

Factors affecting heat-induced gelation

Protein concentration Camou (1989) studied thermally induced gels made from salt extracted salt-soluble pork muscle proteins and found that the compression force increased with increased protein concentration. Yasui et al. (1982) plotted change in gel strength versus change in protein concentration. They suggested that heat-induced gel strength of myosin increases proportionally with
the square of protein concentration, irrespective of the ionic environment and whether or not actin is present in the system. Ishioroshi et al. (1979) also reported that shear modulus measurement of myosin gels increased proportionally to the 1.8 power of myosin concentration.

Ionic strength   Ishioroshi et al. (1979) evaluated the strength of pH 6.0 myosin gels formed by heating at 65°C with varying ionic strengths of 0.1 to 0.6 M KCl. The highest shear modulus of the gel was between 0.1-0.4 M KCl. At 0.4 M KCl, the gel strength reached a minimum and remained constant until an increased ionic strength of 0.6 M KCl was reached. Ishioroshi et al. (1979) explained these results by myosin aggregation: at low ionic strength the myosin molecules assemble into filaments and upon heating, these filaments form three-dimensional structures; at high ionic strength, myosin molecules exist as monomers which, upon heating, produce head-to-head aggregates. Hermansson et al. (1986) studied the transition phases of myosin gels with different salt concentrations. At high salt concentration (0.6M KCl) three transition phases were observed (46°, 52.5° and 57°C), while at low salt concentration (0.1M KCl) only two transition phases were observed (54° and 59°C). They described the ultrastructure of myosin gels as affected by salt treatment and reported that the the microscopic structure of the lower salt concentration treatment (0.1M KCl) appeared as fine networks of
strands, and the higher salt concentration (0.6M KCl) appeared as more aggregated structures.

**pH** Gelation properties of the myosin network is pH dependent (Yasui et al., 1979). The optimal pH for the development of maximum rigidity for myosin and actomyosin gels is between pH 5.0 and 6.3 (Trautman, 1966; Ishioroshi et al., 1979; Yasui et al., 1979; Acton et al., 1981).

Several researchers have reported different optimal pHs for gel strength. The pH at which a gel is formed has definite effects on the ultrastructure of the gel. Ishioroshi et al. (1979) examined myosin gel strength in the pH range of 5 to 8 and found that myosin solutions of pH 6.0 exhibited much greater gel strength than those at other pH values. Acton et al. (1981) measured the extrusion force of natural actomyosin gels at various pH values ranging from 4.0 to 7.5 and determined that optimal gel strength was developed at pH 5.0. Siegel and Schmidt (1979b) found no significant differences in the binding ability of myosin in the pH range of 6 to 8. These differences in optimal pH might be explained by different experimental conditions.

The ultrastructure of actomyosin gels, compared to myosin gels, is one of thinner filamentous strands with larger pore size distribution and a different cross-linked appearance (Yasui et al., 1982). Gels produced at pH values below 5.0 were described by Acton et al. (1981) as particulate, while those at pH 6.0 and above were uniform and
opaque. Yasui et al. (1979) observed that gels formed at pH 6.0 had a lacy network while those made at pH 7.0 had a sponge-like network with relatively large holes. Ishioroshi et al. (1979) described gels produced at a high pH as translucent while those formed at low pH exhibited the symptoms of syneresis or loss of fluid. Acton et al. (1981) described gels formed at pH values of 5.0 and 5.5 as spongy with obvious syneresis. Zeigler and Acton (1984b) reported that syneresis may occur during the storage of a gel as a result of the formation of additional intermolecular bonds. They postulated that this decreases the number of sites available for binding water and reduces the amount of intermolecular space available to immobilize water through capillary forces. Hermansson et al. (1986) found that the strand-like myosin gelation was observed to be spontaneous at pH 4.0 (with 0.6M KCl at 4°C), even before heat treatment was applied.

**Protein-Water Interactions**

The interactions between proteins and water in processed meat products have been widely studied and reviewed (Hamm, 1960, 1975; Schut, 1976; Hermansson and Akesson, 1975; Hermansson, 1979; Schen, 1981; Offer and Trinick, 1983, 1989; Regenstein, 1984). The water-binding ability or water-holding capacity (WHC) has definite effects on final product characteristics. An understanding of the states and properties of water in muscle tissue is important before discussion protein-water relationships.
Properties of water in muscle tissue  

Fennema (1976) stated that water is the major component present in most food systems, being bound or entrapped by different bond types or physical phenomena. He also presented a widely accepted classification description of water in food systems. "Type I" water is very tightly bound and is called "bound water." This type of water is the mono- and possibly the bimolecular layers of water surrounding the proteins and other substances which have an affinity for water due to electrostatic charges. Type I water has very little mobility, is found in small quantities (4.5% of total water) and is unfreezable. "Type II" water (or restricted water) refers to the multilayers of water surrounding the bound water. It can be removed by dehydration and can be frozen. "Type III" (or free water) represents most water in animal and plant tissues, and is relatively easily removed. "Type IV" (or water in the pure state) does not naturally occur in biological matter.

Since bound water (Type I) cannot be removed by processing methods and Type IV water is water in the pure state, the states of water of concern are restricted water (Type II) and free water (Type III). Acton et al. (1983) stated that restricted water, being less ordered molecularly with protein structure than bound water, can be changed in quantity. Thus, the goal of meat processing systems are to
reduce the amount of water in the free state and increase the amount in the restricted state to produce a stable product.

Mechanisms of protein-water interactions  Hamm (1960) defined WHC as the ability of meat to hold its own or added water during application of any force (pressing, heating, grinding, etc.). Swelling or water-binding ability was described as the spontaneous uptake by meat of water from any surrounding fluid, resulting in an increase in weight of muscle. Offer and Trinick (1983) explored the swelling of muscle fibers and redefined the WHC as the fraction of total water which is located between the filaments in myofibrils. This quantity could be expressed as volume of myofibrillar water per unit mass of myofibrillar protein.

Hamm (1960, 1975) suggested that the forces which immobilize water in muscle tissue are not clearly understood. A variety of mechanisms for protein hydration or protein-water interactions have been hypothesized. Wierbicki and Deatherage (1958) stated that the highly polar water molecules are attracted to the muscle proteins by ionizable basic and acidic amino acids like arginine, histidine, lysine, glutamic acid and aspartic acid or by polar, nonionic amino acids such as cystine, cysteine, serine, methionine, threonine, tyrosine and tryptophan.

Hamm (1975) described the swelling of muscle fibers in terms of colloidal chemistry. He stated that the amount of water immobilized
within the tissue is influenced by the spatial molecular arrangement of the myofibrillar proteins, or filaments, of myosin and actin. By decreasing the cohesion between adjacent molecules or filaments (just as it is caused by increasing the electrostatic repulsion between similarly charged groups or by weakening of hydrogen bonds) the network is enlarged, the swelling increases and more water can be immobilized within the larger spaces. As intermolecular cohesion decreases, the network collapses and the gel becomes a colloid solution of the myofibrillar proteins. Conversely, by increasing the attraction between adjacent molecules (as when the electrostatic attraction between oppositely charged groups increases or by interlinking bonds) less space is available for the retention of water. Offer and Trinick (1983), in their discussion of the mechanism of water holding in meat, stated that Hamm's model lacks complete explanation for two major reasons: it does not consider that 1) only a part of the myofibril (the A-band) is solubilized, and 2) the highly ordered structure of myofibrils.

Offer and Trinick (1983) proposed a more thorough explanation of the swelling of myofibrils. In their hypothesis, they assumed, as Hamm (1960) did that as chloride concentration is raised, chloride ions are bound to the proteins, increasing the repulsive force between filaments and tending to cause expansion of the matrix. However, they stated that transverse linkages, particularly attached cross-bridges, strongly restrain this expansion. The influence of the cross-bridges
could be removed in one of two ways: 1) if the cross-bridges become detached from the filaments, or 2) if the thick filament backbone was disrupted; mechanical continuity would also be disrupted. Offer and Trinick (1983) further indicated that the addition of increasing concentrations of sodium chloride and/or pyrophosphate have been shown to 1) displace the equilibrium between the myosin filament and myosin molecules in favor of myosin molecules and 2) directly decrease the strength of binding myosin heads to actin. This would remove the influence of the cross-bridges and thus increase WHC.

Offer et al. (1989) had recently proposed a new hypothesis concerning salt-induced swelling of muscle tissue. They proposed that this swelling was a result of entropy rather than from electrostatic repulsion. When the protein matrix swells, the myosin tails had a greater freedom of motion and thus, they explained, had a higher entropy.

The mechanisms of protein-water interactions are complex, involving chemical bonding, repulsion and attraction forces as well as the structural or molecular arrangement. These protein-water interactions determine the WHC of the meat system.

Influences on protein-water interactions

Acton et al. (1983) stated that WHC is influenced by 1) the ionization and charge density of the protein, which can be increased through salt addition and through increased tissue pH, 2) the extent of physical disruption of
tissue, which allows protein extraction and/or exposure to a higher ionic strength environment which creates more proteinaceous surface and capillary pore areas, and 3) by the distance of water from the protein surface. The factors which influence protein-water interactions are many, but most function in any of these three ways. The major factors are categorized by the effects of pH, chloride ions, phosphates, comminution, freezing and added water.

**pH** The major factor influencing protein-water interactions is pH. Most influences on protein-water interaction can be explained in terms of shifts in pH. Hamm (1960) explained the influence of pH on WHC by changes in the net charge of proteins. An increase of net protein charge will lead to increased repulsion of the peptide chains, and so an increase in meat hydration. But, an increase of electrostatic and hydrogen bonds between the peptide chains will tighten the protein network and therefore decrease meat hydration. Hamm (1975) stated that at the isoelectric point of actomyosin, water hydration is at a minimum, as maximum intermolecular salt linkages between positively and negatively charged groups occur at this pH.

**Chloride anions** The addition of sodium chloride (NaCl) lowers the isoelectric point of the myofibrillar proteins which, therefore, creates a larger net negative charge at the existing pH. This change in net charge at the existing pH is the result of the ionizable
carboxyl groups of the proteins which bind the negatively charged Cl\(^-\) ions (Hamm, 1960). Repulsion between these negatively charged groups make the protein open up its spatial arrangement and increases hydration (Hamm, 1960). Schut (1976) stated that hydrated chloride ions are strongly attracted to the positively charged groups of the proteins, thus breaking the inter- and intra-protein salt bridges. Kinsella (1976) also reported that above the isoelectric point, associated chloride ions increase the net negative charge on the polypeptides, which enhance mutual repulsion between polypeptides, and thereby facilitate retention of water by the protein network.

Offer and Trinick (1983), with their theory on muscle fiber swelling, stated that the addition of NaCl causes a depolymerization of myosin filaments (removal of cross-bridges, the M-line or Z-lines) and weakens the binding of actin and myosin. This causes increased interfilament spacing and thus increased water uptake or swelling. Generally, increases in NaCl concentrations lead to increases in WHC with a maximum occurring between 0.8 and 1.0 M NaCl (Hamm, 1960; Offer and Trinick, 1983). The typical salt concentration in processed meat systems (2.5-3.0% salt, 60% moisture) is about 0.7-0.8 M (Acton et al., 1983).

**Phosphates** The addition of polyphosphates has been shown to increase WHC by a) increasing pH, b) increasing ionic strength, c) chelating divalent metal ions, d) binding meat proteins and
e) dissociating actomyosin (Hamm, 1960). The small pH increase produced by phosphates is only expected to produce small increases in water-binding capacity (Hamm, 1960; Hellendoorn, 1962). However, Trout and Schmidt (1983) reported that pH changes are different for different products and relatively small changes in pH in raw materials have a pronounced effect on the final water-binding capacity.

Increasing the ionic strength of a meat system increases the WHC (Hellendoorn, 1962). The incorporation of phosphates into a meat system would increase the ionic strength and thus, WHC.

Hamm (1960) postulated that the ability of polyphosphates to chelate metal ions, particularly divalent cations such as calcium and magnesium ions, increases WHC by preventing the tightening of the molecular network by the calcium and magnesium ions. However, this theory has been refuted by Inklaar (1967), who demonstrated that polyphosphates did not reduce the amount of protein bound calcium or magnesium ions and Hellendoorn (1962) who showed that the addition of chelating agents did not increase WHC.

The binding of phosphate anions to meat proteins increases the net negative charge of the proteins, which in turn leads to greater protein-protein repulsion and so, increases WHC (Hamm, 1970). Bendall (1954) suggested that pyrophosphate in the presence of Mg$^{2+}$ is a weak dissociation agent of the actomyosin complex. This would increase water swelling as in the theory of Offer and Trinick (1983). A
more in-depth review of phosphate affects in meat systems is given in Section III of the Literature Review.

**Comminution** The increase in WHC of muscle tissue by comminution is primarily the result of increased protein surface area. The comminution or grinding of meat tissue must be efficient enough to disrupt membranes and sarcolemma to free myofibrils and myofilaments and to bring the myofibrillar fraction to a high degree of swelling (Schut, 1976). Hamm (1960) stated that grinding loosens the protein structure by increasing the electrostatic repulsion of the peptide chains and therefore increases the WHC. This disruption by comminution would mechanically disrupt the thick filaments and thus increase WHC as in the swelling theory of Offer and Trinick (1983). This is supported by Hamm (1960) who stated that the more intensive the grinding, the higher the WHC of the meat tissue.

Wilding et al. (1986) and Offer et al. (1989) noted that when the endomysial sheath surrounding a muscle fiber was damaged, much more swelling took place. They concluded that the endomysium acts as a mechanical restraint to swelling.

**Freezing** Many researchers have observed a decrease in WHC when meat is frozen (Criggler and Dawson, 1968; Morrison et al., 1971; Gillett et al., 1977; Puolanne and Turkki, 1985). Protein denaturation and membrane disruption, because of ice crystal
formation, are reasons for this decrease. Frozen storage may also increase proteolysis and decrease pH charge which would have detrimental effects on WHC (Hamm, 1960). Dehydration of meat during freezing by sublimation of ice also reduces WHC. The membrane disruption due to freezing should increase water swelling according to Offer and Trinick's theory (1983). However, if protein denaturation also occurs, decreases in myofibrillar swelling would be expected.

Added water The influence of added water on the WHC of meat is pH dependent. Added water may lower the ionic strength by diluting the negatively charged ions of muscle proteins (Hamm, 1960). On the acidic side of the isoelectric point, increased hydration occurs because of a "screening" effect of the ions, which increases the positive net charge, increasing repulsion of peptide chains (Hamm, 1960).

Protein-Lipid Interactions

Finely comminuted meat batters have been defined as either emulsions or protein matrices, but little agreement exists regarding the most proper definition. To more fully understand the mechanisms of protein-lipid interactions, both concepts will be reviewed.
**Emulsions**  Friberg (1971) defined an emulsion as a mixture of two immiscible liquids, one of them being dispersed into the other as liquid droplets and/or liquid crystals. Hansen (1960) showed with micrographs of dilute protein slurries that a true emulsion did form. He concluded that finely comminuted meat systems were true emulsions.

Schut (1976) defined a meat emulsion as a two-phase system, consisting of a solid dispersed in a liquid in which the solid (fat) is immiscible. The liquid (external or continuous phase) is an aqueous solution of salts and proteins, and is a medium in which insoluble proteins and particles of muscle fibers and connective tissue are dispersed. Saffle (1968) stated that the dispersion must be made with a given amount of shear force and an emulsifying agent (salt-soluble proteins) is required to give stability.

**Interfacial protein film**  The role of actual protein-lipid interactions in comminuted meat systems are related to the biophysical properties of the proteinaceous membranes surrounding lipid particles (Jones, 1984). The presence of an interfacial protein membrane of film surrounding lipid droplets in finely comminuted meat products and "emulsified" meat model systems have been well documented in the literature (Hansen, 1960; Borchert et al., 1967; Saffle, 1968; Theno and Schmidt, 1978; Jones and Mandigo, 1982).
However, very little literature is available regarding the mechanisms of membrane formation around lipid particles in comminuted meat systems. The emulsifying proteins in classical two-phase water-in-oil emulsions are known to unfold (denature) and orient hydrophobic and hydrophilic regions of the proteins at the oil/water interface to gain a more stable enthalpy (Tachibana and Inokuchi, 1953).

