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INTRODUCTION

Recent changes in swine production and processing technique have brought to light various problems of quality confronting the pork industry. Extensive work made possible by new and more objective research techniques indicates the importance of various pork quality factors and their association with sensory palatability characteristics and with economic factors concerned with processing, merchandising and consumption of pork.

Reports in the literature have shown how various post-mortem treatments have improved some of the quality factors in pork. Work has also brought to light many of the biochemical changes that take place during rigor-mortis so that a better understanding of the principles involved may be obtained.

Therefore it was considered worthwhile to study the effect on the muscle and fat characteristics of pork due to processing carcasses before rigor mortis sets in. This included cutting, rapid chilling, freezing, and brine pumping cuts before rigor mortis and then observing the effect upon muscle tenderness, water binding capacity, color, cooking losses and other quality factors. In addition it seemed important to study the relationship between some of these pork quality characteristics.

REVIEW OF LITERATURE

Pork muscles reportedly are moderately dark, dry and firm at the time of slaughter. Following this many physiological
and biochemical changes occur that influence the quality of the final product. These post-mortem changes include glycolysis with a production of lactic acid, breakdown of creatine phosphate and resynthesis and breakdown of adenosine-triphosphate (ATP) resulting in the formation of the actinmyosin complex.

Structure and Function of Striated Muscle

A considerable body of evidence has been accumulated to support the idea that the contractile structure of striated muscle is built up of a succession of overlapping filaments containing the two principle structural proteins, myosin and actin (Huxley, 1959). These two proteins seem to be located as separate rods which appear to be alternately located along the length of the fibrils, thus giving rise to the well known band patterns. Rods of actin attached to a line, the Z line, can be pulled into or out of the A-band, composed of rods of myosin.

At the points of overlap, each actin rod, when seen in three dimensions, is surrounded by three rods of myosin and each myosin rod by six rods of actin. The actin rods are continuous through the Z line, although twisted and joined in a complex manner to their neighbors in the next sarcomere.

Changes in the length of the muscle take place when the actin and myosin filaments slide past each other. This occurs because of the interaction of cross bridges projecting out from myosin to the neighboring actin filaments. When the cross
bridges on the myosin are not attached to the actin, the fila-
ments are free to slide freely past each other and will offer
no resistance to extension. This is the resting state, or in
a dying muscle is recognized as the easily extensible pre-rigor
state. Bendall (1963) points out that in the actual resting
muscle, unlimited extension of the sliding filaments is prevented
by the parallel elastic elements in the sarcolemma which consist
of coiled springs of reticulin and collagen.

The source of energy for muscle-contraction comes directly
from splitting ATP which is present as a Mg-complex of ATP
(MgATP); as stated by Davies, 1959. The splitting of a terminal
phosphate off of ATP is activated by ATP-ase in the presence of
Mg ions. Also present in this system is a relaxing factor that
when in an active state will prevent the splitting of ATP.
Therefore this relaxing factor can put an end to the interaction
between actin and myosin, because without energy from ATP split-
ting, the fibrils are incapable of contracting. Thus, it is
found that after this relaxing factor has stopped the actin-myosin
interaction, contraction ceases completely.

Observations of Briggs (1963) support the hypothesis that
the soluble relaxing factor isolated from muscle is a phospho-
lipid. This relaxing factor can be inhibited by the presence
of calcium ions, thus preventing the relaxation of fibrils and
resulting in contraction. The effect of calcium ions on the
relaxing factor was demonstrated by Howard and Lawrie (1956),
as described by Partmann (1963), where preslaughter injections
of beef with calcium hastened the onset of rigor mortis considerably. Removal of calcium by injection of a chelating agent, ethylene diaminetetraacetate (EDTA), delayed the onset of rigor mortis.

Development of Rigor Mortis

From results of a histological study of muscles shortened in rigor by 20%, Bendall (1951) postulated that shortening in rigor is essentially the same process as physiological contraction. It was shown that the cross-striations of considerable numbers of fibers in rigor are packed at least twice as tightly as those in pre-rigor muscle. Work of Marsh (1954) also lends support to the view that shortening in rigor may be regarded as a slow and irreversible physiological contraction. He found that the most obvious physical change occurring during the onset of rigor mortis is an increase in the modulus of elasticity. In individual experiments with rabbit and beef muscles, the ratio of final to initial modulus ranged from 8 to 79 with a mean value of 32.

