# THE EFFECT OF MARINATION IN SODIUM HEXAMETAPHOSPHATE SOLUTION ON THE PALATABILITY OF BEEF

by

EUNICE MARIE GANAWAY MILLER

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Dorothy L. Harrison
Major Professor

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# INTRODUCTION

Tenderness and juiciness in meat are characteristics highly desired by the consumer. The two are closely related; the more tender the meat, the easier the juices are released by chewing and the juicier the meat appears. The many factors that influence juiciness and tenderness of meat may be broadly divided into ante-mortem and post-mortem factors (Weir, 1960). One of the most important factors influencing meat quality is the water holding capacity (WHC), the ability of meat to hold fast its own or added water during application of any force such as pressing, heating, chewing, or grinding (Hamm, 1959). The WHC of meat is influenced by both post-mortem and ante-mortem conditions. In recent years the object of much research in meats has been an attempt to gain understanding of specific factors that influence WHC and how it can be measured and controlled. Hamm (1959) stated that high WHC results in high juiciness of meat after cooking. Furthermore, tenderness, color, and flavor of meat are related to its capacity for holding water.

The use of alkaline phosphates to increase WHC has been investigated within the past 15 years by various scientists primarily in the United States and Germany. Hamm (1960) pointed out that treatment with alkaline phosphate caused an increase in pH and WHC of raw, ground pork and beef. Recent studies (Mahon, 1962; May et al., 1963; and Schermerhorn et al., 1963) indicated that soaking freshly killed, eviscerated poultry in a phosphate solution resulted in several benefits. There was less "weep" in

prepackaged poultry, reduced thawing drip and cooking loss, and the final product was more tender, flavorsome, and resistant to oxidative deterioration than poultry that had not received the phosphate treatment.

The studies reported to-date on red meat treated with alkaline phosphate have been concerned mainly with the chemical changes that occurred as a result of the treatment. Work in this laboratory (Rust, 1963) consisted of injecting a sodium hexametaphosphate (SHMP) solution into 2-in. loin steaks. The study reported here was undertaken to obtain information on the effect of marinating, in a solution of SHMP, 1-in. steaks from the longissimus dorsi muscle of U. S. Standard beef on the flavor, tenderness, juiciness, and certain related characteristics of the meat.

## REVIEW OF LITERATURE

In reviewing the literature related to use of polyphosphates in meat terms such as water holding capacity, water holding power, water binding capacity, and water binding properties seemingly are used interchangeably. In the following discussion "water holding capacity" (WHC) is used.

### Use of Polyphosphates to Increase Water Holding Capacity

It is claimed that one of the main functions of adding phosphate salts to meat is their promotion of the WHC thereby improving juiciness and often tenderness and flavor since these

qualities are believed to be, in part, affected by water retention. In 1950, Hall and in 1952, Brissey were issued patents involving the use of phosphate in the curing of hams (Mahon et al., 1956). At the present time, it is common practice in the meat industry to inject a pickle containing 2% alkaline phosphate into hams. Wilson (1956) found no effect on yield but phosphate treated hams appeared to be firmer and to have less free moisture than untreated hams. In overall palatability the panel preferred the hams containing SHMP to the other phosphates tested. Phosphate treatment definitely reduced jelly formation in canned hams and made possible the application of more efficient heating procedures so that shelf-life is increased. Hamm (1960) stated the effect of the phosphate is particularly great if the meat has an unfavorable WHC. Use of polyphosphates as a means of increasing WHC of sausages has been extensively investigated in Germany. The additive brings about increased swelling when water is added to the meat and since some of the added water is retained when the meat is cooked, it improves texture and consistency.

Hellendoorn (1962) investigated the action of different phosphate salts on the WHC of ground meat at various pHs in 0.5% concentration, in combination with 2% sodium chloride, and with 50% water added. As a reference, sodium chloride was used alone in a concentration of equal ionic strength. At pH values below 5.5, pyrophosphate and tripolyphosphate exerted a depressing effect on the WHC of uncooked meat. In heated

samples in the normal pH range of 6-6.5 pyrophosphate and tripolyphosphate had a marked specific activity equal to adenosine triphosphate (ATP). The specificity increased with ionic strength of 0.40 upward. Orthophosphate and Graham's salt (metaphosphates) had a minor specificity.

Poultry "weep" has been a long standing problem with prepackaged poultry. Mahon (1962) reported that when 6% KENA (commercial polyphosphate) was added to the slush ice solution in which the freshly killed, eviscerated poultry are allowed to soak, the amount of initial water uptake and the amount of "weep" were significantly reduced. Schermerhorn et al. (1963) conducted a similar experiment in which not only KENA but also 0, 4, 8, and 12% food grade sodium tripolyphosphate were used. As the % polyphosphate in the chill water increased, water uptake decreased. These workers supported the view that polyphosphates could be used effectively in the cooling water for broilers as a means of reducing moisture and cooking loss.

May et al. (1963) studied the effect of polyphosphates (KENA) during chilling of eviscerated poultry on subsequent moisture losses during cutting up and storage at 35°F. A low level of polyphosphate (4 oz/gal) significantly increased water uptake during chilling while a high level (10 oz/gal) significantly depressed water uptake. During storage the phosphate treated birds retained more than 2% more weight than the control.

Sherman (1961a) studied the influence of sodium chloride,

pyrophosphate, and polyphosphate on the WHC of fresh pork. He concluded that all the additives improved fluid retention but that the phosphates were particularly effective.

## Mode of Action of Polyphosphates

Our knowledge of meat hydration is incomplete. Basically the WHC of meat is governed by the state of the muscle proteins (Wismer-Pedersen, 1962), which is affected by factors such as pH and the presence of alkaline earth metals. Swift and Berman (1959) pointed out that present information falls short of explaining differences in meat as reflected by variations in WHC and juiciness and tenderness which, in part, are also thought to be affected by WHC.

There have been several theories proposed as to how the polyphosphates affect the WHC of meat. Hamm (1959) stated that the polyphosphates increase the hydration of meat proteins more than that of other proteins. He postulated that the effect of the alkaline polyphosphates is due not only to their relatively high ionic strengths and to their influence on the meat pH, but that these salts work mainly by their ability to form strong complex compounds with alkaline earth metals. They eliminate primarily the bivalent cations, $Ca^{++}$, $Mg^{++}$, and $Zn^{++}$, in the same manner as the organic polyphosphate ATP. The ease with which these ions are removed is believed to depend on meat pH since ions bind more strongly to meat proteins at pH above 5.5.

Swift et al. (1960) also emphasized the close relationship

between pH and WHC in meat. The pH of meat depends upon both its pre- and post-slaughter history. It is affected also by the addition of neutral salts and polyphosphates. Hamm (1960) pointed out that small changes in meat pH may cause relatively great changes in WHC. The same occurs with swelling. Water absorption by meat falls to a minimum at the isoelectric point of the meat proteins (pH 5.0 - 5.5) and rises at both higher and lower pH values.

Sherman (1961a) stated that the effect of alkaline polyphosphates is not merely a question of pH nor does the ability of polyphosphates to complex $Ca^{++}$ and $Mg^{++}$ in meat explain their efficiency in improving fluid retention. It was suggested that at low temperature the polyphosphates improve WHC of meat primarily through solubilization of the proteins, particularly actomyosin. Aging time and temperature, solution-meat ratios employed, pH and ionic strength of the solution mixed with the meat, previous history, and initial pH of the meat all influence this process.

In a later study (1962) Sherman stated that with alkaline phosphates, cations are preferentially absorbed and the WHC effect is extremely dependent on pH. With increasing pH the concentration difference between anion and cation absorption decreases. Thus, phosphate ion absorption must be of some importance. Through study of temperature effects it was found that at 0°C the influence of polyphosphate is related to ion absorption, and at 100°C the primary factors are the degree of actomyosin solubilization during aging at 0°C and the physical

nature of the heat-coagulated protein mass.

Bendall (1954) investigated the effect of several polyphosphate solutions on the ability to increase WHC of ground rabbit muscle. He found that swelling was increased both before and after cooking and explained this in terms of change in ionic strength, since the pH of the solutions was the same. Pyrophosphate was regarded as having a specific swelling effect on lean meat because of its ability to split actomyosin.

Swift and Ellis (1956) studied factors affecting WHC of phosphate-treated ground meat. Their findings were, in general, consistent with the premise that the factors governing the moisture retention of meat treated with phosphate additives are those that influence solubilization of muscle proteins, namely, temperature, time, ionic strength and pH of treatments.

## Water Holding Capacity and Quality of Meat

Juiciness. Hamm (1960) stated that a correlation between the WHC of cooked meat and its taste should be expected in that the meat is more juicy, the more water it contains and the faster this water is "bound" to the coagulated tissue. However, the question of a relation between the WHC of meat and its juiciness is not easily answered. According to Hamm (1960) it can be solved only by critical measurement of (1) the WHC of the raw meat, (2) the amount of water released during cooking, and (3) WHC of the cooked meat in comparison with the subjective score.