The role of a protein film as a stabilizer between the two phases in a meat emulsion is a very complex one whose stabilizing effect is dependent on the elasticity, viscosity, surface potential and surface concentration of the film. These parameters (viscosity, elasticity, surface potential, surface concentration) are in turn dependent on a wide variety of physical characteristics such as temperature, pH, isoelectric point of the proteins, mechanical stresses and other factors (Schut, 1976). Ivey et al. (1970) found that the stability of emulsions made from dilute protein extracts was dependent on the interfacial film thickness to droplet size ratio and on the droplet size or relative area of the dispersion phase.

Ivey et al. (1970) suggested that oil is emulsified until the continuous phase is spread too thin to prevent the agglomeration of the oil. Their results showed that increasing the meat protein content formed a thicker layer around the fat droplets, thus using more continuous phase per droplet and reducing the total amount of oil that could be emulsified. They explained this phenomenon by the denaturation principle whereby the molecular orientation of the
protein at the surface of the oil droplet becomes denatured when sufficient oil dilution is made to increase emulsion capacity. As the emulsifying agent decreases in concentration within the interfacial protein film, a greater degree of unfolding of the protein helix occurs which allows a greater amount of molecular orientation to take place.

The mechanical strength of an interfacial protein film and its resistance against external forces has long been known to determine the stability of the classical two-phase emulsion (Tachibana and Inokuchi, 1953). Meat proteins are excellent emulsifiers, by lowering the interfacial tension and being strongly absorbed in the fat-water interface (Swift et al., 1961; Borchert et al., 1967; and Schut, 1976). To gain a more stable molecular arrangement at a lower free energy level, protein molecules orient themselves at the interface between the two immiscible phases (fat and water). This orientation occurs such that a multimolecular membrane is formed, and hydrophobic side chains of protein molecules are attracted to the lipid phase and hydrophilic side chains are attracted to the aqueous phase.

**Protein matrices** The stability of a meat emulsion, unlike a true emulsion, cannot be determined by a single factor or even several factors, but is dependent on the interaction of a large number of components in the system at the molecular level. Simultaneous with the formation of the protein membrane that encapsulates fat particles,
a complex, gel-like matrix network of proteins, water and extraneous material is formed (Jones, 1984).

Brown (1972) reviewed the true emulsion and meat emulsion literature and concluded that sausage batters were not true emulsions but were instead a water-protein matrix. Brown presented the matrix theory as a structural concept; the stability of finely comminuted sausage batters arises from the development of a chemical bond between protein and water. The capacity to bind fat is related to the strength of the matrix. As the matrix is stressed by heat or mechanical action, it looses stability, the amount lost depending on the amount of stress. When the matrix is weakened or ruptured, increasing amounts of fat are released from physical entrapment by the protein-water matrix.

Lee (1985) examined the microstructure of meat emulsions in relation to true emulsion and protein matrix theories and concluded that both true emulsion and protein matrix principles should be considered in explaining fat stabilization in meat emulsions. However, from photomicrographic evidence and physical analyses, the protein matrix theory should receive more consideration because of the greater role of the physical properties of the matrix and fat in fat stabilization than the role of the interfacial film. Swasdee et al. (1982) examined the ultrastructure of frankfurter batters during chopping and cooking. They concluded that frankfurters prepared by conventional chopping methods are a heterogeneous, multiphase
system in which not all lipid droplets are uniformly surrounded by a protein-salt-water interface or matrix. Lee et al. (1981) suggested that the protein matrix, rather than the interfacial film, keeps the fat from coalescing by restraining fat mobilization and coalescence once localization of fat is completed.

**Protein hydrophobicity** Protein-lipid interactions primarily involve orientation of hydrophobic portions of proteins to facilitate combination with lipid droplets. Davis et al. (1973) examined protein hydrophobicity and the protein-lipid interaction by monolayer penetration experiments and density gradient analysis. They concluded that while high protein hydrophobicity and surface activity guaranteed the interaction of lipid and protein when measured at the air-water interface, it does not follow that interaction will occur at the protein-lipid interface. In the latter situation, there are more specific requirements for the protein which may involve a precursor of helix formation.

Protein denaturation may not be necessary for solubilized myosin to act as an emulsifying agent during the early phases of interfacial protein film formation. The hydrophobic portions of contractile proteins largely determine their ability to form an interfacial membrane between two immiscible components (fat and water). Although many hydrophobic residues are buried in the interior of native proteins, some hydrophobic groups remain exposed at the
molecular surface or in crevices, as in the myosin region. Free myosin is a unique protein since its surface hydrophobic properties are primarily confined to the head region or the HMM S-1 subfragment (Borejdo, 1983). Borejdo (1983) used cis-parinaric acid, a fluorescent marker, to identify hydrophobic sites on the myosin molecule.

Several authors (Kato et al., 1983; Townsend and Nakai, 1983; and Voutsinas et al., 1983) have shown hydrophobicity to be significantly correlated to many other functional properties (foaming, thickening, coagulation, emulsifying). Kato et al. (1984) reported proportional readings between surface hydrophobicity and a sodium dodecyl sulfate binding method. Li-Chan et al. (1984) postulated that protein solubility and surface hydrophobicity could be used to predict the functional properties of raw materials for use in meat products. However, they said further refinement and research must be done on these methods before industrial application is possible.

Factors influencing emulsion stability The major factor contributing to the stability of meat emulsions seems to be the condition of the external phase or the stability of the protein matrix (Schut, 1976). Schut (1976) stated that the stability of the matrix is determined largely by the rate of hydration of the meat proteins while phenomena, such as Van der Waal's attractive forces, Coulomb's repelling forces, bulk diffusion, surface charge of the dispersed particles and others which appear to have great significance for other
types of emulsions, are unimportant to meat emulsions. Hegarty et al. (1963) stated that the amount of protein denatured at the protein-lipid interface was directly related to the stability of the resulting emulsion.

**Temperature** Helmer and Saffle (1963) chopped frankfurter batters to 15.5, 21, 26.5 and 32°C to determine if protein denaturation played a role in product stability. They concluded that product breakdown or instability was not due to denaturation of the proteins. They speculated that product breakdown was due to continued chopping which increased fat globule surface area and permitted fat globule coalescence in the product.

Carpenter and Saffle (1965) postulated that greater shear force (greater rpm) dispersed oil into smaller droplets, leading to an increased oil surface area to be emulsified and hence limited the quantity of protein available for emulsification. Ackerman et al. (1971) found that the amount of lipid (beef or pork fat) particles, 5 μm or less, increased in frankfurters with increased comminution, but degree of dispersion did not relate directly to emulsion stability. Frankfurters that were unstable contained a greater number of large lipid particles (200μm or greater). Emulsion breakdown at high chopping temperature was believed to be a result of the increased mobility of fat after softening (Lee et al., 1981). Beyond the softening point, the mobility of fat overcomes the ability of the protein matrix to maintain uniform fat
distribution. Webb et al. (1975) studied chopping temperature and postulated that the effect of temperature may not be as significant if mechanical action is prolonged or excessive. However, they felt that a greater degree of protein denaturation would occur with prolonged or excessive mechanical agitation and thereby reduce the emulsification of fats.

The fat binding capacities of proteins have been shown to increase with increasing temperature (10-21°C) after which the capacity decreases (Swift et al., 1961; Townsend et al., 1971; Brown and Toledo, 1975; Schut, 1976). Prolonged chopping also reduces fat and water binding despite temperature control (Brown and Toledo, 1975).

Schut (1976) proposed that the gradual rise in temperature strengthens the interaction between the nonpolar groups of the meat proteins. This strengthened interaction would cause the protein network to contract. The unfavorable influence of the rising temperature may be more than met by the preference of the hydrophobic side chains of the protein molecules for the fat, resulting in an increase of both fat and water binding, as long as the temperature does not exceed about 14°C. At higher temperatures, the hydrophobic interaction between the nonpolar protein groups predominates, whereas the mechanical strength of the protein films around the fat particles diminishes. This is reflected in a sharp increase in water and fat losses.
Jones and Mandigo (1982) explored the endpoint chopping temperatures of frankfurter batters using scanning electron microscopy. From their micrographs, they concluded that a thin protein film surrounds fat globules at low processing temperatures. As chopping temperatures increase from 10°C to 28°C, the protein coating becomes thicker. With increasing thickness of the protein coating, the flexibility for thermal expansion of the fat seems to decrease.

**Composition**  
The melting characteristics of meat fats were researched by Townsend et al. (1971). They reported that emulsion instability occurred with the melting of fats when chopped to higher than 18°C. Lee et al. (1981) examined the relationship of the addition of fats and emulsion stability. They stated that the mobility of fat at a particular chopping temperature affected the fat distribution pattern which in turn determined the fat stabilization in the protein matrix. The distribution pattern and the shape and size of the localized fat was affected primarily by the hardness of added fats and by the physical state of fats (which undergo changes during thermal transition because of temperature rise during chopping or emulsifying).

Morrison et al. (1971) concluded that the amount of added water is the most critical factor in maintaining emulsion stability. They attributed this to the enhanced ability of denatured proteins to unfold sufficiently and increase the emulsion stability more in a dilute (added
water) system than in a concentrated (less water) system. Swift and Sulzbacher (1963) showed that emulsifying capacity was reduced 15-30% by a reduction of water content from 25 to 12.5%.
Phosphates

Phosphorous is an integral part of living tissue. It is associated with skeletal tissue, cell membranes, and is necessary for proper function of RNA, and maintenance of neutral pH. Energy needed for muscle contraction is provided through the phosphate bonds of adenosine triphosphate (ATP), adenosine diphosphate (ADP), and creatin phosphate (CP).

Inorganic phosphates contribute to many functions when added to a meat system. The most noted functional properties attributed to phosphates are increased pH, increased ionic strength, ability to chelate divalent metal ions, the ability to bind meat proteins, and the ability to dissociate actomyosin (Hamm, 1960; 1970). Through these chemical effects and reactions with food components and other additives, phosphates influence water binding, solubility of myosin, color, rancidity, texture, coagulation, leavening, emulsification, curing and reduces the concentration of salt needed for water uptake (Hamm, 1970; Halliday, 1978; Shimp, 1983a, b; Steinhauer, 1983; Tompkin, 1983; Lamkey et al., 1986; Offer et al., 1989).

Nomenclature

In an effort to distinguish between various phosphates used in foods, it would be best to have names based on the structure of the phosphate. When most of these phosphates were developed, however, the analytical methods used to identify the structure of the phosphates
could not distinguish between some phosphates with different chain lengths (Bell, 1971). For the most part, accepted nomenclature of the phosphates is not based on the structure but is more often based on the method of production or the manufacturer.

The basic structure of the phosphate molecule is a single phosphorous atom surrounded tetrahedrally by four oxygen atoms. These simple structures are referred to as the orthophosphates. The mono-, di- and tri- prefixes associated with the orthophosphates refers to the charge of the anion (e.g., Na₃PO₄ is trisodium phosphate while AlPO₄ is trialuminum phosphate).

If any of the oxygen atoms surrounding the phosphorous is shared by another phosphate moiety, these are referred to as condensed or polyphosphates. Among the simpler polyphosphates is pyrophosphate which is actually a diphosphate, and tripolyphosphate which is as the name indicates, a triphosphate. The pyro- prefix was chosen originally because heat is used to form the phosphate. Sofos (1986) stated that the most common polyphosphates are tetratetrametaphosphate and hexametaphosphate, while Young et al. (1987) stated that the most widely use polyphosphate is tripolyphosphate.

**Classification by use** A classification of the phosphates can be constructed according to their use (Bell, 1971). These classifications are presented under the assumption that a given phosphate may be incorporated into two or more of these categories.
Acid and pH Buffering Properties. Acid salts of ortho- and pyrophosphates are good sources of acidity.

Sequestration. Polyphosphoric action which complexes with metal ions.

Precipitation Reactions and Insoluble Materials. Polyphosphates form insoluble salts with multiple charged metal ions. One undesirable effect is the formation of struvite in canned tuna; a magnesium-phosphate complex.

Surface Sorption. Polyphosphates become sorbed on the surface of proteins and change the charge at the surface. By increasing the negative charge on the surface, emulsification is enhanced in an aqueous medium.

Polyelectrolyte Behavior. The interaction between the negatively charged phosphate chain and the positively charged sites on the protein molecule causes a masking of the NH$_2$ groups and increased titration of the protein molecule.

Nutritional Supplementation. The added phosphorous in human food is used very little for intrinsic nutritional value because a phosphorous deficiency is not a problem.

Functional Properties of Phosphates

Moisture retention is the most common reason for adding phosphates to meat. A detailed description of the mechanics of enhanced moisture retention by phosphates is given by Trout and Schmidt (1983). The contributing variables that affect WHC are pH, ionic strength, the binding of phosphates to the meat protein, and dissociation of actomyosin (Trout and Schmidt, 1983, 1986).
Water-holding capacity  Muscle pH and ionic strength have the greatest influence on WHC of meat and meat products (Hamm, 1960). Proteins have the capacity to bind water molecules resulting from the charges on their functional groups. When the pH is on either the basic side or the acidic side of the isoelectric point (pI), the proteins maintain their charges. As the pH moves closer to the isoelectric point, the proteins essentially obtain a neutral charge and the bonds with the water molecules will be broken. The pI of the muscle is about 5.4. Certain phosphates can increase the pH to a point above the pI and thereby increase water binding. Small changes in pH have been observed when phosphates are added to meat. Low molecular weight phosphates, such as pyrophosphate (PP) have the greatest effect on raising pH, while hexametaphosphate (HMP) showed little or no effect (Shults et al., 1972). Tripolyphosphate's (TPP) effect on WHC was shown to be greater than its corresponding effect on pH. Adenine triphosphatase (ATPase) activity producing some PP by hydrolyzing TPP was suggested as a possible reason (Shults et al., 1972).

Ionic strength changes will also affect the water-binding capacity of protein. As the ionic strength of the muscle increases, the WHC tends to increase. Phosphate molecules are polymers of phosphorous atoms, and increase meat product functionality by increasing ionic strength and pH (Hamm, 1960; Acton et al., 1981; Trout and Schmidt,
1986). As the depolymerization increases, the ionic strength will also increase.

Cooking loss and juiciness are directly associated with the ability of the muscle to retain water. Increases in sodium tripolyphosphate (STPP) level decreased cooking losses while increasing juiciness in restructured pork and beef (Schwartz and Mandigo, 1976; Lamkey et al., 1986; Trout and Schmidt, 1986), pork sausage patties (Matlock et al., 1984a,b) beef and pork roasts (Smith et al., 1984), chicken (Young et al., 1987), coarse-ground sausages made with pork and/or goat meat (Reddy et al., 1987), and turkey (Patel et al., 1988). Wierbicki et al. (1976) found that increasing the amount of added phosphate (TPP) above 0.3% had no significant influence on meat shrink. Addition of 0.3% TPP to hams cured with 3.0% to 5.0% salt reduced meat shrinkage to 5.0%. Smaller amounts of PP were needed to achieved the same reduction.

Sequestering metal ions is another property of phosphates in a meat system. The effect that sequestering has on WHC of muscle is controversial. Hamm (1960) first suggested that sequestering of calcium and magnesium ions by phosphates is responsible for some increase in WHC. However, phosphates inability to sequester protein-bound calcium or magnesium (Inklaar, 1967) and no increase in the WHC when ethylenediaminetetraacetic acid (EDTA) was added (Hellendoorn, 1962) suggests that sequestering has little effect on WHC.
Protein solubilization

The theory of muscle contraction postulated by Huxley (1965) shows the importance of ATP in the system to prevent crosslinking of the actin and myosin. Huxley (1965) proposed that calcium binds to troponin, a regulatory protein located on the actin filament. Upon binding to this molecule, calcium caused a structural change. Tropomyosin, a protein also located on the actin filament, structurally inhibits the formation of actomyosin. The conformational change taking place in the troponin molecule causes tropomyosin to move so that actomyosin formation can happen. Hydrolysis of the ATP molecule allows the formation of actomyosin and supplies the energy for the "power stroke." The depletion of ATP results in permanent formation of crossbridges. This observation agrees with many researchers that have shown the formation of actomyosin is directly associated with the depletion of ATP.