Recent results of Partmann (1963) indicate that rigor mortis and muscular contraction have the same mechanism. However, Partmann points out that these two kinds of muscle action differ considerably from each other in the processes leading to their initiation and in the amount of work produced. According to Hamm (1960), some changes that occur in rigor that don't occur in muscular contraction include pH decrease caused by
glycolysis, changes in phosphate containing compounds and change in ion binding to the muscle proteins.

In the live animals ATP is split into adenosine diphosphate (ADP) and phosphate and then can be resynthesized from ADP and sources of creatine phosphate (CP) or through the electron transport scheme, glycolysis or by various other processes. However during rigor mortis ATP splits down to ADP and when the sources of CP are depleted, the ADP continues to breakdown to adenosine monophosphate (AMP) and inosine monophosphate (IMP).

The change in ion binding to the muscle proteins results when the phosphates with high complex-forming ability are split to phosphates with a low complex-forming ability, thus releasing the main part of the original phosphate-bound alkaline earth ions. One part of the released ions are then bound immediately by the negatively charged groups of the muscle proteins so as to be built within the structure of the tissue.

In the live animal and at the time of slaughter, many factors may inhibit contraction or in other words induce relaxation. During this stage the calcium is completely bound to protein, whereas 90% of the magnesium is unbound. Yet during the early stages of rigor, the ATP continues to decompose, thus supplying energy to promote the formation of energy rich bonds of the actomyosin. According to Hamm (1956), this process takes place rather slowly in fresh meat immediately after slaughter because of these inhibiting factors. However, the activity of
these inhibiting factors declines and finally ceases with a decrease in pH as the calcium and zinc ions are released from their complex with proteins. These ions then prevent the activity of the inhibitory factor on ATP, which proceeds to decompose more rapidly. As this happens the contractile proteins actin and myosin form the actinmyosin complex which causes the stiffness in the muscle.

Bendall (1951) suggested that shortening in rigor can best be explained as a very slow irreversible contraction and that disappearance of ATP from the muscle is a fundamental prerequisite for the shortening in both rigor and physiological contraction. He found that during rigor mortis of rested muscles, CP was the first compound to be broken down. The ATP starts to breakdown when 70% or more of the CP has disappeared. Vigorous glycolysis proceeds a relatively quick fall in ATP content at this time. Results of Marsh (1954) provide additional evidence that the onset of rigor is intimately related to the rate of dephosphorylation of ATP.

**Time course of rigor mortis.** Results of Bate-Smith and Bendall (1949) demonstrated two distinct phases during rigor mortis. The first phase, called "delay phase", is that time after slaughter during which the modulus of elasticity either does not change at all or increases very slightly. The second phase, called "rapid phase" is that period during which the modulus of elasticity increases very rapidly to its maximum.

Briskey et al. (1962) developed an apparatus to study
the time course of rigor mortis under various conditions. These workers found that the onset of rigor mortis was extremely variable between pigs, ranging from 2 minutes to 8 hours. They could also induce a prolonged delay phase by the use of a 125 gram weight and accelerated the onset and duration of the rapid phase with the use of a 25 gram weight. This was found to reduce the duration of both the "delay" and "onset" phase by approximately 10%. These results revealed that a long delay phase and an extremely long onset phase resulted in dark, firm muscles that had virtually no shortening after completion of the rigor mortis process. A rapid delay phase resulted in pale, soft, watery tissue. Therefore it was postulated that many of the variations in pork muscle properties can be associated with the time course of rigor mortis.

Bate-Smith and Bendall (1949) showed a pronounced delay in the onset of rigor in muscle fibrils placed in an oxygen atmosphere. This was later substantiated when Briskey et al. (1962) showed that the rigor mortis process was approximately 25% longer in an oxygen atmosphere than in a nitrogen atmosphere.