On the whole, subjective juiciness scores and objective

values for juiciness such as the amount of press fluid do not appear to represent the same thing (Gaddis et al., 1950). Quality as well as quantity of juice in meat is important and is difficult to differentiate from other palatability factors. Many workers including Satorius and Child (1938) and Gaddis et al, (1950) have found a close relationship between quantity and quality of juice. Certainly fat adds flavor, which stimulates saliva and increases the impression of juiciness, richness, and smoothness during the chewing process (Griswold, 1962, p. 113).

Hamm (1960) explained that the taste of cooked meat will be "dry" if the juice is squeezed out as chewing begins. Therefore, it is to be expected that not the amount of expressible water but the amount of water bound to the coagulated muscle tissue (not expressible juice) is related to the subjective impression, "juiciness". The amount of bound water has not been determined in most of the studies, reported in the literature, however.

Relative differences in the WHC of raw meat are retained to a certain extent after heat denaturation. Thus, meat having a high WHC in the raw state will bind its water faster during heating than meat having a low WHC in the raw state (Hamm, 1960).

Rust (1963) studied the palatability characteristics of 2-in. loin steaks from U. S. Standard beef injected with 0.03 M sodium hexametaphosphate solution equivalent

to 5, 10, and 15% of the weight of the steaks. All steaks were significantly more juicy than untreated steaks as measured both subjectively and objectively. A highly significant correlation was found also between pH and juiciness scores. As the pH increased, juiciness scores increased.

Effect of alkaline polyphosphates on palatability of poultry was investigated by Mahon (1962). Freshly killed, eviscerated poultry chilled in ice slush to which KENA was added produced a moist cooked product that could be held in refrigerated storage, reheated and still be as moist and tender as if freshly cooked.

May et al. (1963) conducted a similar experiment using KENA in the chill water in 0, 4, 8, or 10 oz/gal concentrations except that the birds were frozen and stored at -30°F until needed for organoleptic evaluation. These workers reported that the polyphosphate increased mean ratings of juiciness of both white and dark meat in direct proportion to the increase in phosphate levels. Juiciness scores for dark meat from all groups exceeded those of the white meat.

Tenderness. Processes that cause a loosening of the protein structure of muscle also increase WHC. Most of these processes also cause changes in the tenderness of meat. For example, the more aged meat is hydrated, the greater is the distance between the peptide chains in the protein and the more soft and tender is the meat (Hamm, 1960). Wierbicki et al. (1956) studied the relationship of post-mortem tenderization to

the WHC of proteins. The juice expressed during cooking in a standard manner was measured as a possible index to the degree of water hydration. In all cases there was a decrease in the amount of juices (or shrinkage) with aging and an increase in tenderness. In every case pH shift was slightly alkaline and away from the isoelectric point, thus causing an increase in WHC. During post-mortem changes the minimum of muscle hydration (rigor mortis) corresponds to a minimum of tenderness. Of course, tenderness is not only a matter of muscle hydration since such factors as splitting of protein chains during aging and the influence of connective tissue may be important. Therefore, as pointed out by Satorius and Child (1938) it is conceivable that a correlation between WHC and tenderness will not be found in all cases.

In the study on poultry treated with KENA by May et al. (1960) it was reported that the alkaline polyphosphate definitely increased tenderness of white meat, but no real differences were found for treated and untreated dark meat. Mahon (1962) also reported greater tenderness of poultry meat treated with KENA, which allowed more efficient boning of the carcass.

Rust (1963) reported that loin steaks injected with SHMP equivalent to 5, 10, or 15% of the weight were significantly more tender than untreated steaks as measured both subjectively and objectively. Greatest tenderness was achieved at the 10% level of phosphate. Increasing the phosphate beyond 10% of the weight of the steak had a deleterious effect. The

correlation between pH and the subjective measurement was significant, which indicated the increase in pH was at least a contributing factor to the increased tenderness. This also was reported by Hamm (1960).

Color. The color of meat may be affected not only by differences in myoglobin content or by different steps of oxidation of the heme component, but WHC also has considerable influence on the color. Color becomes darker with increasing pH. High WHC caused by a high ultimate pH value, is of primary importance in accounting for the color of "dark-cutting" beef (Bate-Smith, 1948).

Hamm (1960) stated that, in general, it has been observed that an increase in WHC is accompanied by a darker color, and the meat color brightens with decreasing WHC. He explained this phenomenon by pointing out that the higher the WHC of muscle, the more "close" is the structure and the lower is the rate of diffusion of oxygen to the intracellular proteins.

Rust (1960) found that the effect of SHMP on the color of the freshly cut and exposed interior of broiled steaks was relatively minor. Klose et al. (1963) reported that freshly killed, eviscerated poultry allowed to chill in water to which KENA had been added acquired a bluish white appearance but after cooking, no difference was detected.

Flavor. Rust (1963) reported that the mean flavor score for U. S. Standard 2-in. loin steaks improved significantly when the steaks were injected with SHMP equivalent to 5 or 10%

of the weight as compared to untreated steaks or those injected with SHMP at the 15% level. The flavor of the latter was described as "watery".

In a study conducted by Klose et al. (1963) panel members definitely could distinguish between the flavor of control birds and poultry that had been soaked in a phosphate chill water. However, the panel could not distinguish differences in flavor between several phosphates. Flavor effects on the freshly cooked meat, other than saltiness, were not demonstrated by polyphosphate treatments. In a similar study Mahon (1962) mentioned a more flavorsome product when birds were treated with alkaline polyphosphate because more juices were retained.

Effect of Phosphates on Factors Related to Cooking

Mahon (1962) reported that phosphate treated poultry as compared to untreated birds showed significantly reduced non-evaporative fluid associated with the cooking process. He also observed more rapid heat conduction in treated poultry, and suggested that cooking time required for the same degree of "doneness" or the same internal temperature could be reduced by 5-15%.

Klose et al. (1963) found there was a substantial improvement in yield of cooked poultry meat when polyphosphates were used in the chilling process. The authors indicated that this probably represented a greater retention of the original natural moisture, since the water absorption during chilling was

appreciably less for the polyphosphate groups than for controls. Moisture retention in the cooked meat, expressed as % of eviscerated unchilled weight was 2 to 5% greater among the polyphosphate treated birds.

Schermerhorn et al. (1963) used solutions of 0, 4, 8, and 12% food grade sodium tripolyphosphate and the commercial phosphate, KENA, to chill poultry. In cooking, moisture loss was greatest for untreated broilers. In terms of cooked yield the solution of 4% commercial polyphosphate gave 3.1% gain over the control, whereas other polyphosphate treatments gave an average gain of 2.4%.

The Institutional Management Department at Kansas State University investigated the effect of injecting 2% SHMP solution into U. S. Utility top rounds to increase the weight 20%. Controls were compared with roasts injected and cooked immediately, and roasts injected, aged 12 hr, and cooked. Those roasts injected and cooked immediately tended to have decreased cooking losses, increased cooking time, and increased total usable meat. Differences among treatment for cost per serving and palatability were not statistically significant. Since the phosphate treatment did not significantly improve the roasts it was suggested that an acceptable product could be prepared using untreated beef.

Rust (1963) injected SHMP solution into 2-in. U. S. Standard steaks equivalent to 5, 10, or 15% of the weight. There were no significant differences in dripping losses

attributable to percent of phosphate treatment. Any quantity of phosphate solution increased the volatile cooking losses over those for untreated steaks, but at the same time the % total moisture in the cooked steaks was increased by any quantity of phosphate solution. No significant differences were found for the response of cooking time in min/lb to the % of phosphate solution. There was a slight trend for untreated steaks to require less time to cook than treated steaks.

Wierbicki et al. (1957) studied the effect of temperature on WHC, pH, and ion concentration, in beef cooked alone and with added water or sodium chloride. These workers found that WHC decreased with increasing temperature except between 55° and 65°C, when it increased slightly. The released fluid and pH values of the heated meat increased with increasing temperature, especially between 40-70°C. It was suggested that these temperatures coincide with the commencement and termination of protein denaturation. Sherman (1961b) followed this investigation with a study of the influence of heating temperature (25-100°C) on WHC in the presence of distilled water, and solutions of sodium chloride, tetrasodium pyrophosphate, and commercial polyphosphate in a range of concentration of 0.5 to 4.0%. Freshly slaughtered ground pork shoulder was used. With a 4% solution the meat retained all of the added fluid at low heating temperature and the temperature at which fluid release commenced depended on the additive; above 40°C for sodium chloride and above 65-75°C for phosphates. This

suggested that fluid is bound more strongly by meat at elevated temperature in presence of polyphosphates than in the presence of the sodium chloride. Rise of pH as a result of heating appeared to proceed more in the presence of polyphosphate than in the presence of sodium chloride. However, the increased influence of polyphosphate was not attributed to pH alone, but also to the ability of the polyphosphate to split the bond between actin and myosin in actomyosin. Sherman (1961b) also found a stronger coagula developed with alkaline polyphosphates than with sodium chloride. Thus, more fluid was retained by meat at higher temperature in the presence of polyphosphate.