However, in a processed meat system where binding is critical, superior binding is obtained when there is more actin and myosin present in the exudate (Siegel et al., 1978; Hegarty et al., 1963). Certain polyphosphates have the capacity to dissociate actomyosin (Shimp, 1983b; Sofos, 1986). The extraction process occurs primarily on the meat surface, and phosphates extract greater quantities of actin and myosin than salt (Siegel et al., 1978).

Polyphosphates with low molecular weight (i.e. pyrophosphate and tripolyphosphate) enhance binding characteristics through dissociation of actomyosin. Yasui et al. (1965) showed how the dissociation
principles are similar to ATP. Measurements of viscosity show actomyosin to be more viscous than mixtures of actin and myosin. When ATP is added to actomyosin, a decrease in viscosity is observed, indicating a dissociation. As the ATP is hydrolyzed to ADP, the viscosity increases. The addition of phosphates to actomyosin in the absence of ATP also showed a decrease in the viscosity (Swift and Ellis, 1957; Hargett et al., 1980; Knipe et al., 1985c). An increase in the viscosity after a period of time was not observed as it was when ATP was added, due to the lack of phosphatase in the system. Actomyosin shows greater binding ability than myosin in the presence of salt and phosphate but a lower binding ability without salt and phosphate. This may be indicative of phosphate's ability to dissociate actomyosin, freeing myosin for solublization (Knipe et al., 1985c).

**Salt and phosphate synergism** Both salt and phosphate have been shown to be effective in increasing the amount of water that meat can retain. The increase in WHC caused by PP or TPP is remarkably stronger in the presence of salt (Mahon, 1961; Hellendoorn, 1962). The combined effect on the reduction of meat shrinkage using 0.5% TPP with 1-4% NaCl is twice as great as using NaCl alone (Shults et al., 1972). Smokehouse yields were shown to be higher when concentrations of salt and phosphate were used together than concentrations of each alone (Neer and Mandigo, 1977). Extraction of titin and myosin heavy-chain with NaCl and PP was
reported to be an important event with swelling (Paterson et al., 1988). Increasing salt concentrations destabilized the heat resistance of muscle proteins (especially actin) while PP and TPP increased the thermal stability of myosin (Kijowski and Mast, 1988).

Beef rolls made with either salt or a combination of salt and phosphate showed that the combination of salt and phosphate had higher cook yields and better binding strengths than the salt treated rolls (Pepper and Schmidt, 1975; Moore et al., 1976).

The combination of salt and phosphate improved color and sensory panel scores on sensory properties over the addition of either salt or phosphate in flaked and formed hamburger patties (Huffman et al., 1981).

The use of phosphates has received considerable amount of attention with reduced salt processed meat products. Processed meat products with the sodium chloride reduced or replaced with other chloride salts has resulted in inferior product characteristics (Hand et al., 1982a,b,c; Sofos, 1983a,b; Whiting, 1984a; Frye et al., 1986). However, because of the salt/phosphate synergism, various phosphates have been also studied to enhance low salt products.

Puolanne et al. (1980) stated that the maximum effect of 0.3% Sitonal (a commercial sausage phosphate preparation from Finland) was observed when the salt content was at 2.0%. Whiting (1984b) studied the effects of different phosphates with low salt (1.5% NaCl) frankfurters and found that the addition of 0.25% sodium acid
pyrophosphate reduced water exudate. He also noted that low salt with STPP at a lower pH of 5.5 was nearly equal to that of his higher salt treatment (2.5%) with no STPP nor pH adjustment. The effects of sodium and potassium PP and TPP were studied by Knipe et al. (1985a). They found that Na and K forms of pyrophosphate created more stable emulsions than the tripolyphosphate forms.

Knipe and co-workers also explored the effects of low salt products and phosphates with other nonmeat, emulsion enhancers. Emulsions with added MgCl₂ had decreased emulsion stabilities, though there was an increase in the amount of solublized protein (Knipe et al., 1985b). When adding NaOH, an increase in emulsion stability was noted, however, this increase was not as great as that of NaPP, yet both had a synergistic effect (Knipe et al., 1985c). They also found that all phosphates studied (TPP, PP, APP, and HMP) increased emulsion stability with low salt products, however they had lower Hunter "a" (redness) values (Knipe et al., 1988).

Sofos (1985) reported a 50% reduction in bind when salt was reduced to 1.1%, however, STPP restored the binding and increased the raw product pH by 0.17-0.23 units. With low salt turkey frankfurters, Barbut et al. (1988) stated that phosphates enhanced product stability and firmness, especially when the lowest salt level (1.0%) was used.

The microstructure of reduced salt meat batters that contained HMP, SAPP, or TPP was studies by Barbut (1988). He reported that, under the scanning electron microscopy (SEM), the fat globules of the
1.5% salt treatment was very wrinkled and described them as looking like "flat footballs" while the fat globules of the 2.0-2.5% salt treatment were a full, smooth surface. The addition of phosphates to the lower salt treatment gave fat globules that were more like the higher salt treatments, but with some wrinkles.

This salt/phosphate synergism may be due to an electrostatic and chemical effect on the muscle proteins. Belton et al. (1987b) used radioactive Cl\(^-\) ions to study these effects of salt and phosphate. Their results agreed with the hypotheses of Offer and Trinick (1983), however, their observations led them to conclude that salt alone in meat systems causes swelling (increased inter-protein distance) and no loss of order while STPP caused a disruption of the basic protein structure and a net loss of order.

**Cured meat color**  Meat color is strongly influenced by muscle pH, and since phosphates have an effect on muscle pH, they also have an influence on meat color. In cured meat color, dropping the pH by 0.2 units lead to a doubled rate of cured meat color development (Fox et al., 1967). Conversely, cured meat color development is reduced as the pH is increased (Baker et al., 1970). Therefore, sausages containing alkaline phosphates have less complete cured color development, however, it may be superior to the color of sausages not containing phosphates once color is allowed to develop (Swift and Ellis, 1957). Acid phosphates such as sodium acid
pyrophosphate (SAPP) can be used as a curing accelerator in meat processing to increase the rate of cured meat color formation by reducing the pH (Brotsky and Everson, 1973).

Knipe et al. (1988) found that phosphate type (TPP, TSPP, APP, and HMP) did not influence Hunter "L" values of meat emulsions, however, their no-phosphate control had higher Hunter "a" values than any of the phosphate treatments. They concluded that phosphate treatments with reduced cookout resulted in the greatest reduction in cured color development and that holding comminuted meat batters containing STPP or TSPP up to 60 minutes improved cured color.

No detrimental color effects were observed when phosphates were added to uncured meats such as restructured beef steaks (Lamkey et al., 1986) and ground beef (Molins et al., 1987b).

**Phosphate and rancidity development** Phosphates have been widely researched on their effects of reducing the onset of oxidative rancidity in meat products (Schwartz and Mandigo, 1976; Keeton, 1983; Haymon et al., 1976; Matlock et al., 1984a,b; Smith et al., 1984; Lamkey et al., 1986; Molins et al., 1987a,b). Inhibition of oxidative changes may be through the chelation of pro-oxidant metal ions by phosphates (Sofos, 1986), resulting in improved color and flavor of meat products.
Phosphate and antimicrobial activity  Although phosphates are generally chosen for use in increasing meat functionality for processing, they have also demonstrated antimicrobial activity in meat products. Tompkin (1983) reviewed the antimicrobial affects of different phosphates in different food products. Molins and coworkers found mixed results when measuring the microbial numbers of meat products with phosphates. They found that a 0.4% inorganic phosphate level did not reduce the microbial numbers in ground beef, yet did prevent spoilage during temperature abuse at 24-25°C (Molins et al., 1987a), and that the addition of sodium acid pyrophosphate and sodium orthophosphate monobasic to fresh ground pork resulted in reduced microbial numbers and a 50% longer shelf life (Molins et al., 1987c).

Sofos (1986) summarized the work of several studies concerning the antimicrobial activity of phosphates in processed meats and stated that the mechanism for reduction of microorganisms is not fully known. Factors involved in microbial inhibition by phosphates included the type and concentration of phosphate, product pH, amount of NaCl, presence of other inhibitors (nitrite, ascorbate, sorbate, etc.), type and level of contamination, specific product composition, thermal processing, storage conditions, and other unknown variables.

Fate of phosphates in meat systems  As stated earlier in this section, phosphates are an integral part of living tissue. Because of
this fact, the fate of polyphosphates are defined by the post-mortem biochemical processes of muscle. Also as stated earlier, STPP is the most popular phosphate used in meat processing, but TPP is hydrolyzed to PP by phosphatase enzymes found in muscle (Shults et al., 1972; Offer and Trinick, 1983). It is the PP form of phosphates that has the greatest influence with increased WHC in meat (Yasui et al., 1964).

The hydrolysis of polyphosphates occurs rapidly in post-mortem muscle. In chicken meat homogenates, not containing NaCl, TPP was completely hydrolysed to inorganic phosphate (Pi) in just 90 minutes while PP was completely hydrolyzed to Pi in only 30 minutes (Belton et al., 1987a). However with beef homogenates, not containing salt, Yasui et al. (1964) found that 0.5% TPP was completely hydrolyzed in 8-20 minutes while it took 2-15 hours to completely hydrolyze 0.5% PP. Belton et al. (1987a) discovered that chicken homogenates with 3.0% NaCl resulted in a doubling of the TPP hydrolysis rate while the activity of phosphatase was slowed by a factor of two or more. Similar results were reported with beef homogenates as phosphatase activity increased and phosphatase rates decreased with the addition of salt (Yasui et al., 1964). Freeze/thaw cycles have no effect on the enzymatic activity of these phosphatases (Yasui et al., 1964; Douglass, et al., 1979; Belton et al., 1987a), however, low temperature storage may serve to slow the phosphatase activity of meat, as PP is more stable in beef at 0°C than at 25°C (Sutton, 1973).
Preblending of Sausage Products

Preblending is the sausage processing technique of mixing salt (NaCl), water, and nitrite (NaNO2) to comminuted meat. This meat mixture is then stored for a variable length of time before it is used in making sausage products. After mixing, the product is then stored for a variable length of time before it is used in sausage products (Ockerman and Crespo, 1981). Preblending of sausage materials to reduce variation in sausage product composition had its beginnings in the late 1950s (Terrell, 1974). A few years later, Kielsmeier and Gara (1962) developed a patent which outlined a detailed compositional control process for sausage materials. The patent of Sloan and Ahern (1965) further outlined key steps in the continuous manufacture of small, smoked sausages based upon predetermined composition. The practice of preblending sausage materials has since become a widely accepted industry practice.

There have been many advantages of preblending reported, but the primary advantage is compositional control (Kramlich, et al., 1973; Waldman et al., 1974; Rust, 1977; Shannon, 1978, 1983). Other advantages reported are: use of prerigor meat properties, more efficient use of equipment (Kramlich et al., 1973); control of meat spoilage (Kramlich et al., 1973; Shannon, 1978); more efficient material handling (Waldman et al., 1974); computerized meat cost formulation (Terrell, 1974; Rust, 1977); control of bind and color values, high volume continuous systems, increased profitability in high volume
operations (Rust, 1977); and maximum extraction of salt soluble proteins (Shannon, 1978, 1983).

Floeck (1983) showed that the major disadvantages of preblending were the lack of production flexibility in use of raw materials and increased perishability of the preblends over time.

The basic preblending system could be used by a variety of sausage processors with only slight adaptations to their processing facilities. Webb (1968) stated that a preblending system should include the following principles: a) control of the source of raw materials, b) control of types and conditions of materials used in the formulation, c) statistical and compositional evaluation, and d) alternative sausage production systems. Terrell (1974) outlined a typical preblending system that is aided by least cost formulation with predetermined bind and color values for the final product. The system has four basic preblend components; fat and lean pork and fat and lean beef preblends. Rapid fat, moisture and protein analysis then dictate the relative amounts of each preblend to be used in a least cost formulation.

Functions of Preblending

Several researchers have proposed reasons that preblending increases the functional properties of meats and most conclude that the need for holding time is to maximize salt-activated protein extraction. Shannon (1983) stated that during the holding phase of
preblending, salt reacts with protein molecules causing the protein molecules to expand or open its structure, thus increasing the WHC of the protein.

With pre-rigor raw materials, Acton (1979) stated that preblending may provide more time for the salt to penetrate the muscle tissue and interact with the protein. The action of salt may change the configuration of the muscle protein structure, exerting an unfolding action and exposing binding sites for both salt ions and dipolar water molecules.

Preblending gives meat time to combine extensively with added ions and water before final mechanical actions. Connective tissue and sarcolemmal membranes inhibit movement of ions within meat. By allowing more time after preblending for ions to equilibrate throughout tissue, the effects of ions on tissue is more homogeneous (Schmidt, 1984).

Effects of Preblending and Storage Time

Research of preblending systems has been minimal when concerning its effect on the chemical, microbiological or processing properties of raw materials during chilled storage. In summarizing the findings of the reported research on storage of preblends, the results are conflicting. Direct comparisons could be erroneous as different storage time periods and conditions occurred; however, it seems the benefits resulting from preblending are variable because of length of
preblending time, the raw materials used and perhaps the type of sausage product made.

Reagan et al. (1981) stored prerigor beef preblends for 7, 14 or 21 days at 2°C. Percent smokehouse loss was lower for frankfurters from the 14 and 21 day storage treatment. Storage time influenced sensory traits with wieners made from the 14 day preblend having greater appearance, juiciness, and saltiness scores, and greater shear force values than the 7 or 21 day storage treatments. Batter cookout, pH and microbial numbers were not affected by storage time.

Abu-Bakar et al. (1982) preblended prerigor and postrigor beef with 3% salt, 3% salt plus antioxidants, or 3% salt plus sodium nitrite and stored for 0, 7, 14, 21 or 28 days. Salt extractable protein decreased from day 0, but was not different from day 7 to day 21. Total plate count, TBA values, percent fat and moisture increased as storage time increased. Generally, appearance, flavor and overall desirability scores increased with storage time. Smokehouse yield, pH, Hunter "a" and "b," and Warner-Bratzler shear force values were not affected by storage time.

Ockerman and Crespo (1981) preblended lean beef with 20% water, 75 ppm nitrite and 3 or 6% salt and stored the preblends at -10°, 0°, or 15°C for 0, 1, 2 or 3 days. Residual nitrite levels, microbial numbers and rancidity were unchanged for the storage period for preblends stored at 0 or -10°C.
Ockerman and Crespo (1982) also investigated the functional properties of beef preblends as affected by storage time (0, 1, 2, or 3 days). WHC, pH and viscosity increased from day 0 to day 1, but were not significantly different after day 1. Emulsion capacity decreased as storage time increased. In the case of preblends stored at 0 and -10°C, total soluble protein values decreased as storage time increased.

Terrell (1974) used pork, beef and pork-beef combination preblends with three nitrite levels and stored up to 140 hr. He reported frankfurters manufactured after 24 hr had better flavor and quality attributes than did frankfurters manufactured after 67 hr.

Waldman et al. (1974) made preblends with different levels of salt, nitrite, and/or isoascorbate and stored them for 1, 2, 3, or 4 days before frankfurter manufacture. Rancidity and microbial growth increased over storage time; however, pH and residual nitrite were not affected by storage time. Sensory panel desirability of the frankfurters decreased as raw material storage time increased. Consumer cook yield and frankfurter pH were not affected by raw material storage time.