These workers also found that the duration of the delay phase and total time for completion of rigor mortis of fibrils was markedly increased by lowering the temperature. The total time for completion of rigor was 50% longer at 25°C. than at 37°C., 50-60% longer at 21°C. and approximately 130% longer at 10°C. This agrees with earlier work of Bate-Smith and Bendall (1949) demonstrating that lowering the temperature from 37° to
17°C. decreased the "delay" phase about 2.5% and had an even greater effect on the "rapid" phase. These lower temperatures resulted in less shortening of the muscle fibers. DeFremery and Pool (1960) also found that a strip of chicken muscle remained plastic in consistency for a considerable longer period of time at 14°C. than at 43°C.

Bendall et al. (1963) showed that pigs could be divided on the basis of post-mortem changes at constant temperatures into two groups. One group was characterized by a slow post-mortem change while the other group showed a fast change. These two distinct groups, according to rate of post-mortem change were found in the same muscle of different animals within the same breed, treated under the same conditions.

A postulation of Partmann (1963) pointed out that in well fed and rested animals, the length of the delay before rigor begins, is determined in great part by the time that elapses until the relaxing factor becomes more or less inactivated and hence the rapid phase of ATP breakdown begins. This inactivation could be due to the release of sufficient calcium ion by the fibrillar muscle proteins.

Thus the striking differences among animal species and between animals within species in the course of rigor development might be caused by: a) variations in membrane resistance against autolytic processes or increasing acidification, b) deviations in post-mortem release of calcium and other ions by muscle proteins, and c) differences in the relation between
the velocities of glycolytic ATP resynthesis and its breakdown.

**Muscle extensibility.** Bendall *et al.* (1963) found both acceptable quality and poor quality pork carcasses are characterized by a drop in extensibility of about 10% comparatively soon after slaughter. Following this the muscles from acceptable carcasses have a slow rate of decreased extensibility until rigor is complete in 280 minutes. This can be compared to muscles of poor quality carcasses where the extension decreases at a much faster rate so that rigor is complete within 160 minutes.

Marked shortening of certain horse muscles was also observed to coincide with the loss of extensibility (Lawrie, 1953). The time-course of the biochemical and biophysical changes in the four horse muscles studied appeared to be characteristic of each, bearing a systematic relationship to muscle activity and an inverse correlation with the capacity for aerobic metabolism.

Marsh (1953) found a relationship to exist between shortening and extensibility which indicates that diminished cross-bond formation is present with increased shortening. This suggests that individual bonds become available during the onset of rigor for either shortening or an increase in resistance to extension. The rapid decrease in extensibility first sets in when the ATP concentration is approximately 30% of the initial value for both acceptable and poor quality carcasses (Bendall, *et al.* 1963).
In working with the longissimus dorsi of beef cattle, Wang (1956) revealed the existence of a negative correlation between muscle fiber extensibility and tenderness. Then a positive correlation was found between muscle fiber extensibility and shear force values.

**Effect of excising muscles.** DeFremery and Pool (1960) found that poultry muscles excised prior to onset of rigor mortis were less tender than the same muscle on the other side left intact during rigor mortis. Similar results of Kropf (1961) found that muscle samples excised at slaughter from one side of a beef carcass and chilled for 72 hours were also very highly significantly less tender than those samples removed from the other side of the same carcass after chilling for 72 hours.

The final contractile state of a muscle is probably determined by the strain imposed on it in the hanging carcass (Locker, 1960). His work with ox muscles excised or partially detached at time of slaughter showed considerable shortening takes place. These shortened muscles were then judged less tender. Locker concluded that relaxed muscles are more tender than partly contracted muscles and that the effect may be significant in tenderness evaluation of muscles with low connective tissue content.

Partmann (1963) stated that it might be possible to get more tender meat by dissociation of the actinmyosin complex. He also postulated that if the interaction between actin and myosin during rigor mortis could be wholly or partly impeded, this might
also improve tenderness. To prove this, Partmann dissected the diaphragm of beef carcasses immediately after death. Excised strips about 6 cm. wide from one half of the diaphragm were allowed to age as controls, and corresponding muscle strips were loaded with weights and forced to age in the stretched state under the same conditions. Organoleptic testing and measurements with a tenderometer showed that the unloaded muscle strips were significantly less tender than the stretched strips after the same time.