## Determination of Water Holding Capacity

Most changes of WHC of meat do not affect the fixed bound hydration water. Therefore, according to Hamm (1960), WHC is not measured by methods that directly determine the fixed bound hydration water. He explained that the only methods appropriate for study of the WHC concern differences in the immobilization of "free or loose" water. It is not possible to give any absolute figures for the immobilized part of water because the "immobilized" water determined depends on the method used. Thus, WHC must be defined in terms of method of measurement. The WHC of meat may be expressed in terms of the amount of "loose" water related to the total content of moisture in muscle or in terms of the amount of bound water related to muscle

proteins. Most methods are based on measuring the "loose" water liberated by applying pressure on the muscle tissue. The pressure can be produced by sedimentation, centrifugation, filtration, or press methods.

Hamm (1960) reviewed some of the literature reporting procedures that he classified as press methods for determining WHC, and pointed out that the press method has been used particularly for study of the correlation between subjective impression of "juiciness" and an objective test, using "pressometers" at varying pressures. At first, this method was used as a qualitative measurement for the wetness of meat, then transformed to a quantitative technique by using filter paper. In his review Hamm (1960) described a quantitative method developed by Grau and Hamm for determining the WHC of meat that is a combination of the press and filter paper techniques. Meat tissue (300 mg) on filter paper between two Plexiglas plates is pressed to a round thin film, and the water squeezed out is absorbed by the filter paper. The area of the ring of expressed juice absorbed by the filter paper is proportional to the amount of "loose" water. Below the area of pressed meat the pressure is so high that the filter paper absorbs almost no water. The linear correlation between the area of expressed juice and "loose" water is not influenced by added salts, even at high concentrations, or by added water up to 100%. The pressure produced by screwing down the plates by hand is so great that individual differences of pressure do not influence the amount of

expressed "loose" water. Most workers have used the press method for raw meat and a centrifuge method for cooked meat. However, Hamm (1960) pointed out that the filter paper-press method is applicable to raw or heat-denatured meat.

Wierbicki and Deatherage (1958) devised a modification of the Grau and Hamm technique using a hydraulic press to provide constant pressure. A pressure of 500 p.s.i. and pressing time of 1 min were most suitable. When sample size was 400 - 600 mg reproducability was within $\pm$ 5%. By waxing both sides of the filter paper area occupied by the resulting meat film with paraffin and then pressing, it was found that the total moisture area increased by 1.4 to 5.4% over unwaxed filter paper. However, this increase is within the experimental error of the method. These workers pointed out additives that increase the viscosity of fluids, such as Graham's salt, (metaphosphates) tended to decrease the wetted area for the same weight of water in the meat fluid. On the other hand, visible fat particles in the sample being pressed increased the moisture area around the meat film. A compensating polar planimeter was used to measure surface area of the pressed meat film and total area. Percent free water was calculated according to the formula:

$$\% \text{ free water} = \frac{(\text{total area} - \text{meat film area}) \times 61.10}{\text{total moisture (mg) in muscle sample}} \times 100$$

A separate sample of the same meat was analyzed to obtain total moisture (mg) content. Beef, pork, veal, and lamb were tested

and the proportionality constant (61.10) did not change for the different meats. Wierbicki and Deatherage (1958) stated that the results obtained by their method are best expressed as the % of the free water out of the total moisture content of the meat. The % of bound water equals 100 minus % of free water. The amount of free or bound water may also be expressed as % of the meat weight, or as the amount of bound or free water per unit weight of protein of the muscle.

Canadian workers, Asselbergs and Whitaker (1961) used the press technique on samples of cooked meat. The samples were pressed on a Carver press in a special pressure cell (inside diameter 0.788 in.). Weight of the samples before and after pressing was used to determine % free moisture content. Sample range of 1.5 - 3.0 g gave consistent data when pressed 1 min at 500 p.s.i.

Briskey et al. (1959) measured expressible water by modifying the rapid method proposed by Grau and Hamm. Their modified apparatus consisted of Plexiglas plates placed between two 1/4-in. aluminum sheets. Samples of raw meat (0.3 g) were placed on humidified filter paper and a force of 4,350 lb was applied to the center of the top plate by screwing a bolt. The muscle and water areas were marked on the filter paper, measured with a polar planimeter, and the relative amount of expressible water recorded as a ratio of muscle area to water area.

Raymond (1963) used a similar technique. Three (0.3 g)

samples of meat were placed on filter paper, arranged alternately between four Plexiglas plates (Clear Plex G) and subjected to 10,000 p.s.i. for 5 min in a Carver press. Boundaries of pressed meat film and expressed juice were marked with pencil, and traced with a polar planimeter. The results were reported as an expressible moisture index equal to the ratio of the area of pressed meat film to the area of expressed juice.

Sanderson and Vail (1963) placed a 0.5 g sample of cooked meat between two pieces of aluminum foil. After 4 samples were weighed between foils, each was transferred to a Plexiglas plate, the top foil removed, a piece of Whatman filter paper was slipped between the lower foil and meat sample, and a Plexiglas plate placed on top. The process was continued until 4 samples were arranged in like manner. The pile of samples then was placed in a Carver press with paper cushions above and below the samples and pressed for 1 min at 2000 lb pressure. After pressing the samples were peeled off the filter paper and replaced between the same two foils used for weighing. The loss in weight from the original weighing was termed "press fluid". Raymond (1963) used a similar technique except that the meat sample was pressed on the foil and did not have to be peeled from the filter paper. The percent weight loss after pressing was termed "% expressible moisture".

Urbin et al. (1962) used an electrically driven centrifugal pump instead of a hand operated pump to exert a uniform

pressure. This gave increased reproducability between multiple samples of 15% gelatin. Test procedures with gelatin supported the recommendation of other laboratories that a pressure to 500 p.s.i. was adequate. This modified procedure was subsequently used to study full moisture values of various portions of the longissimus dorsi (LD) muscle.

## PROCEDURE

### Meat Used in the Experiment

Sixteen short loins, graded U. S. Standard or equivalent, were purchased from a Kansas City meat packer and shipped to the Kansas State University Meats Laboratory where the LD muscles were stripped from the bone. Much of the beef that would grade U. S. Standard is not given a U.S.D.A. grade in the Kansas City market; thus, several loins were not graded by government graders.

The middle 10-in. section of each loin was cut into 5 2-in. steaks, and the remaining anterior and posterior portions cut into 1-in. steaks (Fig. 1). Steaks were weighed, coded numerically (01-16) according to loin and with letters to denote position within the loin, wrapped individually in aluminum foil, and frozen on shelves containing coils in an upright household freezer maintained at approximately -15°F until used (7 to 9 mos). The 2-in. steaks were used in a previous experiment reported by Rust (1963), and 48 1-in. steaks in this experiment (Table 6, Appendix).

Fig. 1. The division of a short loin.

U. S. Standard grade beef comes from grass fed steers or young cows. Thus, there was wide variation in the degree of finish, marbling, and size of the LD muscle in the steaks from the 16 short loins (Fig. 2).

## Design of the Experiment

Steaks were treated and cooked according to a randomized complete block design (Table 1). A block (cooking period) consisted of 4 steaks, 1 untreated and 3 marinated at room temperature (approximately 78°F) in 0.03 M SHMP ($Na_6P_6O_{18}$) solution for 1, 2, or 6 hr.

## Precooking, Cooking, and Sampling Methods

Prior to each cooking period 4 steaks were defrosted 24 hr in a refrigerator (5° to 7°C), unwrapped, weighed, and 3 of them placed in SHMP solution to cover for the time designated by the experimental design. SHMP solution was prepared the previous day by dissolving 36.9126 g of the phosphate salt (dried 6 hr at 82°C) in distilled water and made up to 2-liters.

A thermometer was inserted into the center of the LD muscle of each steak and the internal temperature recorded. Each marinated steak was placed on a wire rack 5-in. high, allowed to drain 5 min, weighed, replaced on the rack, and set in a shallow roasting pan. Percent weight increase during marination (WIM) was computed. Unmarinated steaks were held wrapped at room temperature 1 hr before placing on a wire rack

Fig. 2. Four steaks illustrating the variation in degree of finish, marbling, and size of the LD among the short loins.

Table 1. Randomized complete block design.

| Blocks (cooking periods) | Treatments | | | |
|---|---|---|---|---|
| | Untreated | Marinating time, hr | | |
| | | 1 | 2 | 6 |
| | Steak code numbers[a] | | | |
| 1 | 15c | 16a | 03b | 12c |
| 2 | 15a | 06f | 07b | 06c |
| 3 | 06b | 14a | 15d | 11d |
| 4 | 16c | 12a | 10b | 15c |
| 5 | 15b | 01a | 07a | 10d |
| 6 | 09a | 08c | 13b | 11c |
| 7 | 03c | 12b | 14b | 16b |
| 8 | 02b | 04b | 06d | 10c |
| 9 | 08a | 09c | 05c | 05f |
| 10 | 06a | 13a | 10c | 06c |
| 11 | 04a | 09b | 05b | 05d |
| 12 | 12d | 08b | 13c | 02a |

[a]Arabic numbers refer to loins; letters refer to steaks within a loin.