Sung and Lee (1985) studied preblends made with prerigor and postrigor pork, different salt levels and stored up to 6 days at 4°C. Microbial growth, rancidity and pH increased with storage time while functional attributes (salt extractable protein, emulsifying capacity and WHC) did not change.
Hand (1986) preblended both pork and beef to manufacture a coarse-ground sausage product and held at either 0, 4, 8, 12, 24 or 48 hr in his first study, and 0, 4, 8, 12, 16, 48, 96, 144, 192 or 240 hr in his second study. His first study showed that the greatest stability occurred at 0 hr while the lowest stability was observed at 24 hr. Product texture (as measured by Kramer-shear and compression) decreased with increased preblend holding time. His second study showed that pH increased with storage time, expressable water increased from 0-16 hr, total losses decreased from 0-16 hr, but increased from 48-240 hr. The thermoprocessing yields rapidly increased during short-term preblending, with a maximum at 8 hr, then rapidly decreased. Both bind and product texture decreased during long-term preblending. Hand (1986) concluded that the advantages of preblending occurs early (within about 0-16 hours), and that long-term preblending (48-240 hours) may be detrimental to the final product quality parameters.

In a second experiment, Hand (1986) preblended pork and beef to manufacture a fine-ground sausage product (frankfurters) and held the preblends at either 0, 4, 8, 12, 16, 20, 24, 48 or 72 hr. In this study, pH was not influenced by preblending time. The expressible moisture of pork preblends decreased with increased holding time, yet beef preblends were not affected. Product emulsion stability, processing yield and consumer cooking yields were not affected by short or long term preblending. Hunter "L" values increased from 0-16
hr while Hunter "a" values decreased from 0-24 hr. Preblending time did not affect shear force values, however, short-term preblending (0-24 hr) resulted in higher compression forces. Hand (1986) concluded that preblending increased protein interactions and bind in raw material preblends, however, the improved bind that occurred from preblending was lost in processing through machinery such as an emulsion mill.

Gumpen and Sørheim (1987) studied the effects of chopping time on water retention of preblended pork and beef batters. Preblending had a more pronounced effect in the early stages of chopping and then gradually decreased and disappeared as chopping time increased. They also reported that preblending effect was greater with pork than with beef.

Preblending meat with hot-boned fat increased thermoprocessing yields, decreased fat cookout, yet was not detrimental to shear-force values (Bently et al., 1988). They also reported that preblending to 7 days caused an increase in the release of juices and a decrease in redness and yellowness.

**Effect of Additives on Preblending**

Nonmeat additives play an important role in the manufacture of processed meat products. Salt levels, nitrite, antioxidants, added water and phosphates have all been investigated to determine their influence
on the physical, chemical and microbiological properties of preblended raw materials.

**Salt effects** The effects of salt level on processing and product characteristics has received the most attention in the literature. Reagan et al. (1981) preblended prerigor beef with either 0, 3, or 5% added salt. With refrigerated storage, salt level used in the preblending did not affect chemical composition, weight loss, microbial level or batter stability. Generally, sensory values were not significantly influenced by the level of salt used, however, saltiness scores were lower, while shear force values were higher, for wieners prepared from 3% salt preblends than wieners from 0% salt preblends. Under frozen storage (-10°C), level of added salt did not significantly affect any of the chemical, physical or sensory traits measured.

Puolanne and Terrell (1983a) studied prerigor preblends made with 0, 1, 2, 3 or 4% salt. Sausages made with nonsalted preblends had less water binding capacity (WBC) and more released fat than sausages made with preblends of 2, 3 or 4% salt. Level of salt in preblends did not affect WBC when salt contents of the finished sausages were reduced from 2 to 1.5%. In another study, the level of salt in the preblend (2 or 4%) did not affect most of the parameters measured except in the case of the 4% salt added preblends which resulted in a higher pH and lower sensory panel firmness scores (Puolanne and Terrell, 1983b).
Ockerman and Crespo (1981) investigated the effects of 3 and 6% salt levels on the stability of beef preblends. The amount of added salt had a significant effect on rancidity development. Preblends containing 3% salt resulted in lower TBA values than preblends containing 6% salt. When Ockerman and Crespo (1982) preblended beef with either 3 or 6% salt, emulsifying capacity, pH and viscosity values were not affected by salt level, although preblends containing 3% salt were lower in WHC than the preblends containing 6% salt.

Waldman et al. (1974) preblended sausage meats with 0, 1.5 or 3% salt. Treatments with salt had increased pH and TBA values and decreased microbial numbers when compared to the no-salt treatments. Sung and Lee (1985) also found increased microbial inhibition and increased TBA values as salt level increased under both refrigerated and frozen storage conditions.

Testing reduced salt levels for frankfurter manufacture, Sofos (1983a) found that holding beef for 16 hr with a reduced salt level (1.5%) was not detrimental frankfurter characteristics compared to a 2.5% salt control.

Hand et al. (1987) used preblending to investigate the effects of fat (20 and 30%) and salt levels (1.5, 2.0 and 2.5%) on frankfurter characteristics. They found that preblending had minimal effects on color and texture, and in many cases the low fat/low salt treatments provided the best product characteristics.
Antioxidant effects  Antioxidants are used to retard rancidity in meat products. The use of antioxidants in preblended meat could circumvent the pro-oxidant effects of added salt (Waldman et al., 1974; Ockerman and Crespo, 1981; Sung and Lee, 1985). Abu-Bakar et al. (1982) reported that the addition of a mixture of butylated hydroxyanisole (BHA), butylated hydroxytolulene (BHT) and citric acid to the preblend had no effect on functional quality of the raw materials and did not retard microbial growth, but depressed lipid oxidation during extended storage time.

Nitrite effects  The addition of nitrite to preblended meats could provide microbiological inhibition plus the inhibition provided by NaCl (Waldman et al., 1974; Sung and Lee, 1985). The addition of sodium nitrite (78 or 156 ppm) to preblends lowered microbial numbers over 140 hr of storage time (Terrell, 1974). Abu-Bakar et al. (1982) reported that the addition of nitrite did not effect the functional quality indicators, but retarded microbial growth. Waldman et al. (1974) stated that the addition of nitrite with or without isoascorbate resulted in preblends with higher pH and higher populations of aerobes and anaerobes.

Added water effects  Johnson et al. (1977) examined the effects of five levels of added water (0, 10, 20, 30 or 40%) in preblending pork shoulder meat. As the level of added water
increased, emulsion firmness decreased. The addition of 10% added water had higher cooked emulsion stability as compared to 20, 20 or 40% added water.

Abu-Bakar et al. (1989) studied the effects of four levels of added water (0, 7, 14 or 21%) to beef preblends in a model system. Added water did not improve WHC and gel-forming capacities of the beef preblends, but did improve salt-soluble protein extraction.

Phosphate effects There has been little published concerning the effects of phosphate in preblended meats. Choi (1987) studied pork preblends with 0% salt, a1.5% salt plus 0.5% phosphate mixture, or 3% salt, and found that the 1.5% salt plus 0.5% phosphate mixture seemed to compensate for the reduction of salt.

Puolanne and Ruusunen (1980) found that phosphates (type not specified) reduced the WHC of cooked sausages when added as a preblend but increased the WHC when added during chopping.

Puolanne and Terrell (1983b) researched the effects of rigor state (pre- or post-rigor), preblend NaCl level (2.0 or 4.0%), final product NaCl level (1.5 or 2.5%) and STPP level (0 or 0.375%) of frankfurter-types sausages. They found that prerigor preblending produced frankfurters with greater moisture, lower shear force values, and optimal physical and chemical properties when a 4.0% NaCl level was used. They did not, however, find any positive attributes that could be related to preblending with phosphate. They hypothesized
that the preblended pH values and preblending itself were at the optimal conditions for the most effective product characteristics even without phosphate.


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PART I. METHODS OF SODIUM TRIPOLYPHOSPHATE ADDITION IN PREBLENDED PORK AND ITS EFFECTS ON FINE-CUT AND COARSE-GROUND PORK SAUSAGE PRODUCT CHARACTERISTICS
METHODS OF SODIUM TRIPOLYPHOSPHATE ADDITION
IN PREBLENDED PORK AND ITS EFFECTS ON FINE-CUT AND
COARSE-GROUND PORK SAUSAGE PRODUCT CHARACTERISTICS

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ABSTRACT

The addition of sodium tripolyphosphate (STPP) to pork preblends for maximum sausage stability was investigated during the production of fine-cut batters and coarse-ground pork sausage. Lean pork and fat pork trimmings were preblended with and without STPP and held for 20 hr before final sausage processing. The addition of STPP to the fine-cut sausage, regardless of the method of addition, resulted in minimal improvement of finished product characteristics. However, for coarse-ground sausages, preblending with STPP improved all finished product characteristics. STPP was most effective in stabilizing coarse-ground sausage when it was added to the 80% lean preblend.
INTRODUCTION

Alkaline phosphates are widely used in the meat industry to improve water retention, emulsification, color retention and binding properties of meat products (Sofos, 1986). These phosphates improve the functional properties of meat proteins by increasing the ionic strength and pH of meat batters (Hamm, 1960) and by altering the hydrophobic interaction of muscle proteins (Trout and Schmidt, 1986). Several different types of polyphosphates have been investigated in the past (Knipe et al. 1985; Trout and Schmidt, 1986; Whiting, 1984); but, Young et al. (1987) stated that the most common type used in the meat industry is sodium tripolyphosphate (STPP).

Likewise, preblending has shown many advantages with improved functional properties of meat proteins among the most important. Preblending involves holding ground meat, which normally contains sodium chloride, sodium nitrite, and water, for a time period before further processing. The benefits of preblending include the increased extraction of salt-soluble proteins during subsequent comminution, increased emulsifying ability of extracted proteins, decreased emulsion breakdown, and more desirable cured color formation (Acton and Saffle, 1969).

The use of polyphosphates in combination with preblending to maximize product stability has not been fully investigated. Choi (1987) found when investigating an emulsion type pork sausage that preblending pork with a 0.5% phosphate mixture (composed of sodium
acid pyrophosphate, sodium tripolyphosphate, and sodium hexametaphosphate) and 1.5% salt gave similar functional properties and processing yields when compared to a 3% salt treatment. However, Puolanne and Ruusunen (1980) found that phosphates reduced the water-holding capacity (WHC) of cooked sausages when added as a preblend. In addition, Knipe et al. (1990) found that STPP offered no benefit to fine-cut sausages when added to their preblends.

Very little published information is available regarding the effects of preblending meats with STPP on final product stability. Therefore, the objective of this study was to determine the effects of STPP addition during preblending on the characteristics of finished fine-cut and coarse-ground sausages.
MATERIALS AND METHODS

Preblend and Sausage Production

Pork trimmings (obtained from the Iowa State University Meat Laboratory for the fine-cut sausage study and from a local processor for the coarse-ground sausage study) consisted of lean pork trimmings (i.e., about 80% lean and 20% fat, or 80/20 pork) and fat pork trimmings (i.e., about 50% lean and 50% fat, or 50/50 pork).

Treatments for both fine-cut (frankfurters) and coarse-ground (Polish-style) sausages included: 1) the addition of STPP to the 80/20 pork preblend (referred to here as "Lean Blend"), 2) STPP added to the 50/50 pork preblend ("Fat Blend"), 3) STPP added to both the 80/20 and 50/50 pork preblends ("Lean/Fat Blend"), 4) STPP added only during final batching ("Control") and, 5) a control with no STPP added to either preblend ("No-STPP Blend").

Lean pork preblends and fat pork preblends were made separately and held separately. The pork trimmings were ground through a 12.7-mm grinder plate and mixed with 2.83% (meat-weight basis) sodium chloride (NaCl), 0.014% sodium nitrite, 8.9% water, and 0.94% STPP (for the phosphate-containing treatments) in a Leland mixer for 5 min. The 0.94% STPP level in the preblends was targeted such that a 0.40% level would result in the final raw product.

The preblends were held at 0-2°C for 20 hr, at which time equal amounts of each preblend (80/20 and 50/50 pork) were combined and
mixed with 1.67% (preblend-weight basis) seasoning, 0.055% sodium erythorbate, and an additional 0.006% sodium nitrite and 13.3% water. For Control treatment, 0.40% STPP was added at this stage.

Twenty hours after preblending, blends for fine-cut sausages were reground through a 3.18-mm plate and passed once through a Steffan (Steffan Co., West Germany) emulsion mill. Because polyphosphates reduce the viscosity of meat batters (Knipe et al., 1985), making it more difficult to achieve the elevated temperatures needed during chopping and/or emulsifying, final temperatures out of the emulsion mill were targeted at 15°-16°C by adjusting the water temperature used during the final batching step. Consequently, all treatments were subjected to a single pass through the emulsion mill and had the same temperature history. The raw product was then stuffed into 22-mm Teepak Wienie-Pak® casings using a vacuum stuffer and cooked to 68°C internal temperature in a Maurer thermoprocessing unit.

Coarse-ground sausage preblending treatments were identical to the fine-cut treatments. The mixing of preblends for the coarse-ground sausages was done by using the same procedures as with the fine-cut product except that only an additional 2.3% water was added during the final blending step.

After the final blending step, the coarse-ground blends were reground through a 4.0-mm grinder plate, stuffed into 34-mm collagen casings and thermoprocessed by using the same procedure as with the fine-cut sausage.
pH Determination

Initial pH determination (Acton, 1972) of pork trimmings before preblending and on the 80/20 and 50/50 preblends was conducted after the 20-hr holding time.

Raw Product Analysis

To facilitate rapid analysis, proximate composition of raw products just before cooking was determined by using the CEM (CEM Corp., Matthew, N.C.) Automatic Extraction System and the Soxlet crude lipid method for fat measurements, and the CEM Moisture/Solids Analyzer and vacuum oven method for moisture measurements. All the proximate composition techniques used are AOAC (1984) approved methods.

A modified version of the Townsend et al. (1968) emulsion stability procedure was used to determine raw batter or blend stability. Gel-water and fat losses were measured from triplicate 34-g raw product samples collected just prior to stuffing. These samples were stuffed into 22.2 x 101.6 mn polycarbonate tubes and cooked in an 80°C water bath for 20 min at which time the rendered fluid was decanted into 15-mL centrifuge tubes and measured. The pH of the raw products was also measured just before cooking.
Cooked Product Analysis

The cooked yield of the products was determined by dividing the cooked product weights by the raw, stuffed product weights. Fat and moisture contents were measured on the final cooked product by using the methods described. Textural measurements were made by using an Instron Universal Testing Machine (Instron Corp., Canton, Mass.) equipped with a Warner-Bratzler Shear (WBS) apparatus. Samples were cored to remove the outer protein skin and tested with the WBS. The Instron was set up with a 50-Kg load cell, full scale load of 1.0, and a crosshead speed of 100 mm/min. Results are expressed as g force required to shear the 15-mm core.

A modified version of the Tauber and Lloyd (1947) method for "consumer cooking yield" was used for both fine-cut and course ground products. Water (1 L) was brought to a boil in a 3-L covered beaker. A labeled link from each treatment was added to the boiling water. The beaker was left on the burner until the water temperature reached 95°C, the beaker was then removed from the burner. After 7 min, the links were removed from the water and allowed to cool at room temperature for 15 min. Percent consumer cooking yield was calculated by dividing the "consumer cooked weight" by the initial weight.

Lipid oxidation was measured by using the distillation method of Tarladgis et al. (1960), which measures malonaldehyde production.
with 2-thiobarbituric acid (TBA). TBA measurements were measured biweekly for 6 weeks.

Each treatment was replicated three times, and triplicate samples from each treatment and replication were measured for each parameter. Differences between means were analyzed by the Least Significant Difference (LSD) method and linear regression using the Statistical Analysis System (SAS, 1982). An alpha level of 0.05 was used to determine significance.
RESULTS AND DISCUSSION

Preblend Analysis

Pork trimming pH values prior to preblending were not different (P>0.05) (data not shown). After 20 hr holding time, the "Lean Blend" (STPP added to the 80/20 pork) resulted in the highest pH (or greatest pH increase) for the 80/20 preblends (P<0.05), while the "Fat Blend" (STPP added to the 50/50 pork preblend) resulted in the greatest pH increase (P<0.05) of any of the treatments (Tables 1 and 2). This phenomenon held true for both the fine-cut and coarse-ground products, even though the initial pH of the raw materials used for the coarse-ground sausage was about 0.3 pH units higher than the pH of the raw materials used for the fine-cut sausages.