5-in. high for cooking in an attempt to have the internal temperature of all steaks similar at the beginning of the cooking period. The average internal temperature for unmarinated steaks was 14°C and that of the marinated was 21°C. The unmarinated steaks had internal temperatures of approximately 18°C with the exception of 3 steaks which were approximately 6°C. Thus, the average internal temperature was lower than that of most marinated steaks.

Four steaks were cooked to 70°C in a rotary gas oven preheated and maintained at 400°F by the modified broiling method described by Hay et al. (1953), and sampled for evaluation according to the plan presented in Figure 3.

Cooking data. Total, volatile, and dripping cooking losses were calculated as percentages of the weight of the raw steak after marinating or after defrosting for unmarinated steaks. Cooking time (total and min/lb) also was determined.

Objective measurements. Warner-Bratzler shear values (25-lb dynamometer) were measured on 3 1/2-in. cores from each steak with 2 measurements on each core (Fig. 3). Meat remaining after shear cores and palatability samples were removed from the steaks was trimmed of all visible fat, connective tissue, and browned surface, and placed in polyethylene bags. It was refrigerated overnight, then ground, and total moisture and pH measured. Total moisture was determined by drying 10 g ground meat in a C. W. Brabender Moisture Tester for 90 min at 121°F, and pH measured with the Beckman Expanded Scale pH Meter (Model 76). A homogenate sample was prepared by blending 5 g of ground meat with 50 ml distilled water in a Waring Blendor for 2 min. The pH of 3 aliquots of the homogenate was measured against a standard commercially prepared buffer, pH 6.86.

Hamm (1959) defined WHC as the ability of meat to hold fast its own or added water during application of any force such as pressing, heating, chewing, or grinding. For this

Explanation of Fig. 3

Plan for sampling steaks

Longissimus dorsi muscle

1. Cores (1/2-in.) for shear value
2. Water holding capacity (the center portion of each core)
3. Cubes (1/2-in.) for palatability scores were cut from area 3. Total moisture and pH were determined on samples of ground meat prepared from that remaining after the cubes for palatability evaluation were removed.

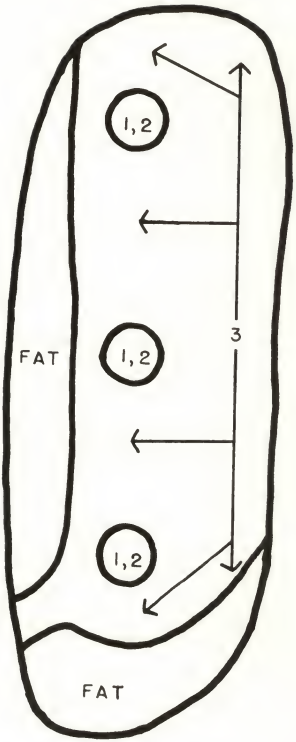


Fig. 3. Plan for sampling steaks.

study, the method used to determine the WHC of meat is a modification of that reported by Briskey et al. (1959). Each sample (0.3 g) was placed in the center of a 6x6 in. Whatman No. 1 filter paper (previously cut and marked so the grainline of all papers was the same and dried at approximately 180°F for 1 1/2 hr), which was placed between two 6-in. square Plexiglas plates (Clear Plex G., 3/8 inch thick). The 3 samples thus placed formed a unit of 4 Plexiglas plates with 3 filter papers and samples placed alternately between them. This unit then was placed in a Carver press and subjected to 10,000 lb pressure for 5 min. During this process, 2 distinct rings were formed on the filter paper. The innermost ring (A) represented the circumference of the pressed meat and the outermost ring (B) the circumference of the expressed liquid (Fig. 4). Immediately after the unit was removed from the press, A was traced with pencil and the pressed meat promptly removed. B was distinct without tracing and did not change upon drying of the filter paper. A compensating polar planimeter (4236 M) was used to obtain the areas of pressed meat (C) and expressed liquid (D) (Fig. 4). Two tracings of both A and B were taken within $\pm$ 0.2 sq cm and the average of A (area of pressed meat, C) subtracted from that of B to obtain the area of expressible liquid (D). The expressible liquid index was calculated as the ratio of C:D. Unity arbitrarily was assumed as the maximum expressible liquid index for any particular sample of meat, and the relative WHC was expressed as:

Explanation of Fig. 4

A = circumference of pressed meat sample

B = circumference of expressed liquid

C = area of pressed meat

D = area of expressed liquid

Expressible liquid index =

$$\frac{\text{area of pressed meat (sq cm)}}{\text{area of expressed liquid (sq cm)}}$$

Arbitrarily assuming unity as the maximum expressible liquid index for any particular meat sample:

1.0 - (expressible liquid index) =

water holding capacity

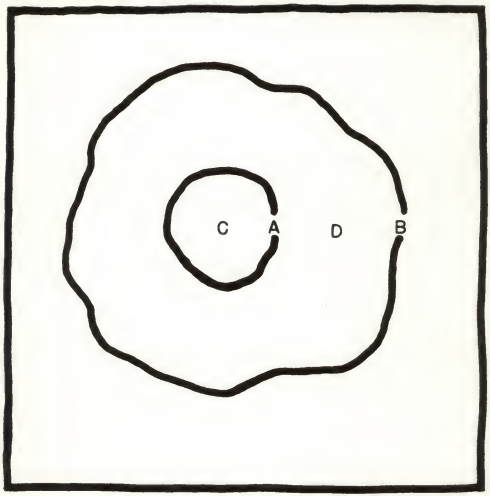


Fig. 4. Diagram showing circumference and area of a pressed meat sample and its expressible liquid as marked on filter paper.

1.0 - (expressible liquid index) = water holding capacity

Organoleptic evaluation. Flavor, juiciness, and tenderness (initial impression and impression after chewing) of each steak was scored by a panel of 6 to 8 experienced judges on a 1 to 7 point scale (1, least desirable and 7, most desirable, Form 1, Appendix). Each judge selected at random 1/2-in. cubes of meat for scoring.

## Statistical Analyses

Analyses of variance were run on data for: (1) flavor scores, (2) tenderness scores (initial scores and scores based on chews); (3) number of chews; (4) juiciness scores: (5) total cooking losses; (6) volatile cooking losses: (7) dripping cooking losses; (8) cooking time (total min and min/lb); (9) WHC; (10) Warner-Bratzler shear values; (11) % total moisture; (12) pH; and (13) % WIM. The following analysis was used:

| Source of variation | D/F |
|---|---|
| Treatments | 3 |
| Remainder | 44 |
| Total | 47 |

When appropriate, least significant differences were calculated.

Correlation coefficients were determined for: (1) juiciness scores vs % WIM; (2) juiciness scores vs % total moisture; (3) juiciness scores vs WHC; (4) juiciness scores vs pH; (5)

juiciness scores vs % total cooking losses; (6) % WIM vs % total moisture; (7) % WIM vs WHC; (8) % WIM vs pH; (9) WHC vs pH; (10) flavor scores vs pH; (11) initial tenderness scores vs pH; (12) initial tenderness scores vs scores based on chews; (13) initial tenderness scores vs shear values; and (14) number of chews vs scores based on chews.

## RESULTS AND DISCUSSION

The effect of 3 intervals of marination in 0.03 M SHMP solution, as compared to no marination, on the palatability and certain related characteristics of steaks from the LD muscle of beef, graded U. S. Standard or equivalent, was investigated. Detailed data for subjective and objective evaluation of the treatments are presented in tables in the Appendix.

### Juiciness Scores and Related Objective Measurements

Juiciness of the cooked steaks was determined subjectively using a 7 point scale (Form 1, Appendix). Objective measurements related to juiciness included % WIM, % total moisture, WHC, and % cooking losses. Mean and F-values attributable to treatment and least significant differences at the 5% level for these data are presented in Table 2.