Resultant pH increase from the addition of STPP was found to be less for the raw materials that were initially higher in pH than for the lower-pH raw materials (Tables 1 and 2). This agrees with the results of Knipe et al. (1985).

Clarke et al. (1987) found that STPP increased the pH of comminuted beef from 5.6 to 6.0 (pH increase of 0.40), whereas Sofos (1985) noted a pH increase of 0.17-0.23. The greater pH differences caused by STPP reported in this study are attributable to the higher than normal concentration of STPP in the preblends. A 0.40% STPP concentration was calculated on the raw sausage weight; therefore, the STPP level in the "Lean Blend" and "Fat Blend" preblends was 0.94%.
The phosphate concentration for each of the preblends making up the "Lean/Fat Blend" treatments was 0.40%.

Raw Product Analysis

Raw product pH values for fine-cut and coarse-ground mixtures just before cooking are shown in Tables 1 and 2, respectively. As expected, all raw products containing STPP, regardless of method of addition, were significantly higher in pH than the "No-STPP Control."

Regardless of the method of addition, uncooked, fine-cut batters (Table 1) with STPP had less gel-water and fat released upon cooking than did the "No-STPP Control" (P<0.05). With raw coarse-ground sausage products (Table 2), adding STPP to the 80/20 pork trim ("Lean Blend") reduced (P<0.05) the amount of gel-water cookout below that of all other treatments. Whereas the gel-water cookout for the "Fat Blends," "Lean/Fat Blends," and "Control" was greater (P<0.05) than that of the "Lean Blend," these treatments resulted in less (P<0.05) cookout than that of the "No-STPP Control" treatment.

STPP added during preblending resulted in less (P<0.05) fat cookout than the "No-STPP Control" or "Control" treatments for fine-cut (Table 1) and coarse-ground (Table 2) batters. It is generally accepted that alkaline phosphates increase stability and reduce cookout of processed meat products (Barbut et al., 1988; Knipe et al., 1988); however, Puolanne and Terrell (1983) found that phosphates did not affect juiciness of preblended franks. Puolanne and Ruusunen (1980)
found that phosphates (type not specified) only increased water-holding capacity (WHC) when they were added during chopping of nonpreblended meats.

**Final Product Analysis**

STPP did not affect (P<0.05) smokehouse yield or consumer-cooked yield of fine-cut sausages (Table 1). However, coarse-ground sausages (Table 2) containing STPP, with or without preblending, had significantly greater (P<0.05) smokehouse and consumer-cooked yields than the "Control" treatment. The "Lean Blend" resulted in the highest consumer-cooked yield (P<0.05) of any of the coarse-ground treatments.

Gumpen and Sørheim (1987) found that a 24-hr preblending ("presalting") time, using salt but not phosphate, aided the moisture-holding characteristics of coarse-ground sausages but resulted in no beneficial effect on finely comminuted sausages. Since fine-cut sausages are either chopped in a bowl chopper or passed through an emulsion mill. The particle size is reduced, thereby increasing protein extraction and stability of meat batters. Therefore, the mechanical action of chopping or emulsifying may play a more important role with product stability than the increased ionic strength of the added alkaline phosphates. Preblending alone for the production of coarse-ground sausage has not always been found to be beneficial to product stability (Hand et al., 1987), yet in this study, the greatest benefit of
preblending of coarse-ground sausages was from STPP used in the preblend (especially when used with the 80/20 pork preblend).

There were no differences (P>0.05) in final product composition among the fine-cut pork sausages (Table 1). However, coarse-ground links (Table 2) of the "Lean Blend" and "Control" treatments had a higher (P<0.05) final product moisture. Bendall (1954) found that a 24-hr storage increased the WHC of pyrophosphate-treated muscle. However, Puolanne and Ruusunen (1980) found that phosphates (type not specified) reduced the WHC of cooked sausages when added to a preblend. Puolanne and Terrell (1983) reported that preblending with 0.375% STPP for frankfurter production provided little benefit in cooking yield.

The "Lean Blend" treatment had the highest percentage of fat in the final coarse-ground product (Table 2), which could indicate that greater product stability was achieved by preblending STPP with the 80/20 pork. But smokehouse yields were no do different.

Preblending with STPP generally reduced shear force values of fine-cut pork sausages (Table 1), yet with coarse-ground sausages (Table 2), preblending with STPP increased shear force values. Coarse-ground links with STPP generally had higher shear force values than the "No-STPP Control," and links from the "Lean Blend" treatment had the highest shear values (P<0.05) of any of the treatments (Table 2).

Previous research has revealed that preblending without phosphate resulted in little or no effect on fine-cut sausage texture. No
differences were found with preblended frankfurters when using either Warner-Bratzler Shear (WBS) (Abu-Bakar et al., 1982) or Kramer shear (Hand et al., 1987). Hand et al. (1987) concluded that the benefits of preblending did not include textural enhancements. However, phosphate usage without preblending had been found to increase the texture and binding characteristics of meat products (Barbut et al., 1988; Young et al., 1987). Because the addition of STPP to preblended fine-cut links reduced product shear values, yet increased shear force values for coarse-ground links, it is likely that the different processing schemes used for fine-cut versus coarse-ground sausage production may play a critical role in the effectiveness of STPP in preblending. The increased ionic strength produced from STPP aids in the protein extraction from the myofiber when used with coarse-ground sausages, however, the mechanical action of fine-cutting may overcome any increased ionic strength benefits.

TBA values increased linearly (P<0.05) for fine-cut (Fig. 1) and coarse-ground (Fig. 2) sausage links during the 6-week test period, yet there were no differences (P>0.05) in TBA values among treatments. Yet, phosphates are generally known to decrease oxidative rancidity (Matlock et al., 1984; Molins et al., 1987). Even though links from the "No-STPP Control" and "Control" had higher TBA values for each of the measured times for coarse-ground sausage links, these results were not significantly different from the links produced from preblends that contained STPP. Molins et al. (1987) found that phosphates may
interfere with TBA results, which could explain the lack of significant differences among treatments during the 6-week test period of this study.

Although the addition of STPP to meat preblends for use in fine-cut sausages increased the stability of the products, the method of addition, during the preblending process, resulted in no differences in finished product characteristics. However, preblending with STPP, for coarse-ground sausage production, resulted in more significant advantages, especially when STPP was added to the 80/20 pork preblends. On the basis of all coarse-ground finished product parameters, the addition of STPP to lean pork (80/20) preblends resulted in the most stable product.

Our results suggest that the mechanical action of chopping or emulsifying produced a sufficiently stable meat mixture such that no additional stabilization was observed upon the addition of alkaline phosphates. To the contrary, the stability level of coarse-ground products allowed them to be more responsive to the chemical action of alkaline phosphates.
REFERENCES


TABLE 1. Effects of the methods of addition of sodium tripolyphosphate (STPP) during preblending on characteristics of fine-cut pork sausage products

<table>
<thead>
<tr>
<th></th>
<th>No-STPP Control</th>
<th>Lean Blend</th>
<th>Fat Blend</th>
<th>Lean/Fat Blend</th>
<th>Control</th>
<th>SE</th>
</tr>
</thead>
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<td><strong>Preblends</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>20 hr pH (80/20 pork)</td>
<td>5.8c</td>
<td>6.4a</td>
<td>5.8c</td>
<td>6.1b</td>
<td>5.8c</td>
<td>0.01</td>
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<td>5.9c</td>
<td>5.9c</td>
<td>6.7a</td>
<td>6.4b</td>
<td>5.9c</td>
<td>0.02</td>
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<td>pH change (80/20 pork)</td>
<td>0.1c</td>
<td>0.7a</td>
<td>0.1c</td>
<td>0.4b</td>
<td>0.1c</td>
<td>0.02</td>
</tr>
<tr>
<td>(50/50 pork)</td>
<td>0.1c</td>
<td>0.1c</td>
<td>0.9a</td>
<td>0.6b</td>
<td>0.1c</td>
<td>0.03</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw product pH</td>
<td>5.8b</td>
<td>6.3a</td>
<td>6.3a</td>
<td>6.3a</td>
<td>6.3a</td>
<td>0.01</td>
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<tr>
<td>Gel-water cookout (mL)6</td>
<td>1.3a</td>
<td>0.9b</td>
<td>0.8b</td>
<td>0.8b</td>
<td>0.8b</td>
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<td>Fat cookout (mL)6</td>
<td>0.4a</td>
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<td>0.1b</td>
<td>0.2b</td>
<td>0.1b</td>
<td>0.06</td>
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<td></td>
<td></td>
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<tr>
<td>Smokehouse yield (%)</td>
<td>91.7</td>
<td>91.8</td>
<td>91.8</td>
<td>91.9</td>
<td>92.0</td>
<td>0.31</td>
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<tr>
<td>Consumer-cooked yield (%)</td>
<td>97.7</td>
<td>97.8</td>
<td>97.8</td>
<td>97.6</td>
<td>97.7</td>
<td>0.40</td>
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<td>Final product moisture (%)</td>
<td>56.8</td>
<td>60.2</td>
<td>60.2</td>
<td>60.0</td>
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<td>Final product fat (%)</td>
<td>23.0</td>
<td>19.6</td>
<td>19.6</td>
<td>19.9</td>
<td>19.6</td>
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<td>Warner Bratzler Shear (g)</td>
<td>399.0a</td>
<td>366.7ab</td>
<td>348.9b</td>
<td>356.7ab</td>
<td>352.2ab</td>
<td>17.45</td>
</tr>
</tbody>
</table>

1 No STPP used.
2 STPP added to the 80/20 (80% lean/20% fat) preblends.
3 STPP added to the 50/50 (50% lean/50% fat) preblends.
4 STPP divided between the 80/20 and 50/50 preblends.
5 STPP not added to preblends, but added during the batching step.
6 mL cookout per 34-g sample.

abc Means in the same row bearing like or no superscripts are not different (P>0.05).
Fig. 1. Effect of points-of-addition of sodium tripolyphosphate (STPP) during preblending on thiobarbituric acid values (TBA) of fine-cut sausage. Standard error of the means was 0.02
TABLE 2. Effects of the methods of addition of sodium tripolyphosphate (STPP) during preblending on characteristics of coarse-ground pork sausage products

<table>
<thead>
<tr>
<th>Preblends</th>
<th>No-STPP Control</th>
<th>Lean Blend</th>
<th>Fat Blend</th>
<th>Lean/Fat Blend</th>
<th>Control</th>
<th>SE</th>
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</thead>
<tbody>
<tr>
<td>20 hr pH</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(80/20 pork)</td>
<td>6.1c</td>
<td>6.5a</td>
<td>6.1c</td>
<td>6.4b</td>
<td>6.1c</td>
<td>0.04</td>
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<td>(50/50 pork)</td>
<td>6.2c</td>
<td>6.2c</td>
<td>6.9a</td>
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<td>6.2c</td>
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<tr>
<td>pH change</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(80/20 pork)</td>
<td>0.0c</td>
<td>0.5a</td>
<td>0.0c</td>
<td>0.3b</td>
<td>0.0c</td>
<td>0.02</td>
</tr>
<tr>
<td>(50/50 pork)</td>
<td>0.0c</td>
<td>0.1c</td>
<td>0.8a</td>
<td>0.6b</td>
<td>0.1c</td>
<td>0.02</td>
</tr>
<tr>
<td>Raw Product</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw product pH</td>
<td>6.1b</td>
<td>6.5a</td>
<td>6.5a</td>
<td>6.5a</td>
<td>6.5a</td>
<td>0.02</td>
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<tr>
<td>Gel-water cookout (mL)6</td>
<td>2.7a</td>
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<td>1.6b</td>
<td>1.6b</td>
<td>1.9b</td>
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<tr>
<td>Fat cookout (mL)6</td>
<td>1.6a</td>
<td>1.2b</td>
<td>1.3b</td>
<td>1.1b</td>
<td>1.6a</td>
<td>0.09</td>
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<tr>
<td>Finished Product</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Smokehouse yield (%)</td>
<td>90.7b</td>
<td>92.5a</td>
<td>92.3a</td>
<td>92.8a</td>
<td>91.8a</td>
<td>0.42</td>
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<tr>
<td>Consumer-cooked yield (%)</td>
<td>92.8d</td>
<td>95.8a</td>
<td>94.2b</td>
<td>95.1c</td>
<td>94.3b</td>
<td>0.29</td>
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<tr>
<td>Final product moisture (%)</td>
<td>45.6b</td>
<td>46.9a</td>
<td>45.3b</td>
<td>45.5b</td>
<td>45.8a</td>
<td>0.45</td>
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<tr>
<td>Final product fat (%)</td>
<td>27.7c</td>
<td>31.0a</td>
<td>29.2b</td>
<td>29.5b</td>
<td>28.5bc</td>
<td>0.45</td>
</tr>
<tr>
<td>Warner Bratzler Shear (g)</td>
<td>435.5c</td>
<td>657.7a</td>
<td>499.0bc</td>
<td>526.2b</td>
<td>476.3bc</td>
<td>29.10</td>
</tr>
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</table>

1 No STPP used.
2 STPP added to the 80/20 (80% lean/20% fat) preblends.
3 STPP added to the 50/50 (50% lean/50% fat) preblends.
4 STPP divided between the 80/20 and 50/50 preblends.
5 STPP not added to preblends, but added during the batching step.
6 mL cookout per 34-g sample.

abcd Means in the same row bearing like or no superscripts are not different (P>0.05).
Fig. 2. Effect of points-of-addition of sodium tripolyphosphate (STPP) during preblending on thiobarbituric acid values (TBA) of coarse-ground sausage. Standard error of the means was 0.02
PART II. THE EFFECTS OF PREBLENDING TIME, MEAT TEMPERATURE AND SODIUM TRIPOLYPHOSPHATE ON COARSE-GROUND PORK SAUSAGE CHARACTERISTICS
THE EFFECTS OF PREBLENDING TIME, MEAT TEMPERATURE AND SODIUM TRIPOLYPHOSPHATE ON COARSE-GROUND PORK SAUSAGES CHARACTERISTICS

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Journal Paper of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project 2723

Running title: Preblending meat with phosphate

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ABSTRACT

Coarse-ground pork sausages were made from preblends which were manufactured with or without sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. A model system was studied first to select test parameters for subsequent sausage production. Sausages made from preblends containing STPP had more desirable product characteristics than those made without STPP. Sausages made from preblends held at -2°C also had more desirable product characteristics than those held at 2°C.
INTRODUCTION

Preblending is the meat-processing technique of holding ground meat, to which sodium chloride, sodium nitrite and water have been added, for a period of time before further processing. The advantages to preblending include the increased extraction of salt-soluble proteins, increased emulsifying ability of extracted proteins, decreased emulsion breakdown and more desirable cured color formation (Acton and Saffle, 1969).

Preblend-holding time has been investigated. Smokehouse yield (Reagan et al., 1981), water-holding capacity (WHC) and batter viscosity (Ockerman and Crespo, 1982) were reported to increase with increasing preblend-holding time. Hand (1986) reported that the advantages of preblending occur within 0-16 hr while longer preblending times (48-240 hr) may be detrimental to coarse-ground sausage characteristics.

Alkaline phosphates are widely used in the meat industry to improve water retention, emulsification, color retention and binding properties of meat products (Sofos, 1986). Using polyphosphates with preblended meat systems have not always proved to be beneficial. Choi (1987) found that preblended pork containing a 0.5% phosphate mixture (composed of sodium acid pyrophosphate, sodium tripolyphosphate, and sodium hexametaphosphate) and low salt (1.5%) gave similar functional properties and processing yields when
compared to a high salt (3%) treatment. Improved product characteristics were noted with coarse-ground sausages made from preblends with sodium tripolyphosphate (STPP), especially if the STPP was added to the lean preblended fraction (Frye et al., 1990). However, Puolanne and Ruusunen (1980) found that phosphates reduced the WHC of cooked sausages when added as a preblend. Knipe and coworkers (Knipe et al., 1989; Frye et al., 1990) found that STPP provided no benefit to fine-cut sausages when added during preblending.