Steaks marinated 2 and 6 hr received identical mean juiciness scores and were significantly more juicy than steaks marinated 1 hr. The mean score for steaks marinated 1 hr was lower than that of the unmarinated steaks, but the difference was not

Table 2. Mean and F-values attributable to treatment and least significant difference for juiciness scores, weight increase during marination, total moisture, water holding capacity, and cooking losses.

| Marination (hr) | Juiciness scores[a] | Weight increase during marination (%) | Total moisture (%) | Water holding capacity | Cooking losses (%) | | |
|---|---|---|---|---|---|---|---|
| | | | | | Volatile | Drip | Total |
| 0 | 5.96 | --- | 65.58 | 0.67 | 12.37 * | 5.8 | 17.85 * |
| 1 | 5.85 * | 1.44 | 64.19 * | 0.67 | *15.87 * | 5.4 | 21.23 * |
| 2 | 6.26* | 1.09* * | 66.45* | 0.69 | 14.84 | 4.6 | 19.08* |
| 6 | 6.26 | 2.80 | 67.71 | 0.68 | 14.69 | 4.3 | 19.00 |
| F-value | 3.03* | 4.43* | 3.83* | 0.62 ns | 6.91*** | 1.26 ns | 3.56* |
| Lsd | 0.34 | 1.25 | 2.16 | | 1.61 | | 2.13 |

[a]Range, 7 (very juicy) - 1 (extremely dry).
ns = non significant, *P = 0.05, ** P = 0.01, *** P = 0.001.
Lsd = least significant difference at the 5% level.

significant. Increase in mean juiciness scores for steaks marinated 2 or 6 hr over the unmarinated steaks approached significance. These data indicate that it took at least 2 hr of marinating to produce an effect on juiciness and additional marinating after 2 hr was useless so far as ability of the judges to detect increased juiciness. Rust (1963) injected steaks with 0.03 M SHMP solution equivalent to 5, 10, and 15% of the weight and reported that all were significantly ($P = 0.001$) more juicy than untreated steaks. May et al. (1963) used polyphosphates in the chill water for freshly killed, eviscerated poultry and reported that juiciness scores increased in direct proportion to the increase in phosphate concentration in the chill water.

Steaks marinated for 2 hr showed the least % WIM, but only the mean value for 6 hr marination was significantly greater. Marination for 6 hr also gave significantly greater % WIM than marination for 1 hr. The data indicate that it took more than 2 hr of marinating and probably nearly 6 hr to affect the weight of steaks noticeably. Although steaks marinated for 2 hr showed least % WIM, they were similar to steaks marinated for 6 hr in respect to % total cooking losses, % total moisture, and juiciness scores. On the other hand, steaks marinated 1 hr had greater % WIM than those marinated 2 hr, and showed significantly greater % total cooking losses, significantly less total moisture, and significantly lower juiciness scores than those marinated 2 or 6 hr. This indicated that % WIM was not the primary

factor in determining the "juiciness" of the cooked meat. Also, the correlation coefficient (Table 3) for juiciness scores vs % WIM was extremely low. May et al. (1963) used varying concentrations of polyphosphates in the chill water in which freshly killed, eviscerated poultry was soaked 6 hr and reported that a low level of phosphate (4 oz/gal) significantly increased water uptake during chilling, whereas a high

Table 3. Correlation coefficients for certain paired variates.

| Paired variates | r-values | D/F |
|---|---|---|
| Juiciness scores vs % WIM | -0.0095 ns | 35 |
| Juiciness scores vs % total moisture | 0.4338** | 47 |
| Juiciness scores vs WHC | -0.1074 ns | 47 |
| Juiciness scores vs pH | 0.0555 ns | 47 |
| Juiciness scores vs % total cooking losses | -0.2817* | 47 |
| % WIM vs % total moisture | 0.3208* | 35 |
| % WIM vs WHC | -0.1100 ns | 35 |
| % WIM vs pH | 0.3961 ns | 35 |
| WHC vs pH | -0.4510 ns | 47 |
| Flavor scores vs pH | -0.3347* | 47 |
| Initial tenderness scores vs pH | -0.4693** | 47 |
| Initial tenderness scores vs scores based on chews | 0.9361*** | 47 |
| Initial tenderness scores vs shear values | -0.5396** | 47 |
| Number of chews vs score based on chews | -0.9669*** | 47 |

ns = non significant, * P = 0.05, ** P = 0.01, *** P = 0.001

level (10 oz/gal) significantly depressed water uptake. Mean % water uptake for the control was 5.6; for low level phosphate, 6.8; for medium level phosphate (8 oz/gal), 5.1; and for high level phosphate, 4.7. These workers also reported increased mean juiciness ratings for both white and dark meat in direct proportion to the phosphate levels.

Mean values indicated a significant increase in % total moisture between unmarinated steaks and those marinated for 6 hr, between steaks marinated 1 and 6 hr, and between steaks marinated 1 and 2 hr. Thus, 6 hr marination was necessary before the % total moisture in the meat was affected significantly. Steaks marinated for 1 hr contained less % total moisture than unmarinated steaks, although the difference was not significant. Marination for 1 hr also produced steaks that averaged higher total cooking losses and lower juiciness scores than those given any other treatment. The correlation coefficient for juiciness scores vs % total moisture ($r = 0.4338^{**}$) was highly significant but only moderately high. Rust (1963) obtained similar results ($r = 0.5651^{**}$) with data for these two factors. Also, the coefficient for % WIM vs % total moisture was significant ($r = 0.3208^{*}$) but low.

Values for WHC were obtained by subtracting the expressible liquid index from 1 which was arbitrarily chosen as the maximum expressible liquid index. Since the magnitude of the expressible liquid index is inversely related to the amount of liquid expressed from the sample, the larger the WHC value the

greater the amount of liquid expressed. The F-value for WHC (Table 2) was not significant indicating that there were no differences attributable to marination in SHMP solution. Several workers (Hamm, 1959; Swift et al., 1960; and Sherman, 1961a and 1962) have indicated that one of the functions of polyphosphates is to increase WHC, and that part of the effect is attributable to change in pH. Hamm (1959) stated that polyphosphates increase hydration only at pH values greater than 5.5 and the effect increases with increasing pH. Rust (1963) injected steaks with 0.03 M SHMP solution equivalent to 5, 10, and 15% of the weight and observed that pH increased linearly with an increase in phosphate. However, no determinations of WHC were made. In the study reported here the F-value for pH (Table 4) was not significant, and while steaks marinated 1, 2, or 6 hr progressively increased in alkalinity the mean pH for steaks marinated 6 hr was identical to that for unmarinated steaks. The correlation coefficient for WHC vs pH was not significant (Table 3).

Volatile, dripping, and total cooking losses were measured and data are presented in Table 2. Mean values for % volatile cooking losses indicate that any length of marination significantly increased volatile loss, but steaks marinated for 1 hr showed more volatile loss than either the unmarinated steaks or steaks marinated 2 or 6 hr. Volatile losses (%) for steaks marinated 2 or 6 hr were similar and were significantly greater than those for the unmarinated steaks. All treated steaks

Table 4. Mean and F-values attributable to treatment and least significant differences for tenderness, pH, and flavor.

| Marination (hr) | Tenderness scores[a] Initial | Based on chews | Shear values (lb) | pH | Flavor score[b] |
|---|---|---|---|---|---|
| 0 | 5.2 | 5.2 | 8.1 | 5.92 | 4.90 * |
| 1 | 5.7 | 5.7 | 7.3 | 5.75 | 5.43 * |
| 2 | 5.6 | 5.6 | 7.3 | 5.86 | 4.95 * |
| 6 | 5.6 | 5.6 | 6.4 | 5.92 | 5.00 |
| F-value | 1.42 ns | 1.16 ns | 1.30 ns | 1.53 ns | 3.81* |
| Lsd | | | | | 0.36 |

[a]Range, 7 (very tender) - 1 (extremely tough).
[b]Range, 7 (very desirable) - 1 (undesirable).
ns - non significant, * P = 0.05.
Lsd = least significant difference at the 5% level.

except those marinated for 1 hr contained more total moisture than unmarinated steaks. A similar effect of phosphate treatment was reported by Rust (1963). She found that any quantity of injected SHMP solution increased volatile cooking losses, but at the same time the treated steaks contained more total moisture than the untreated. There were no significant differences in % dripping loss attributable to treatment; however, there was a trend for the dripping loss to decrease with increasing time of marination. Previous work in this laboratory by Rust (1963) indicated that % dripping loss from phosphate treated steaks was decreased with increasing amounts of injected 0.03 M SHMP

solution. Mahon (1963) reported reduced non-evaporative loss associated with the cooking process when polyphosphates were used in the chilling water for poultry.

Total cooking losses (%) followed a pattern similar to those for % volatile cooking losses. Total losses from steaks marinated 1 hr were significantly greater than those given any other treatment, whereas steaks receiving no marination exhibited the least total loss. Total cooking losses (%) from steaks marinated 2 or 6 hr were similar. The correlation coefficient for juiciness scores vs % total cooking losses (Table 3) was low ($r = -0.2817^{*}$) but significant at the 5% level. Rust (1963) also found the % total cooking loss was least for untreated steaks followed by steaks injected with SHMP equivalent to 10, 5, and 15% of the weight. The only significant difference between means was for untreated steaks and those injected at 15% of the weight. In addition, she reported a positive and very highly significant coefficient ($r = 0.6339^{***}$) for % total cooking losses vs juiciness. Other authors (Klose et al., 1963; and Schermerhorn et al., 1963) working with phosphates in the chilling water for poultry reported decreased cooking losses and increased juiciness and yield in the treated cooked product as compared to birds not chilled in water to which phosphates had been added.

There were no significant differences among treatments for cooking time either in total min required for cooking steaks or for min/lb (Table 5). Except for steaks marinated 1 hr, which

Table 5. Mean and F-values attributable to treatment for cooking time.

| Marination (hr) | Total min | Min/lb |
|---|---|---|
| 0 | 25.0 | 43.6 |
| 1 | 28.0 | 44.4 |
| 2 | 24.0 | 41.2 |
| 6 | 22.0 | 36.4 |
| F-value | 2.40 ns | 2.22 ns |

ns - non significant.

required the longest time to cook, there was a slight trend for cooking time to decrease with increasing time of marination. This agrees with Mahon's (1963) postulation that phosphates reduce cooking time. However, previous work at this institution by Rust (1963) and by the Institutional Management Department (1963) indicated that phosphate treated meat tended to take more time to cook than the untreated meat.

Correlation coefficients for selected paired variates are presented in Table 3. Coefficients were not significant for juiciness scores vs WIM, WHC, or pH, % WIM vs WHC or pH, and WHC vs pH. Coefficients that were significant have been pointed out earlier in the discussion.

Tenderness, Flavor, and pH

The palatability committee scored the steaks for initial impression of tenderness and tenderness based on the number of chews required to masticate a 1/2-in. cube of meat. Tenderness was determined objectively by the Warner-Bratzler shearing apparatus using 1/2-in. cores. Mean tenderness scores, shear values, and F-values attributable to treatment and least significant differences for these data are recorded in Table 4.

F-values attributable to marination for initial tenderness scores, tenderness scores based on chews, and for Warner-Bratzler shear values were all non significant. However, marinated steaks were rated slightly more tender by both the subjective and objective evaluation. Rust (1963) compared untreated steaks with those injected with SHMP solution equivalent to 5, 10, and 15% of the weight and obtained a highly significant F-value attributable to treatment for both subjective tenderness scores and Warner-Bratzler shear values. All phosphate treated steaks were significantly more tender than the untreated steaks, but there were no significant differences among the phosphate treatments. Also, May et al. (1960) reported that phosphate used in the chill water for poultry increased tenderness for white meat, but no differences were found between treated and untreated dark meat.

An excellent correlation was obtained for initial tenderness scores vs scores based on chews ($r = 0.9361^{***}$) and for number of chews vs scores based on chews ($r = -0.9669^{***}$,

Table 3). Rust (1963) also found these factors to be closely related. The palatability panels for the two studies were composed of several of the same individuals. Apparently counting chews was an aid in standardizing tenderness scores, but after counting chews panel members did not change their evaluation from that of their initial impression. The r-value (-0.4693**) for initial tenderness scores vs Warner-Bratzler shear values was significant at the 1% level, but only moderately high.

A highly significant but only moderately high correlation (r = -0.4693**) was obtained for initial tenderness scores vs pH. However, mean tenderness scores were about the same for all marinated steaks even though pH increased slightly with increased time of marination. Rust (1963) reported a very highly significant correlation (r = 0.7547***) between pH and tenderness for phosphate treated steaks. As pH increased, tenderness increased.

Untreated steaks received the lowest flavor scores of all meat, but only steaks marinated for 1 hr received significantly greater mean flavor scores, and mean scores for steaks marinated 2 or 6 hr were significantly lower than those for steaks marinated 1 hr. Rust (1963) obtained a significant difference between the means for the flavor of uninjected steaks and those that received SHMP solution at the 5 and 10% levels. Steaks injected at the 10% level had the highest mean flavor score.

Klose et al. (1963) reported that panel members definitely

could distinguish between the flavor of poultry that had been soaked in phosphate treated chill water, then cooked, and of birds that had not received the treatment. Flavor of cooked, treated birds was described as salty, but no distinction could be made between several phosphates. In this study in which 48 steaks were tasted only 5 comments pertaining to flavor were made by the palatability panel. These comments included phrases such as "not a beef flavor", "watery", and "off-flavor". Comments were distributed approximately equal among untreated steaks and those marinated for 1, 2 or 6 hr.

Flavor scores and pH were significantly correlated ($r = -0.3347^{*}$) although the r-value was low. Steaks marinated 1 hr showed the lowest pH value and received the highest flavor score. However, untreated steaks and those marinated 6 hr exhibited higher pH than those marinated 2 hr but received about the same mean flavor score.

## SUMMARY

Steaks 1-in. thick from the LD muscle of U. S. Standard grade beef were marinated in 0.03 M SHMP solution and compared with unmarinated steaks to determine the effect of marination in the phosphate solution on the palatability and certain related characteristics of the beef.

A complete block design consisting of 48 steaks randomly assigned to 12 blocks of 4 steaks each was used. Of the 4 steaks in each block, 1 was unmarinated and each of the

remaining 3 steaks was marinated in the phosphate solution for either 1, 2, or 6 hr. Steaks were cooked to 70°C using the modified broiling method of Hay et al. (1953).

Data were obtained for: cooking losses, cooking time, WIM, pH, WHC, total moisture, Warner-Bratzler shear values, and organoleptic scores for flavor, juiciness, and tenderness.

Data indicated at least 2 hr of marinating were needed to produce an effect on juiciness scores, and additional marinating after 2 hr was useless so far as ability of judges to detect increased juiciness. There was no significant effect of marination in SHMP solution on initial tenderness scores or tenderness scores based on chews. Untreated steaks received the lowest flavor scores, but only those marinated 1 hr received significantly greater mean flavor scores. Steaks marinated 2 or 6 hr were scored significantly lower in flavor than steaks marinated 1 hr.

It took more than 2 hr of marinating and probably nearly 6 to affect % WIM of the steaks noticeably. Also, 6 hr marination were necessary before the % total moisture was affected significantly. Warner-Bratzler shear values, WHC, and pH measurements were not affected significantly by marination.

Any length of marination definitely increased % volatile cooking loss, but the volatile loss did not increase significantly with increased time of marination. There was a slight but non significant trend for % dripping loss to decrease with increasing time of marination. Marinating 1 hr definitely

resulted in the greatest % total cooking losses, whereas no marination produced the least total losses. There was no clear effect of marination on cooking time either in total min or in min/lb, but there was a slight trend for the time to decrease with increasing marination time.

Excellent and very highly significant correlations were obtained for initial tenderness scores vs tenderness scores based on chews and for number of chews vs score based on chews. Highly significant, but only moderately high, correlations were obtained for initial tenderness scores vs Warner-Bratzler shear values, initial tenderness scores vs pH, and juiciness scores vs % total moisture. Significant, but low, correlation coefficients were obtained for juiciness scores vs % total cooking losses, % WIM vs % total moisture, and flavor scores vs pH.

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# APPENDIX

Form 1. SCORE CARD FOR BROILED STEAK

Judge_____ Block_____ Date_____

| Sample No. | Flavor | Juiciness | Tenderness | | | Comments |
|---|---|---|---|---|---|---|
| | | | Initial | Chews No. | Chews Score | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |

Descriptive terms for scoring:

| Flavor | Juiciness | Tenderness |
|---|---|---|
| 7. Very desirable | 7. Very juicy | 7. Very tender |
| 6. Desirable | 6. Juicy | 6. Tender |
| 5. Moderately desirable | 5. Moderately juicy | 5. Moderately tender |
| 4. Slightly desirable | 4. Slightly dry | 4. Slightly tough |
| 3. Neutral | 3. Dry | 3. Tough |
| 2. Slightly undesirable | 2. Very dry | 2. Very tough |
| 1. Undesirable | 1. Extremely dry | 1. Extremely tough |

Sodium Hexametaphosphate Solution (0.03 M)

1. Weigh 36.9126 g of reagent grade sodium hexametaphosphate ($Na_6P_6O_{18}$) on an analytical balance.
2. Make to 2 liters volume with distilled water in a volumetric flask.
3. Close flask with ground glass stopper.
4. Shake flask until phosphate crystals are in solution.

Table 6. Forty-eight 1-in. steaks from 16 U. S. Standard short loins.

| Loin number | Code number | Initial weight (g) | Loin number | Code number | Initial weight (g) |
|---|---|---|---|---|---|
| 01 | 01a | 236 | 10 | 10b | 248 |
| | | | | 10c | 268 |
| 02 | 02a | 314 | | 10d | 305 |
| | 02b | 285 | | 10e | 252 |
| 03 | 03b | 270 | 11 | 11c | 231 |
| | 03c | 231 | | 11d | 248 |
| 04 | 04a | 231 | 12 | 12a | 270 |
| | 04b | 248 | | 12b | 304 |
| | | | | 12c | 326 |
| 05 | 05b | 245 | | 12d | 276 |
| | 05d | 244 | | | |
| | 05e | 248 | 13 | 13a | 291 |
| | 05f | 310 | | 13b | 346 |
| | | | | 13c | 373 |
| 06 | 06a | 261 | | | |
| | 06b | 244 | 14 | 14a | 275 |
| | 06c | 236 | | 14b | 271 |
| | 06d | 247 | | | |
| | 06e | 292 | 15 | 15a | 237 |
| | 06f | 272 | | 15b | 252 |
| | | | | 15c | 267 |
| 07 | 07a | 232 | | 15d | 277 |
| | 07b | 229 | | 15e | 245 |
| 08 | 08a | 301 | 16 | 16a | 266 |
| | 08b | 358 | | 16b | 255 |
| | 08c | 276 | | 16c | 281 |
| 09 | 09a | 261 | | | |
| | 09b | 304 | | | |
| | 09c | 325 | | | |

Code numbers listed above the horizontal line are for steaks from the anterior end of the short loin and those listed below the line are for steaks from the posterior end of the short loin.