Low meat temperatures are desired for optimal protein extraction (Pardee and Spudich, 1982; Yates and Greaser, 1983) and particle definition. However, many meat processors do not have the capability to manipulate meat temperatures during processing (with such means as flaked ice as a water source or carbon dioxide injection into blenders or mixers) in order to achieve maximum protein extraction, and therefore, maximum product characteristics.

There is very little published information available regarding the effects of preblending meat using STPP and the effects of holding time and temperature of preblends on pork sausage quality. Therefore, the objectives of this study were to determine the effects of the addition of STPP to preblends, preblending holding times and holding temperatures on the characteristics of coarse-ground pork sausages.
MATERIALS AND METHODS
The effects of holding time and holding temperature on preblended pork sausages, made with and without STPP, were evaluated using a model system and a typical product system. Results of the model system were used to determine which treatment combinations should be investigated for the sausage product study. Lean pork trimmings (27% fat) and fat pork trimmings (52% fat) were purchased from a local commercial source.

Model System Study
Pork trimmings were ground through a 12.7-mm grinder plate and mixed with 2.83% (meat-weight basis) sodium chloride (NaCl), 0.014% sodium nitrite, 8.9% water. Lean pork preblends (13 Kg each) were made with or without 0.94% STPP and held at either -2°C or 2°C. Fat pork preblends were made without STPP and held at 0°C. At 0, 6, 12, 18, 24, 36 and 48 hr, 1.0 Kg of the lean preblend was combined with 0.23 Kg of the fat preblend and mixed in a Kitchenaid® blender with 0.055% sodium erythorbate, an additional 0.006% sodium nitrite and 2.3% water.

Batter Stability Determination
After this blending step, the blends were reground through a 4.0-mm grinder plate. A modified version of the Townsend et al. (1968) emulsion stability procedure was used to determine raw batter
or blend stability. Gel-water and fat losses were measured from triplicate 34-g raw product samples that were cooked in an 80°C water bath for 20 min.

A new method for measuring stability was also used. Whatman® cellulose extraction thimbles (22mm x 80mm) were filled with 25-g of the raw batter and cooked in an 80°C convection oven for 20 min. In an attempt to simulate a typical smokehouse environment, a pan (46cm x 61cm) was filled with 7.5-Kg water and placed in the bottom of the convection oven so that the relative humidity inside the convection oven was increased to 15%. Thermoprocessing yields were collected from this thimble method in the following manner:

\[
\frac{\text{final cooked wt.} - \text{empty thimble wt}}{25 \text{ g}} \times 100\%
\]

pH Determination

Determination of raw batter pH was conducted as described by Acton (1972).

Phosphate Determination

Cooked samples from the model system study were minced, and 10-g of each were combined with 10-mL of distilled, deionized water and homogenated. The homogenates were then filtered through Whatman® #1 filter paper. The filtrates were collected and the qualitative measurements of tripolyphosphate, pyrophosphate and
orthophosphate contents were determined using the paper chromatography method of Greenfield and Clift (1975).

Sausage Product Study

Lean and fat pork preblends were made separately at either 0, 18, 24, or 48 hr before product manufacture. Preblend manufacturing procedures, STPP levels and holding temperature treatments were identical to those of the model study described previously. Coarse-ground sausage manufacture consisted of combining the lean preblends (13-Kg) with 2.5-Kg of the appropriate fat preblend and mixing with 1.67% (preblend-weight basis) seasoning, 0.055% sodium erythorbate, and an additional 0.006% sodium nitrite and 2.3% water.

After the final blending step, the blends were reground through a 4.0-mm grinder plate, stuffed into 34-mm collagen casings and cooked to 68°C internal temperature in a Maurer thermoprocessing unit.

Raw Product Analysis

Proximate composition of raw products before cooking was determined using the Soxlet crude lipid method for fat measurements, and vacuum oven method for moisture measurements. Protein content was determined using the Buchi rapid protein analyzer. All proximate composition techniques used are AOAC (1984) approved methods.
Raw batter stability was measured by the thimble and the modified Townsend methods described previously.

**Cooked Product Analysis**

The cooked yield (hot product weight) of the products was determined by dividing the cooked product weights (immediately after cooking) by the raw, stuffed product weights. Chilled yield of the cooked products was determined by dividing the chilled product (after overnight chilling at 2°C) weights by the hot product weights. "Consumer cooking yield" was measured using the Tauber and Lloyd (1947) method, as modified by Frye et al. (1990). Overall product yield was calculated by multiplying the smokehouse yield by the chilled yield by the consumer cooking yield by 100%.

Fat, moisture and protein contents were measured on the final cooked product by using the methods previously described. Compression and Warner-Bratzler Shear (WBS) textural measurements were made by using an Instron Universal Testing Machine (Instron Corp., Canton, Mass.). Cooked samples were cored to remove the outer protein skin before testing. For compression testing, each core sample was compressed twice to 50% of its original thickness. First compression results were expressed as g force needed to compress the 15-mm core sample. Cohesion was the result of the area under the second compression peak divided by the area under the first peak. Results of WBS are expressed as g force required to shear the 15-mm core. For
both tests, the Instron was set up with a 500-Kg load cell, full scale load of 1.0-Kg, and a crosshead speed of 100 mm/min.

Color measurements of the external links were taken on each treatment using a Hunter Lab Colorimeter (Hunter Laboratory, Inc., Reston, VA) equipped with a fluorescent lighting system. Hunter "L", "a" and "b" values were measured on vacuum packaged, cooked, coarse-ground pork links at 0 day and at 7 days of retail lighting conditions. Lighting consisted of 60-watt Sylvania® Cool White fluorescent lights (195 foot candles, or 2,100 lux) in a 0-1°C environment.

The experiments were replicated three times and results were analyzed using a 2x2 factorial design with a repeated measure. The Statistical Analysis System (SAS, 1986) was used to determine means, standard errors and analysis of variance. Least significant difference (P<0.05) was used as a method of means separation.
RESULTS AND DISCUSSION

Model System Study

Meat preblends held at -2°C generally had less (P<0.05) gel-water cookout than those held at 2°C (Fig. 1, Appendix Table 2). Averaged over all treatments, there was a decrease in gel-water cookout at 36 hr holding time (Appendix Fig. 1). Likewise, preblends containing STPP had less gel-water cookout (P<0.05) than the preblends without STPP (Fig 1. and Appendix Tables 1 and 2). Similar results were reported when STPP was used in nonpreblended (Reddy et al., 1987) and preblended (Frye et al., 1990) coarse ground sausages. Preblend-holding time also affected gel-water cookout (P<0.05). This agrees with Ockerman and Crespo (1982) who found that WHC increased with holding time for preblends not containing phosphates. However, Sung and Lee (1985) found that holding time for preblends not containing phosphates did not influence water-binding ability of emulsion-type sausage.

Preblends held at -2°C also resulted in less fat cookout (P<0.05) than those held at 2°C (Fig. 2, Appendix Table 2). Likewise, preblends containing STPP resulted in less fat cookout (P<0.05) than the preblends without STPP (Fig. 2 and Appendix Tables 1 and 2). Similar results were found when preblends containing STPP had less fat cookout than preblends not containing STPP (Frye et al., 1990). This agrees with Ockerman and Crespo (1982) who reported a decrease in
emulsion capacity with increased holding time for preblends not containing phosphate. However, Reagan et al. (1981) found that batter cookout was not influenced by preblend-holding time and Hand (1986) reported that the greatest stability of a coarse-ground sausage batter (not containing phosphates) was at 0 hr and the lowest at 24 hr.

The thimble method was not sensitive enough (P>0.05) to separate phosphate and temperature differences (Fig. 3). For all treatments, optimal yields (P<0.05) for thimble cooking were observed between 12-24 hr (Fig. 3 and Appendix Table 1).

Preblend-holding temperature did not (P>0.05) influence pH (Fig. 4, Appendix Table 2). Preblends containing STPP had significantly higher (P<0.01) pH values that those without STPP (Fig. 4, Appendix Table 2). This result was expected, as phosphates are known to increase raw batter pH (Hamm, 1960; Acton et al., 1981; Trout and Schmidt, 1986). Preblend-holding time influenced pH as there was a decrease (P<0.05) in raw batter pH at 18 hr, however, it seems that pH was not influenced by the 48 hr holding time. This conflicts with previous findings that product pH increased with increased preblend-holding time (Ockerman and Crespo, 1982; Sung and Lee, 1985; Hand, 1986) or remain unchanged with preblend-holding time (Waldman et al., 1974; Reagan et al., 1981; Abu-Bakar et al., 1982; Hand, 1986).

Preblends made without STPP and held at 2°C (Fig. 5) and at -2°C (Fig. 6) show only the presence of orthophosphate (OP). For preblends made containing STPP and held at 2°C, there seems to be a trace of
tripolyphosphate (TPP) at 0 hr. Pyrophosphate (PP) is present from 0-36 hr, and OP is present during all preblending holding times (Fig. 7). However, TPP was observed at 0 hr in preblends made with STPP and held at -2°C TPP (Fig. 8). PP remained present through 48 hr of preblend-holding time in STPP-containing preblends held at -2°C. Thus, reducing preblend-holding temperature from 2°C to -2°C slows phosphatase activity.

Sutton (1973) found that the extent of phosphatase activity was slower in beef stored at 0°C than at 25°C. It seems that preblend-holding temperature is also important to the hydrolysis of STPP and the product stability of coarse-ground sausages.

It is also interesting to note that at 0 hr only, sausages made from 2°C preblends with STPP had less gel-water and fat cookout as measured by the batter stability test (Figs. 1 and 2), whereas the -2°C treatments with STPP had less gel-water and fat cookout after 0 hr. Since it seems that STPP is hydrolyzed quicker at 2°C than at -2°C, it is likely that preblends made with STPP and held at 2°C has greater functionality at 0 hr due to a greater amount of PP, because it is PP that increased the functional properties of meat (Yasui et al., 1964).

Based on the results of the model system study, a coarse-ground sausage product study was investigated with identical STPP and temperature treatments. However, 0, 18, 24 and 48 hr were chosen as preblend-holding times.
Sausage Product Study

There were no differences in raw product composition or final product composition (P>0.05) for any of the treatment tested (data not shown). Raw product composition was 57.3% moisture, 21.2% fat and 15.5% protein. Final product composition was 49.7% moisture, 27.0% fat and 18.1% protein.

Sausages made from preblends held at -2°C resulted in less (P<0.05) gel-water and fat cookout (Figs. 9 and 10, Appendix Table 6). Likewise, sausages made from preblends containing STPP resulted in less (P<0.05) gel-water and fat cookout. These results from batter stability tests were similar to the data collected with the model system study, however reduced gel-water and fat cookouts are more apparent at 18 to 24 hr preblend holding time.

Like the model system results, preblend-holding time was significant (P<0.05) for thimble cooking yields with peaks at 18-24 hr (Fig. 11). However, unlike the model system, batters containing STPP had greater (P<0.05) yields than those not containing STPP.

The main effects of temperature, STPP or preblend-holding time did not influence (P>0.05) smokehouse yields (Fig. 12) or chilled yields (Fig. 13), however, trends for increased smokehouse yields approached a significant level (P<0.06) for sausages containing STPP. The effect of holding time of preblends not containing STPP on smokehouse yields has produced varied results according to other researchers. Ockerman and Crespo (1982) reported increased smokehouse yield with
increased preblend-holding time, however, Abu-Bakar et al. (1982) found that holding time did not affect smokehouse yield. Hand (1986) found that smokehouse yield peaked after 8 hr preblending, then rapidly decreased with increased preblending time. Choi (1987) and Frye et al. (1990) reported increased smokehouse yields with preblends made with phosphate. However, Puolanne and Ruusunen (1980) found that phosphates added to preblends resulted in reduced cooked sausage yields. Chilled yields were also not affected (P>0.05) by preblend-holding temperature, STPP or holding time (Fig. 13).

Fig. 14 shows the results of the consumer cooking test. Preblends held at -2°C had greater (P<0.01) consumer cooking yields than those held at 2°C (Fig. 14, Appendix Table 6). Likewise, preblends made with STPP had greater (P<0.01) consumer cooking yields than those made without STPP, which supports Frye et al. (1990) who found that STPP added to preblends resulted in increased consumer cooking yields of coarse ground sausages. Preblend-holding time did not influence consumer cooking yields (P>0.05), however, consumer cooking yield peaks were noticed at 18 to 24 hr of holding time for preblends held at -2°C and containing STPP. Waldman et al. (1974) preblended raw materials without phosphates up to 4 days and also found that holding time did not influence consumer cooking yields.

Overall yields were calculated by multiplying the smokehouse yields by the chilled yields and consumer yields (Fig. 15). Preblends held at -2°C resulted in greater (P<0.05) overall product yields than
those held at 2°C. Similarly, preblends made containing STPP resulted in greater (P<0.05) overall yields than those made without STPP. Preblend-holding time was also a factor (P<0.01), as the overall yields increased up to 18-24 hr then decreased with additional holding time (Appendix Tables 4 and 6).

Sausages made from preblends containing STPP resulted in greater WBS values (P<0.01) than those made without STPP (Fig. 16, Appendix Table 6). This agrees with Frye et al. (1990) who found that coarse-ground sausages made from preblends with STPP resulted in greater WBS values than those made without STPP. However, WBS values were not affected by preblend-holding temperature or holding time (P>0.05).

Sausages containing STPP were firmer (P<0.01) than those not containing STPP (Fig. 17). Likewise, those made from preblends held at -2°C were firmer (P<0.05) than those from preblends held at 2°C (Appendix Table 6). Firmness for sausages containing STPP increased with preblend-holding time while those not containing STPP decreased or remain unchanged with preblend-holding time as shown by a Holding Time by STPP interaction (P<0.01). Hand (1986) also found that preblends made without phosphates resulted in coarse-ground sausage texture that decreased with increased preblend-holding time.

Sausages made from preblends not containing STPP were more cohesive (P<0.05) than those containing STPP (Fig. 18). Likewise, those made from preblends held at -2°C had greater (P<0.05) cohesion than
those from preblends held at 2°C (Appendix Table 6). This result suggests that much of the increased firmness achieved with STPP addition is lost after the first compression.

Sausages made from preblends containing STPP resulted in lower (P<0.01) Hunter "L" (darkness) values (Fig. 19) and greater (P<0.05) Hunter "a" (redness) values (Fig. 20) than those made without STPP (also see Appendix Table 9). Knipe et al. (1989) found that phosphate addition did not influence Hunter "L" values of nonpreblended meat emulsions, however, their no-phosphate control had higher Hunter "a" values. The effect of holding temperature did not (P>0.05) influence Hunter values. The effect of preblend-holding time in this study did not (P>0.05) influence Hunter "L" or "b" values, however, Hunter "a" values were enhanced with increased (P<0.05) holding time through 18 to 24 hr for preblends containing STPP. This conflicts with Hand (1986) who reported that fine-ground sausages made from preblends (not containing STPP) resulted in increased Hunter "L" values from 0-16 hr while Hunter "a" values decreased from 0-24 hr. Hunter "b" (yellowness) values (Fig. 21) increased up to 18-24 hr of preblend-holding time then decreased with additional holding time.

Color values of cooked sausages after 7 days under retail lighting conditions are given in Figs. 22-24. Sausages made from preblends that were held at -2°C had greater (P<0.05) Hunter "a" (Fig. 23) and Hunter "b" (Fig. 24) values (also see Appendix Table 9). Sausages made with STPP had lower (P<0.01) Hunter "L" values (Fig. 22), greater
(P<0.05) Hunter "a" (Fig. 23) and Hunter "b" (Fig. 24) values (also see Appendix Table 9). Preblend-holding time did not influence (P>0.05) Hunter "L" and "a" results.

Sausages held under retail lighting conditions which were made from preblends held at -2°C were higher (P<0.05) in Hunter "b" values that those held at 2°C (Fig. 24). Sausages made from preblends containing STPP had greater (P<0.05) Hunter "b" values than those made without STPP (also see Appendix Table 9). Preblend-holding time was a factor (P<0.05) of the 7 day retail lighting conditions Hunter "b" value response.

Based on much of the data collected, it seems that some time is needed for the hydrolysis of STPP to PP for optimal product characteristics. For most product parameters, characteristics of sausages made with STPP increased after 0 hr. At 2°C, phosphate hydrolysis was shown to occur rapidly. However, at -2°C, phosphatase activity may be slowed since STPP was present at 0 hr as shown by paper chromatography.

Frye et al. (1990) found that STPP enhanced the functional characteristics of preblended coarse-ground pork sausages, especially when added to the lean-fraction preblend. The results from this study indicate that the characteristics of coarse-ground pork sausages manufactured from preblends are enhanced when STPP is added to the lean-fraction preblend and held at temperature of -2°C during the 48 hr preblend-holding time. Holding preblends at 2°C resulted in
sausages with less than optimum product functionality, however, the use of STPP provided characteristics that were closer to the preblend treatments which were held at -2°C and made without STPP.
REFERENCES


phate additives during frozen storage by $^{31}$P-F.T. n.m.r. spectroscopy. J. Food Technol. 14:193.


ACKNOWLEDGEMENTS

The authors would like to thank Dr. David F. Cox for his statistical assistance and Mr. Greg K. Williams for his technical assistance.
Fig. 1. Gel-water cookout from batters made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.21
Fig. 2. Fat cookout from batters made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C. Standard error of the means was 0.12.
Fig. 3. Thimble cooking yields from batters made from preblends made with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.13
Fig. 4. Raw batter pH from batters made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.02
Fig. 5. Phosphate breakdown products during 48 hr preblend holding time. Lean preblends made without STPP and held at 2°C. Standard composed of tripolyphosphate (TPP), pyrophosphate (PP) and orthophosphate (OP) at 0.05 mg each.
Fig. 6. Phosphate breakdown products during 48 hr preblend holding time. Lean preblends made without STPP and held at -2°C. Standard composed of tripolyphosphate (TPP), pyrophosphate (PP) and orthophosphate (OP) at 0.05 mg each.
Fig. 7. Sodium tripolyphosphate (STPP) breakdown products during 48 hr preblend holding time. Lean preblends containing STPP and held at 2°C. Standard composed of tripolyphosphate (TPP), pyrophosphate (PP) and orthophosphate (OP) at 0.05 mg each.
Fig. 8. Sodium tripolyphosphate (STPP) breakdown products during 48 hr preblend holding time. Lean preblends containing STPP and held at -2°C. Standard composed of tripolyphosphate (TPP), pyrophosphate (PP) and orthophosphate (OP) at 0.05 mg each.
Fig. 9. Gel-water cookout from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2 or -2°C. Standard error of the means was 0.20
Fig. 10. Fat cookout from sausages made from preblends made with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.16.
Fig. 11. Thimble cooking yields from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2 or -2°C. Standard error of the means was 0.19
Fig. 12. Smokehouse yields from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C. Standard error of the means was 0.55
Fig. 13. Chilled yield from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.19.
Fig. 14. Consumer cooking yield from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2\(^\circ\) or -2\(^\circ\)C. Standard error of the means was 0.24
Fig. 15. Overall yields from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.54
Fig. 16. Warner-Bratzler Shear (WBS) values from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 3.08
Fig. 17. Compression values for sausages made from preblends made with (w) or without (wo) sodium tripolyphosphate (STPP) and held at up to 48 hr 2°C or -2°C. Standard error of the means was 29.5.
Fig. 18. Cohesiveness of sausages made from preblends made with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.01.
Fig. 19. Hunter "L" values from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C. Standard error of the means was 1.10
Fig. 20. Hunter "a" values from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.26
Fig. 21. Hunter "b" values from sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.37
Fig. 22. Hunter "L" values after 7 days of retail lighting of sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C. Standard error of the means was 0.84
Fig. 23. Hunter "a" values after 7 days of retail lighting of sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Standard error of the means was 0.46
Fig. 24. Hunter "b" values after 7 days of retail lighting of sausages made from preblends with (w) or without (wo) sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C. Standard error of the means was 0.38
SUMMARY

Alkaline phosphates are widely used in the meat industry to improve product characteristics. The most common phosphate used in the meat industry is sodium tripolyphosphate (STPP). Preblending is also used in the meat industry to improve compositional controls and product characteristics. Past studies that have investigated preblending meat with phosphates reported no beneficial use for the manufacture of fine-cut sausage products. Since it is generally accepted that polyphosphates are hydrolyzed by the muscle enzyme, phosphatase, it seemed logical that preblends that contained less phosphatase (fat trimming preblends, for example) would provide improved product parameters.

The objective of the first study was to determine the effects of STPP addition during preblending on the characteristics of finished fine-cut and coarse-ground pork sausage products. To accomplish this objective for fine-cut and course-ground sausages, lean preblends and fat preblends were made with or without STPP and stored separately. Treatment combinations included "Lean Blend" (STPP added to the 80/20 pork preblend), "Fat Blend" (STPP added to the 50/50 pork preblend), "Lean/Fat Blend" (STPP added to both the 80/20 and the 50/50 preblends), "Control" (STPP added during final batching), and "No-STPP Blend" (STPP not added to either preblend or during final batching).
The addition of STPP to meat preblends for use in fine-cut sausages increased the batter stability of the products, however, the method of addition during the preblending process resulted in no differences in finished product characteristics. STPP generally decreased shear strength of fine-cut sausages. For coarse-ground sausages, preblending, with added STPP, resulted in more significant advantages, especially when STPP was added to the 80/20 pork preblend. On the basis of all coarse-ground finished product parameters, the addition of STPP to the lean pork (80/20) preblends resulted in the most stable product.

These results suggested that the mechanical action of chopping or emulsifying produced a sufficiently stable meat mixture such that no additional stabilization was observed upon the addition of STPP. To the contrary, the stability level of coarse-ground products allowed them to be more responsive to the chemical action of the alkaline phosphate.

Based on the results of the first study just described, it seemed logical to investigate factors which might harm or enhance the product parameters of coarse-ground sausages made from STPP-manufactured pork preblends. Therefore, the objectives of the second study were to further evaluate the effects of the addition of STPP to preblends, the preblending holding times and holding temperatures on the characteristics of coarse-ground pork sausages.
To accomplish these objectives, a 2x2 factorial design (preblends made with or without STPP, and held at 2° or -2°C) with a repeated measure (preblends were studied throughout a 48 hr holding time before final batching and sausage manufacture) was used. Preblends were made in a similar manner as before, except STPP was added only to the lean preblends. A model system was used to aid in determining parameters for the subsequent larger scale study. The preblend holding times of the model system were 0, 6, 12, 18, 24, 36 and 48 hr. From this model system it was observed that manufacturing preblends with STPP and a holding temperature of -2°C gave the most beneficial results. A new method for measuring raw batter stability (the "thimble method") helped determine the optimal preblend holding times at 18-24 hr. A qualitative paper chromatographic method was used to determine polyphosphate breakdown products. For lean preblends made with STPP and held at 2°C, STPP seemed to be hydrolzed to pyrophosphate almost immediately. For those made with STPP and held at -2°C, tripolyphosphate was present at 0 hr, but was not observed at the 6 hr holding time.

Coarse-ground sausages made from preblends held at 2°C gave less that optimal results. However, the use of STPP provided characteristics that were closer to the preblend treatments which were held at -2°C and made without STPP.

The results from these two experiments indicate that preblending pork with STPP can be optimized if the final product is a coarse-
ground sausage instead of fine-cut sausage. Coarse-ground product parameters can be optimized if colder holding temperatures are used (-2°C in this research), and held for at least a period of time to allow STPP to be broken down to the more effective phosphate form.
CONCLUSIONS

1. The addition of STPP to preblends for the production of the fine-cut sausage, despite the point-of-addition, resulted in minimal improvement of finished product characteristics. STPP added to preblends generally resulted in lower resistance to shear, as measured by Warner-Bratzler Shear values.

2. The addition of STPP to coarse-ground pork preblends showed improvement in all finished product characteristics.

3. STPP was most effective in stabilizing coarse-ground sausage when it was added to the 80% lean preblend.

4. Based on much of the data collected, it was apparent that some time is needed for STPP to be hydrolyzed to pyrophosphate for optimum product characteristics. At 2°C, this hydrolysis was shown to occur rapidly. However, at -2°C, phosphatase activity may be slowed since STPP was present at 0 hr as shown by the paper chromatography results.

5. A preblend holding temperature of -2°C was more beneficial to product stability, as indicated by both a model system and a product system.
6. Preblends containing STPP and held at 2°C resulted in increased batter stability than those not containing STPP and held at 2°C.

7. Trends for optimal preblend holding time before final batching and product manufacturing was shown to be at 18-24 hr, as indicated by both a model system and a product system.
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Fig. 1. Fat cookout from pooled means of batters made with or without sodium tripolyphosphate (STPP) and held at 2° or -2°C for up to 48 hr.
Like superscripts are not different (P>0.05). Standard error=0.15
Table 1. Means of model system sausages made from preblends made with or without sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C

<table>
<thead>
<tr>
<th>Treatment</th>
<th>gel-water cookout</th>
<th>fat cookout</th>
<th>Thimble</th>
<th>raw-batter yield</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT/Temp/STPP</td>
<td>2°C/wo</td>
<td>2°C/w</td>
<td>-2°C/wo</td>
<td>-2°C/w</td>
<td>2°C/wo</td>
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<tr>
<td>0 hr/2°C/wo</td>
<td>3.9a</td>
<td>1.6bcd</td>
<td>92.2bcde</td>
<td>5.8c</td>
<td>1.9fg</td>
</tr>
<tr>
<td>0 hr/2°C/w</td>
<td>2.2fg</td>
<td>0.8fg</td>
<td>92.0cde</td>
<td>6.1a</td>
<td>3.6ab</td>
</tr>
<tr>
<td>0 hr/-2°C/wo</td>
<td>2.8bcde</td>
<td>0.8fg</td>
<td>92.3abcd</td>
<td>5.8cd</td>
<td>1.5g</td>
</tr>
<tr>
<td>0 hr/-2°C/w</td>
<td>1.8efg</td>
<td>0.9fg</td>
<td>92.3abcd</td>
<td>6.1ab</td>
<td>3.1abcd</td>
</tr>
</tbody>
</table>

1 Preblend treatment combinations include holding time (HT=0, 6, 12, 18, 24, 36 or 48 hr), holding temperature (Temp=2° or -2°C), and STPP level (w=with, wo=without).
2 Raw batter stability, mL gel-water cookout from a 34-g sample.
3 Raw batter stability, mL fat cookout from a 34-g sample.
4 Cooking yields from 25-g of raw batter cooked in a cellulose thimble container.

abcdefgh Means in the same column bearing like superscripts are not different (P<0.05).
## Table 1. (continued)

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<th>Treatment</th>
<th>Parameter</th>
<th>gel-water cookout²</th>
<th>fat cookout³</th>
<th>Thimble Yield⁴</th>
<th>raw-batter pH</th>
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<td>0.6gh</td>
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<tr>
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<td>36 hr/2°C/w</td>
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<tr>
<td>36 hr/-2°C/wo</td>
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<td>1.3bcdef</td>
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<td>5.8cd</td>
</tr>
<tr>
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<td>1.3bcdef</td>
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<tr>
<td>48 hr/-2°C/w</td>
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<td>0.4h</td>
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Table 2. Results of the main effects of holding temperature and sodium tripolyphosphate (STPP) on preblended model system batters

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<th>Main Effect</th>
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<td>-2°C</td>
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<tr>
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</tbody>
</table>

1 Raw batter stability, mL gel-water cookout from a 34-g sample.
2 Raw batter stability, mL fat cookout from a 34-g sample.
3 Level of Significance.
   NS = means in the same column per main effect are not different (P>0.05).
   * = means in the same column per main effect are different (P<0.05).
   ** = means in the same column per main effect are different (P<0.01).
Table 3. Raw batter stability of sausages made from preblends made with or without sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Parameter</th>
<th>Gel-Water Cookout</th>
<th>Fat Cookout</th>
<th>Thimble Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT/Temp/SITP1</td>
<td></td>
<td>0.20</td>
<td>0.16</td>
<td>0.19</td>
</tr>
<tr>
<td>0 hr/2°C/wo</td>
<td>gel-water cookout</td>
<td>3.6a</td>
<td>0.6abcd</td>
<td>91.4bc</td>
</tr>
<tr>
<td>0 hr/2°C/w</td>
<td></td>
<td>0.8fg</td>
<td>0.4bcd</td>
<td>91.5abc</td>
</tr>
<tr>
<td>0 hr/-2°C/wo</td>
<td></td>
<td>2.1de</td>
<td>0.6abcd</td>
<td>91.2abc</td>
</tr>
<tr>
<td>0 hr/-2°C/w</td>
<td></td>
<td>1.3fg</td>
<td>0.2cd</td>
<td>91.5abc</td>
</tr>
<tr>
<td>18 hr/2°C/wo</td>
<td></td>
<td>2.4cd</td>
<td>0.5abcd</td>
<td>91.5abc</td>
</tr>
<tr>
<td>18 hr/2°C/w</td>
<td></td>
<td>0.9fg</td>
<td>0.3bcd</td>
<td>92.0ab</td>
</tr>
<tr>
<td>18 hr/-2°C/wo</td>
<td></td>
<td>1.5ef</td>
<td>0.7abc</td>
<td>91.8abc</td>
</tr>
<tr>
<td>18 hr/-2°C/w</td>
<td></td>
<td>0.6g</td>
<td>0.1d</td>
<td>92.0ab</td>
</tr>
<tr>
<td>24 hr/2°C/wo</td>
<td></td>
<td>2.4cd</td>
<td>0.8ab</td>
<td>91.5abc</td>
</tr>
<tr>
<td>24 hr/2°C/w</td>
<td></td>
<td>1.1fg</td>
<td>0.4bcd</td>
<td>91.8abc</td>
</tr>
<tr>
<td>24 hr/-2°C/wo</td>
<td></td>
<td>1.4f</td>
<td>0.5abcd</td>
<td>91.9abc</td>
</tr>
<tr>
<td>24 hr/-2°C/w</td>
<td></td>
<td>0.9fg</td>
<td>0.2cd</td>
<td>92.1a</td>
</tr>
<tr>
<td>48 hr/2°C/wo</td>
<td></td>
<td>3.1ab</td>
<td>1.0a</td>
<td>91.5abc</td>
</tr>
<tr>
<td>48 hr/2°C/w</td>
<td></td>
<td>1.1fg</td>
<td>0.3bcd</td>
<td>91.8abc</td>
</tr>
<tr>
<td>48 hr/-2°C/wo</td>
<td></td>
<td>2.8bc</td>
<td>0.5bcd</td>
<td>91.6abc</td>
</tr>
<tr>
<td>48 hr/-2°C/w</td>
<td></td>
<td>1.0fg</td>
<td>0.3bcd</td>
<td>91.6abc</td>
</tr>
</tbody>
</table>

1 Preblend treatment combinations include holding time (HT=0, 18, 24, or 48 hr), holding temperature (Temp=2°C or -2°C), and STPP level (w=with, wo=without).
2 Raw batter stability, mL gel-water cookout from a 34-g sample.
3 Raw batter stability, mL fat cookout from a 34-g sample.
4 Cooking yields from 25-g of raw batter cooked in a cellulose thimble container.

abcdefg Means in the same column bearing like superscripts are not different (P>0.05).
Table 4. Yield means of sausages made from preblends made with or without sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C