Table 7. Weight of steaks prior to cooking, % weight increase during marination, and cooking time.

| Block | Weight prior to cooking | | | | Weight increase during marination (%) | | | Cooking time | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Total min | | | | Min/lb | | | |
| | 0 | 1 | 2 | 6 | 1 | 2 | 6 | 0 | 1 | 2 | 6 | 0 | 1 | 2 | 6 |
| 1 | 265 | 267 | 274 | 327 | 0.38 | 1.48 | 0.31 | 33.0 | 32.0 | 33.0 | 30.0 | 56.5 | 54.4 | 54.6 | 41.7 |
| 2 | 228 | 285 | 230 | 243 | 4.78 | 0.43 | 2.97 | 22.0 | 29.0 | 20.0 | 18.0 | 43.8 | 46.2 | 39.4 | 33.6 |
| 3 | 237 | 275 | 278 | 258 | 0.0 | 0.73 | 4.03 | 21.0 | 22.0 | 20.0 | 22.0 | 40.2 | 36.3 | 32.7 | 38.7 |
| 4 | 276 | 265 | 245 | 251 | 0.76 | 0.82 | 3.72 | 26.0 | 24.0 | 27.0 | 23.0 | 42.8 | 41.0 | 50.0 | 41.6 |
| 5 | 243 | 238 | 233 | 307 | 1.28 | 1.30 | 3.02 | 22.0 | 24.0 | 26.0 | 21.0 | 41.1 | 45.8 | 50.7 | 31.1 |
| 6 | 248 | 288 | 345 | 244 | 4.73 | 0.0 | 5.63 | 23.0 | 28.0 | 27.0 | 26.0 | 42.1 | 44.2 | 35.5 | 48.4 |
| 7 | 225 | 299 | 270 | 257 | -0.33 | 0.0 | 2.39 | 22.0 | 29.0 | 20.0 | 19.0 | 44.4 | 44.0 | 33.6 | 33.6 |
| 8 | 285 | 249 | 251 | 270 | 0.40 | 1.62 | 0.75 | 35.0 | 37.0 | 26.0 | 22.5 | 55.7 | 67.5 | 47.0 | 37.8 |
| 9 | 301 | 334 | 249 | 314 | 2.77 | 0.40 | 0.96 | 35.0 | 38.0 | 29.0 | 28.5 | 52.8 | 51.6 | 52.9 | 41.2 |
| 10 | 254 | 273 | 260 | 300 | 1.03 | 3.59 | 4.17 | 20.0 | 20.0 | 19.0 | 18.0 | 35.8 | 31.0 | 33.2 | 29.2 |
| 11 | 224 | 306 | 248 | 247 | 0.66 | 1.64 | 1.23 | 18.0 | 22.5 | 19.0 | 16.0 | 36.5 | 33.4 | 34.8 | 29.4 |
| 12 | 269 | 360 | 377 | 328 | 0.84 | 1.07 | 4.46 | 19.0 | 30.0 | 25.0 | 23.5 | 32.0 | 37.8 | 30.1 | 32.5 |
| Mean | 255 | 288 | 272 | 279 | 1.44 | 1.09 | 2.80 | 25.0 | 28.0 | 24.0 | 22.0 | 43.6 | 44.4 | 41.2 | 36.4 |

0, 1, 2, 6 = Hours of marination.

Table 8. Cooking losses of steaks.

| Block | Volatile (%) | | | | Dripping (%) | | | | Total (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 6 | 0 | 1 | 2 | 6 | 0 | 1 | 2 | 6 |
| 1 | 13.6 | 17.2 | 17.9 | 15.6 | 6.0 | 4.1 | 4.7 | 8.9 | 19.6 | 21.3 | 22.6 | 24.5 |
| 2 | 13.2 | 19.3 | 13.5 | 14.4 | 6.1 | 4.9 | 3.5 | 4.1 | 19.3 | 24.2 | 17.0 | 18.5 |
| 3 | 12.2 | 16.4 | 13.7 | 19.0 | 6.8 | 2.9 | 5.0 | 2.3 | 19.0 | 19.3 | 18.7 | 21.3 |
| 4 | 12.7 | 12.8 | 16.7 | 15.9 | 4.7 | 8.3 | 6.9 | 5.6 | 17.4 | 21.1 | 23.7 | 21.5 |
| 5 | 10.3 | 13.9 | 13.3 | 12.4 | 4.9 | 3.4 | 3.0 | 4.2 | 15.2 | 17.2 | 12.4 | 16.3 |
| 6 | 12.1 | 16.0 | 13.3 | 19.3 | 3.2 | 7.6 | 6.4 | 3.3 | 15.3 | 23.6 | 19.7 | 22.5 |
| 7 | 12.9 | 14.7 | 13.7 | 12.5 | 4.4 | 9.7 | 3.3 | 3.1 | 17.3 | 24.4 | 17.0 | 15.6 |
| 8 | 12.6 | 18.1 | 15.1 | 13.7 | 3.9 | 3.2 | 4.0 | 4.8 | 16.5 | 21.3 | 19.1 | 18.5 |
| 9 | 14.0 | 18.9 | 16.1 | 13.7 | 7.6 | 4.2 | 3.2 | 3.5 | 21.6 | 23.1 | 19.3 | 17.2 |
| 10 | 12.2 | 12.3 | 13.1 | 13.3 | 6.3 | 6.5 | 5.4 | 4.3 | 18.5 | 18.8 | 18.5 | 17.7 |
| 11 | 12.9 | 14.7 | 15.3 | 14.6 | 4.0 | 3.6 | 2.4 | 3.6 | 17.0 | 18.3 | 17.7 | 18.2 |
| 12 | 9.7 | 16.1 | 16.4 | 11.9 | 7.8 | 6.1 | 6.9 | 4.3 | 17.5 | 22.2 | 23.3 | 16.2 |
| Mean | 12.4 | 15.9 | 14.8 | 14.7 | 5.8 | 5.4 | 4.6 | 4.3 | 17.9 | 21.2 | 19.1 | 19.0 |

0, 1, 2, 6 = Hours of marination.

Table 9. Juiciness scores, total moisture, and water holding capacity.

| Block | Juiciness scores[a] | | | | Total moisture (%) | | | | Water holding capacity | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 6 | 0 | 1 | 2 | 6 | 0 | 1 | 2 | 6 |
| 1 | 6.2 | 5.3 | 6.2 | 5.8 | 67.59 | 62.62 | 64.20 | 64.42 | 0.77 | 0.61 | 0.67 | 0.69 |
| 2 | 6.4 | 6.3 | 6.0 | 6.4 | 67.42 | 65.67 | 65.32 | 70.52 | 0.69 | 0.70 | 0.67 | 0.71 |
| 3 | 6.0 | 6.3 | 6.3 | 6.0 | 67.60 | 62.40 | 68.10 | 65.17 | 0.70 | 0.62 | 0.68 | 0.63 |
| 4 | 6.5 | 6.3 | 6.0 | 5.5 | 62.60 | 66.53 | 64.43 | 67.60 | 0.61 | 0.71 | 0.67 | 0.63 |
| 5 | 6.3 | 6.1 | 5.9 | 6.3 | 67.95 | 67.15 | 65.03 | 64.50 | 0.67 | 0.69 | 0.70 | 0.69 |
| 6 | 5.9 | 5.8 | 6.4 | 6.4 | 66.43 | 61.88 | 65.90 | 68.83 | 0.60 | 0.71 | 0.70 | 0.68 |
| 7 | 6.0 | 6.0 | 6.5 | 6.6 | 62.70 | 65.20 | 62.88 | 64.45 | 0.64 | 0.69 | 0.63 | 0.62 |
| 8 | 5.2 | 5.7 | 6.3 | 6.7 | 66.93 | 58.95 | 69.60 | 66.70 | 0.71 | 0.67 | 0.73 | 0.62 |
| 9 | 4.8 | 5.0 | 6.4 | 6.6 | 60.68 | 63.28 | 67.90 | 66.75 | 0.67 | 0.64 | 0.69 | 0.71 |
| 10 | 6.0 | 6.6 | 6.1 | 6.6 | 69.35 | 68.33 | 67.10 | 71.35 | 0.72 | 0.67 | 0.70 | 0.69 |
| 11 | 6.5 | 5.6 | 6.8 | 6.4 | 62.90 | 65.73 | 70.05 | 70.40 | 0.63 | 0.68 | 0.70 | 0.74 |
| 12 | 5.7 | 5.5 | 6.2 | 5.8 | 64.75 | 62.53 | 66.83 | 71.78 | 0.68 | 0.69 | 0.73 | 0.71 |
| Mean | 6.0 | 5.9 | 6.3 | 6.3 | 65.58 | 64.19 | 66.45 | 67.71 | 0.67 | 0.67 | 0.69 | 0.68 |

[a]Maximum score possible, 7.
0, 1, 2, 6 = Hours of marination.