<table>
<thead>
<tr>
<th>Treatment Parameter</th>
<th>Parameter</th>
<th>smokehouse yields</th>
<th>chilled yields</th>
<th>consumer cooked yields</th>
<th>overall yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT/Temp/SIPP1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 hr/2°C/wo</td>
<td>86.6</td>
<td>98.7</td>
<td>97.8de</td>
<td>83.6efg</td>
<td></td>
</tr>
<tr>
<td>0 hr/2°C/w</td>
<td>87.2</td>
<td>98.7</td>
<td>98.8abc</td>
<td>85.1bcde</td>
<td></td>
</tr>
<tr>
<td>0 hr/-2°C/wo</td>
<td>86.7</td>
<td>98.5</td>
<td>98.4cd</td>
<td>84.0defg</td>
<td></td>
</tr>
<tr>
<td>0 hr/-2°C/w</td>
<td>87.2</td>
<td>98.7</td>
<td>98.8abc</td>
<td>84.9bcdde</td>
<td></td>
</tr>
<tr>
<td>18 hr/2°C/wo</td>
<td>87.4</td>
<td>98.8</td>
<td>97.9de</td>
<td>84.6cde</td>
<td></td>
</tr>
<tr>
<td>18 hr/2°C/w</td>
<td>87.6</td>
<td>98.6</td>
<td>99.3ab</td>
<td>86.4ab</td>
<td></td>
</tr>
<tr>
<td>18 hr/-2°C/wo</td>
<td>87.0</td>
<td>98.4</td>
<td>98.8abc</td>
<td>85.8abc</td>
<td></td>
</tr>
<tr>
<td>18 hr/-2°C/w</td>
<td>88.1</td>
<td>98.7</td>
<td>99.6a</td>
<td>87.3a</td>
<td></td>
</tr>
<tr>
<td>24 hr/2°C/wo</td>
<td>87.0</td>
<td>98.7</td>
<td>96.4f</td>
<td>82.9g</td>
<td></td>
</tr>
<tr>
<td>24 hr/2°C/w</td>
<td>87.6</td>
<td>98.8</td>
<td>99.2abc</td>
<td>85.8abc</td>
<td></td>
</tr>
<tr>
<td>24 hr/-2°C/wo</td>
<td>87.3</td>
<td>98.8</td>
<td>98.9abc</td>
<td>85.4bcd</td>
<td></td>
</tr>
<tr>
<td>24 hr/-2°C/w</td>
<td>86.8</td>
<td>98.7</td>
<td>99.3ab</td>
<td>85.8abc</td>
<td></td>
</tr>
<tr>
<td>48 hr/2°C/wo</td>
<td>86.9</td>
<td>98.4</td>
<td>97.6e</td>
<td>83.5fg</td>
<td></td>
</tr>
<tr>
<td>48 hr/2°C/w</td>
<td>68.2</td>
<td>98.4</td>
<td>99.2abc</td>
<td>85.3bcd</td>
<td></td>
</tr>
<tr>
<td>48 hr/-2°C/wo</td>
<td>86.3</td>
<td>98.6</td>
<td>98.5bcd</td>
<td>84.2defg</td>
<td></td>
</tr>
<tr>
<td>48 hr/-2°C/w</td>
<td>87.1</td>
<td>98.7</td>
<td>99.3ab</td>
<td>85.1bcde</td>
<td></td>
</tr>
<tr>
<td>Standard error</td>
<td>0.55</td>
<td>0.19</td>
<td>0.24</td>
<td>0.54</td>
<td></td>
</tr>
</tbody>
</table>

1 Preblend treatment combinations include holding time (HT=0, 18, 24, or 48 hr), holding temperature (Temp=2° or -2°C), and STPP level (w=with, wo=without)

abcdefg Means in the same column bearing like superscripts are not different (P>0.05).
Table 5. Firmness means of sausages made from preblends made with or without sodium tripolyphosphate (STPP) and held up to 48 hr at 2° or -2°C

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Parameter</th>
<th>Parameter</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>173</td>
<td>WBS^2</td>
<td>compression^3</td>
</tr>
<tr>
<td>0 hr/2°C/wo</td>
<td>53.0d</td>
<td>427.4d</td>
<td>0.83bcde</td>
</tr>
<tr>
<td>0 hr/2°C/w</td>
<td>64.2abc</td>
<td>551.0bc</td>
<td>0.80b</td>
</tr>
<tr>
<td>0 hr/-2°C/wo</td>
<td>65.8abc</td>
<td>550.1bc</td>
<td>0.84abcd</td>
</tr>
<tr>
<td>0 hr/-2°C/w</td>
<td>67.6ab</td>
<td>634.6a</td>
<td>0.82bcd</td>
</tr>
<tr>
<td>18 hr/2°C/wo</td>
<td>57.1bcd</td>
<td>427.8d</td>
<td>0.83abcd</td>
</tr>
<tr>
<td>18 hr/2°C/w</td>
<td>70.0a</td>
<td>679.5a</td>
<td>0.82def</td>
</tr>
<tr>
<td>18 hr/-2°C/wo</td>
<td>57.2bcd</td>
<td>473.0c</td>
<td>0.83abcd</td>
</tr>
<tr>
<td>18 hr/-2°C/w</td>
<td>63.3abc</td>
<td>672.7a</td>
<td>0.82bcde</td>
</tr>
<tr>
<td>24 hr/2°C/wo</td>
<td>62.2abcd</td>
<td>430.1d</td>
<td>0.84abc</td>
</tr>
<tr>
<td>24 hr/2°C/w</td>
<td>64.5abc</td>
<td>647.4a</td>
<td>0.82cde</td>
</tr>
<tr>
<td>24 hr/-2°C/wo</td>
<td>60.2abcd</td>
<td>522.3c</td>
<td>0.84abcd</td>
</tr>
<tr>
<td>24 hr/-2°C/w</td>
<td>67.0abc</td>
<td>720.4a</td>
<td>0.84a</td>
</tr>
<tr>
<td>48 hr/2°C/wo</td>
<td>57.2bcd</td>
<td>452.9d</td>
<td>0.83abcd</td>
</tr>
<tr>
<td>48 hr/2°C/w</td>
<td>70.4a</td>
<td>695.5a</td>
<td>0.81ef</td>
</tr>
<tr>
<td>48 hr/-2°C/wo</td>
<td>57.3bcd</td>
<td>473.2cd</td>
<td>0.84abcd</td>
</tr>
<tr>
<td>48 hr/-2°C/w</td>
<td>67.4abc</td>
<td>706.8a</td>
<td>0.83abcd</td>
</tr>
<tr>
<td>Standard error</td>
<td>3.08</td>
<td>29.46</td>
<td>0.01</td>
</tr>
</tbody>
</table>

1 Preblend treatment combinations include holding time (HT=0, 18, 24, or 48 hr), holding temperature (Temp=2° or -2°C), and STPP level (w=with, wo=without).
2 Warner-Bratzler Shear (WBS), g force required to shear 15-mm core samples.
3 Force (g) of first compression of 15-mm core samples.
4 Area under second compression curve/under area under first compression curve.
abcdef Means in the same column bearing like superscripts are not different (P>0.05).
Table 6. Results of the main effects of holding temperature and sodium tripolyphosphate (STPP) on preblended course-ground sausages

<table>
<thead>
<tr>
<th>Main Effect</th>
<th>gel-water cookout&lt;sup&gt;1&lt;/sup&gt;</th>
<th>fat cookout&lt;sup&gt;2&lt;/sup&gt;</th>
<th>consumer cook yields</th>
<th>overall yields</th>
<th>WBS&lt;sup&gt;3&lt;/sup&gt; compression</th>
<th>cohesiveness&lt;sup&gt;4&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Holding</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2°C</td>
<td>1.9</td>
<td>0.5</td>
<td>98.3</td>
<td>85.3</td>
<td>62.3</td>
<td>538.9</td>
</tr>
<tr>
<td>-2°C</td>
<td>1.4</td>
<td>0.4</td>
<td>99.0</td>
<td>84.6</td>
<td>63.2</td>
<td>594.1</td>
</tr>
<tr>
<td><strong>L. O. S.</strong>&lt;sup&gt;6&lt;/sup&gt;</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td>*</td>
<td>NS</td>
<td>*</td>
</tr>
<tr>
<td><strong>STPP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without STPP</td>
<td>2.4</td>
<td>0.7</td>
<td>98.0</td>
<td>84.2</td>
<td>58.7</td>
<td>469.6</td>
</tr>
<tr>
<td>with STPP</td>
<td>1.0</td>
<td>0.3</td>
<td>99.2</td>
<td>85.7</td>
<td>66.8</td>
<td>663.5</td>
</tr>
<tr>
<td><strong>L. O. S.</strong>&lt;sup&gt;6&lt;/sup&gt;</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

<sup>1</sup> Raw batter stability, mL gel-water cookout from a 34-g sample.
<sup>2</sup> Raw batter stability, mL fat cookout from a 34-g sample.
<sup>3</sup> Warner-Bratzler Shear (WBS), g force required to shear 15-mm core samples.
<sup>4</sup> Force (g) of first compression of 15-mm core samples.
<sup>5</sup> Area under second compression curve/area under first compression curve.
<sup>6</sup> Level of Significance.

NS = means in the same column per main effect are not different (P>0.05).
* = means in the same column per main effect are different (P<0.05).
** = means in the same column per main effect are different (P<0.01).
Table 7. Color measurements of sausages made from preblends made with or without sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Hunter color values&lt;sup&gt;1&lt;/sup&gt;</th>
<th>L</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 hr/2°C/wo</td>
<td>42.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>8.6&lt;sup&gt;f&lt;/sup&gt;</td>
<td>11.1&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>0 hr/2°C/w</td>
<td>38.9&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>9.6&lt;sup&gt;bcde&lt;/sup&gt;</td>
<td>11.5&lt;sup&gt;ef&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>0 hr/-2°C/wo</td>
<td>40.3&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>9.5&lt;sup&gt;cde&lt;/sup&gt;</td>
<td>11.7&lt;sup&gt;def&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>0 hr/-2°C/w</td>
<td>39.8&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>9.5&lt;sup&gt;bcde&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;bcddef&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>18 hr/2°C/wo</td>
<td>42.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.2&lt;sup&gt;def&lt;/sup&gt;</td>
<td>13.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>18 hr/2°C/w</td>
<td>39.4&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>10.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>18 hr/-2°C/wo</td>
<td>40.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>9.6&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>12.7&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>18 hr/-2°C/w</td>
<td>39.4&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>10.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>12.5&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>24 hr/2°C/wo</td>
<td>42.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.6&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>12.6&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>24 hr/2°C/w</td>
<td>38.5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>9.9&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>12.7&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>24 hr/-2°C/wo</td>
<td>41.9&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>9.5&lt;sup&gt;cde&lt;/sup&gt;</td>
<td>12.8&lt;sup&gt;abc&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>24 hr/-2°C/w</td>
<td>40.7&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>10.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.7&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>48 hr/2°C/wo</td>
<td>41.4&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>9.2&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>48 hr/2°C/w</td>
<td>38.7&lt;sup&gt;d&lt;/sup&gt;</td>
<td>10.1&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>12.4&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>48 hr/-2°C/wo</td>
<td>39.4&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>9.1&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Standard error</td>
<td>1.10</td>
<td>0.26</td>
<td>0.37</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> Hunter "L" value=darkness, Hunter "a"=redness, Hunter "b"=yellowness.

<sup>2</sup> Preblend treatment combinations include holding time (HT=0, 18, 24, or 48 hr), holding temperature (Temp=2°C or -2°C), and STPP level (w=with, wo=without).

abcdef Means in the same column bearing like superscripts are not different (P>0.05).
Table 8. Color measurements of sausages made from preblends made with or without sodium tripolyphosphate (STPP) and held up to 48 hr at 2°C or -2°C. Sausages were held for 7 days under retail-sales lighting.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Hunter color values&lt;sup&gt;1&lt;/sup&gt;</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>0 hr/2°C/wo</td>
<td>48.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.5&lt;sup&gt;g&lt;/sup&gt;</td>
<td>10.8&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>0 hr/2°C/w</td>
<td>42.4&lt;sup&gt;e&lt;/sup&gt;</td>
<td>8.7&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>12.6&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>0 hr/-2°C/wo</td>
<td>46.1&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>7.9&lt;sup&gt;bcef&lt;/sup&gt;</td>
<td>12.5&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>0 hr/-2°C/w</td>
<td>43.6&lt;sup&gt;de&lt;/sup&gt;</td>
<td>8.8&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>13.2&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>18 hr/2°C/wo</td>
<td>46.7&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>7.2&lt;sup&gt;efg&lt;/sup&gt;</td>
<td>12.7&lt;sup&gt;abc&lt;/sup&gt;</td>
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<tr>
<td>18 hr/2°C/w</td>
<td>44.4&lt;sup&gt;cde&lt;/sup&gt;</td>
<td>8.2&lt;sup&gt;abcdef&lt;/sup&gt;</td>
<td>13.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>18 hr/-2°C/wo</td>
<td>46.3&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>7.4&lt;sup&gt;defg&lt;/sup&gt;</td>
<td>12.9&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>18 hr/-2°C/w</td>
<td>42.7&lt;sup&gt;e&lt;/sup&gt;</td>
<td>9.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>13.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>24 hr/2°C/wo</td>
<td>47.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.9&lt;sup&gt;fg&lt;/sup&gt;</td>
<td>12.4&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>24 hr/2°C/w</td>
<td>42.3&lt;sup&gt;e&lt;/sup&gt;</td>
<td>8.3&lt;sup&gt;bcdef&lt;/sup&gt;</td>
<td>12.9&lt;sup&gt;abc&lt;/sup&gt;</td>
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<tr>
<td>24 hr/-2°C/wo</td>
<td>44.7&lt;sup&gt;cde&lt;/sup&gt;</td>
<td>8.3&lt;sup&gt;abcde&lt;/sup&gt;</td>
<td>13.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>24 hr/-2°C/w</td>
<td>42.5&lt;sup&gt;e&lt;/sup&gt;</td>
<td>9.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>48 hr/2°C/wo</td>
<td>45.3&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>7.3&lt;sup&gt;efg&lt;/sup&gt;</td>
<td>12.3&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>48 hr/2°C/w</td>
<td>43.4&lt;sup&gt;de&lt;/sup&gt;</td>
<td>7.8&lt;sup&gt;cdef&lt;/sup&gt;</td>
<td>12.5&lt;sup&gt;bc&lt;/sup&gt;</td>
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<tr>
<td>48 hr/-2°C/wo</td>
<td>47.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.1&lt;sup&gt;efg&lt;/sup&gt;</td>
<td>12.3&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
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<td>44.4&lt;sup&gt;cde&lt;/sup&gt;</td>
<td>8.2&lt;sup&gt;abcdef&lt;/sup&gt;</td>
<td>13.5&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
<td>Standard error</td>
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<td>0.38</td>
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<sup>1</sup> Hunter "L" value=darkness, Hunter "a"=redness, Hunter "b"=yellowness.

<sup>2</sup> Preblend treatment combinations include holding time (HT=0, 18, 24, or 48 hr), holding temperature (Temp=2°C or -2°C), and STPP level (w=with, wo=without).

abcdefg Means in the same column bearing like superscripts are not different (P>0.05).
Table 9. Results of the main effects of holding temperature and sodium tripolyphosphate (STPP) on Hunter color values of preblended course-ground sausages held for 7 days in a retail-sales lighting.

<table>
<thead>
<tr>
<th>Main Effect</th>
<th>Hunter color values</th>
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<tbody>
<tr>
<td></td>
<td>L</td>
<td>a</td>
<td>b</td>
<td>L</td>
<td>a</td>
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<td>Holding temperature</td>
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<tr>
<td>L. O. S.²</td>
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<td>*</td>
<td>NS</td>
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</tr>
</tbody>
</table>

1 Hunter "L" value=darkness, Hunter "a"=redness, Hunter "b" yellowness
2 Level of Significance
   NS = means in the same column per main effect are not different (P>0.05)
   * = means in the same column per main effect are different (P<0.05)
   ** = means in the same column per main effect are different (P<0.01)