Table 10. Tenderness scores and shear values of steaks.

| Block | Tenderness scores: Initial score[a] 0 | 1 | 2 | 6 | Score based on chews[a] 0 | 1 | 2 | 6 | Number of chews 0 | 1 | 2 | 6 | Shear value (lb) 0 | 1 | 2 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.5 | 5.5 | 5.2 | 4.2 | 3.0 | 5.5 | 5.3 | 3.7 | 56 | 33 | 32 | 48 | 8.9 | 4.0 | 4.1 | 9.0 |
| 2 | 4.4 | 5.8 | 5.9 | 4.9 | 4.1 | 5.3 | 5.5 | 4.6 | 49 | 34 | 32 | 46 | 7.4 | 7.7 | 4.6 | 7.4 |
| 3 | 4.8 | 5.8 | 5.0 | 5.9 | 4.6 | 5.4 | 4.6 | 6.0 | 45 | 35 | 45 | 31 | 10.0 | 8.2 | 8.3 | 5.3 |
| 4 | 6.0 | 5.7 | 5.7 | 4.8 | 6.2 | 5.8 | 6.2 | 5.2 | 28 | 31 | 28 | 38 | 5.3 | 6.8 | 8.2 | 8.9 |
| 5 | 4.8 | 6.4 | 5.9 | 5.9 | 4.8 | 6.6 | 6.0 | 5.6 | 43 | 24 | 28 | 34 | 9.0 | 5.1 | 5.8 | 5.4 |
| 6 | 5.8 | 5.9 | 5.0 | 6.0 | 5.6 | 6.1 | 5.1 | 6.3 | 33 | 28 | 39 | 27 | 7.5 | 8.9 | 11.3 | 5.7 |
| 7 | 5.6 | 5.4 | 6.5 | 6.1 | 5.8 | 5.3 | 6.1 | 6.1 | 33 | 42 | 30 | 30 | 5.0 | 7.1 | 5.4 | 4.9 |
| 8 | 6.0 | 5.0 | 4.8 | 5.7 | 6.0 | 5.3 | 4.7 | 5.8 | 29 | 33 | 41 | 30 | 6.8 | 6.4 | 9.4 | 5.3 |
| 9 | 5.6 | 5.4 | 6.0 | 6.2 | 5.6 | 5.6 | 5.8 | 6.2 | 34 | 33 | 29 | 27 | 6.9 | 8.0 | 4.5 | 3.9 |
| 10 | 4.9 | 5.3 | 5.9 | 4.7 | 4.1 | 5.7 | 5.9 | 4.7 | 50 | 33 | 30 | 43 | 10.2 | 9.2 | 6.8 | 8.6 |
| 11 | 6.1 | 5.5 | 6.5 | 6.4 | 6.0 | 5.4 | 6.4 | 6.1 | 29 | 38 | 27 | 29 | 7.0 | 8.2 | 7.0 | 6.4 |
| 12 | 5.3 | 6.2 | 5.2 | 6.3 | 5.3 | 6.3 | 5.3 | 6.5 | 40 | 27 | 36 | 26 | 12.6 | 7.9 | 12.4 | 5.8 |
| Mean | 5.2 | 5.7 | 5.6 | 5.6 | 5.1 | 5.7 | 5.6 | 5.6 | 39 | 33 | 33 | 34 | 8.1 | 7.3 | 7.3 | 6.4 |

[a]Maximum score possible, 7.

0, 1, 2, 6 = Hours of marination.

Table 11. Flavor scores and pH values.

| Block | Flavor scores[a] | | | | pH | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 6 | 0 | 1 | 2 | 6 |
| 1 | 3.8 | 4.8 | 4.8 | 5.0 | 6.10 | 5.76 | 5.80 | 5.84 |
| 2 | 5.1 | 5.6 | 5.6 | 5.3 | 6.11 | 6.15 | 5.80 | 6.38 |
| 3 | 4.6 | 5.5 | 4.4 | 5.1 | 6.22 | 5.69 | 6.10 | 5.79 |
| 4 | 5.7 | 5.0 | 5.3 | 4.8 | 5.68 | 5.71 | 5.75 | 6.10 |
| 5 | 4.8 | 5.8 | 5.3 | 4.9 | 6.11 | 5.65 | 5.80 | 5.71 |
| 6 | 5.6 | 5.9 | 5.1 | 4.9 | 5.64 | 5.70 | 6.00 | 5.82 |
| 7 | 5.0 | 5.6 | 4.9 | 5.0 | 5.65 | 5.74 | 5.63 | 5.76 |
| 8 | 5.5 | 5.5 | 4.0 | 4.8 | 6.41 | 5.60 | 6.24 | 5.70 |
| 9 | 4.6 | 5.6 | 5.2 | 5.0 | 5.60 | 5.65 | 5.65 | 5.70 |
| 10 | 4.7 | 5.3 | 5.1 | 4.6 | 6.22 | 6.02 | 5.80 | 6.17 |
| 11 | 5.4 | 5.3 | 5.4 | 5.4 | 5.60 | 5.60 | 5.65 | 5.71 |
| 12 | 4.0 | 5.3 | 4.3 | 5.2 | 5.71 | 5.68 | 5.12 | 6.48 |
| Mean | 4.9 | 5.4 | 5.0 | 5.0 | 5.92 | 5.75 | 5.86 | 5.92 |

[a]Maximum score possible, 7.

0, 1, 2, 6 = Hours of marination.

# THE EFFECT OF MARINATION IN SODIUM HEXAMETAPHOSPHATE SOLUTION ON THE PALATABILITY OF BEEF

by

EUNICE MARIE GANAWAY MILLER

B. S., University of Missouri, 1961

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AN ABSTRACT OF A THESIS

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Steaks 1-in. thick from the longissimus dorsi muscle of U. S. Standard grade beef were marinated in 0.03 M sodium hexametaphosphate (SHMP) solution and compared with unmarinated steaks to determine the effect of marination in the phosphate solution on the palatability and certain related characteristics of the beef.

A complete block design consisting of 48 steaks randomly assigned to 12 blocks of 4 steaks each was used. Of the 4 steaks in each block, 1 was unmarinated and each of the remaining 3 steaks was marinated in the phosphate solution for either 1, 2, or 6 hr. Steaks were cooked to 70°C using the modified broiling method of Hay et al. (1953).

Data were obtained for: cooking losses, cooking time, weight increase during marination (WIM), pH, water holding capacity (WHC), total moisture, Warner-Bratzler shear values, and organoleptic scores for flavor, juiciness, and tenderness.

Data indicated that at least 2 hr of marinating were needed to produce an effect on juiciness scores, and additional marinating after 2 hr was useless so far as ability of judges to detect increased juiciness. There was no significant effect of marination in SHMP solution on initial tenderness scores or tenderness scores based on chews. Untreated steaks received the lowest flavor scores, but only those marinated 1 hr received significantly greater mean flavor scores. Steaks marinated 2 or 6 hr were scored significantly lower in flavor than steaks marinated 1 hr.

It took more than 2 hr of marinating and probably nearly 6 hr to affect % WIM of the steaks noticeably. Also, 6 hr marination were necessary before the % total moisture was affected significantly. Warner-Bratzler shear values, WHC, and pH measurements were not affected significantly by marination.

Any length of marination definitely increased % volatile cooking loss, but the volatile loss did not increase significantly with increased time of marination. There was a slight but non significant trend for % dripping loss to decrease with increasing time of marination. Marinating 1 hr definitely resulted in the greatest % total cooking losses, whereas no marination produced the least total losses. There was no clear effect of marination on cooking time either in total min or in min/lb, but there was a slight trend for the time to decrease with increasing marination time.

Excellent and very highly significant correlations were obtained for initial tenderness scores vs tenderness scores based on chews and for number of chews vs score based on chews. Highly significant, but only moderately high, correlations were obtained for initial tenderness scores vs Warner-Bratzler shear values, initial tenderness scores vs pH, and juiciness scores vs % total moisture. Significant, but low, correlation coefficients were obtained for juiciness scores vs % total cooking losses, % WIM vs % total moisture, and flavor scores vs pH.