Thaw rigor. Thaw rigor is the process occurring in muscles frozen before rigor mortis and then thawed. Perry (1950) showed that rigor takes place when completely frozen frog sartorius muscle is thawed ("thaw rigor"). It is accompanied by a decrease in length of 70% of original length and a loss in weight of 35%, whether the muscle is frozen in the resting or exhausted condition or during isometric tetanus. The frozen sartorius muscle which had been frozen at -22°C. was allowed to stand at room temperature. Shortening then took place as soon as thawing was complete. This shortened muscle was thicker and more turgid in appearance, no longer respired, and rested in a pool of exuded fluid. In comparison, muscles stored at room temperature or at 5°C. until rigor occurred, then frozen and thawed, failed to show the above shortening.

The loss of water or synaeresis and shortening are very similar to the phenomenon of "contraction" of actomyosin threads, which is accompanied by an increase in protein
contraction, a decrease in volume and a similar loss in weight. Perry postulated that as a result of the disorganization of the muscle protoplasm produced by the freezing and thawing, the ATP which is thought to be bound in the resting muscle, can act on the myofibril causing additional contraction.

When the muscle tissue was frozen immediately after the death of warm-blooded animals, the glycolytic processes slowed down and became almost completely inhibited at a low enough temperature (-30°C.) (Partmann, 1963). The ATP still present at that moment will persist. When the temperature increases sufficiently during thawing, the ATP will be split quickly as contraction of the tissue occurs, producing thaw rigor, followed by a high drip loss. This marked exudation occurring during "thaw rigor" is caused by a very high rate of ATP breakdown as reported by Bendall (1951). This has been substantiated by recent work of DeFremery and Pool (1960). The inactivation of the relaxing factor by freezing of the tissue is probably not caused by destruction of the relaxing factor itself, for the microsomes seem to be resistant against repeated freezing and thawing (Gergely, 1959). Apparently the inhibition of the relaxing factor is inhibited by the release of calcium (Hamm, 1959b) during freezing and thawing.

DeFremery and Pool (1960) also found that "thaw rigor" induces a highly significant decrease in tenderness of cooked poultry. In comparison they found the effect of freezing and thawing similar muscles that have passed through rigor mortis
is negligible. Thus, apparently, the toughening effect of pre-rigor freezing is due to the accelerated onset of rigor mortis.

Effect of Food Adjuncts

Partmann (1957) has shown that the disorganization of the fine structure of muscle fibers is correlated with the loss of contractility as various food adjuncts are added. It was also observed that an animal injected with sodium chloride before being dressed out, had muscle tissue that was extremely tender and had 100% ability to hold water (Hamm, 1959a). He explained this phenomenon as a shift in the ionic balance. The results of Weber (1963) show that binding of exchangeable calcium by myofibrils was highest in KCl solution and decreased to approximately one-half on the addition of either ethylene glycol bis-N,N-tetraacetic acid (EGTA) or MgATP. The data also indicates two different binding sites for calcium in myofibrils.

Different work by Belenkij (1962) involved an injection of a compound termed "demotin" as an immobilizer. When "demotin", which has diacetyl choline iodide as one component, was injected, heart activity and breathing increased, resulting in a more complete bleeding. Post-mortem reactions included a reduction in lactic acid, a higher muscle pH, retardation of ATP decomposition and retardation of the combining of actin and myosin. Therefore, the muscle did not become rigid, and through retardation of rigor mortis, it remained more tender
Kamstra and Saffle (1959) observed that a highly significant advantage in tenderness was obtained when sodium hexametaphosphate was injected into hams removed 15 minutes after slaughter, as compared to the control which was injected with water at the same time. Significantly higher pH values were also observed for the treated samples as compared to the control samples at the end of 24, 48 and 72 hour periods. They pointed out that these high pH values for the treated samples could be explained by either a low post-mortem acid production in the muscle or to the buffering action of the sodium hexametaphosphate solution injected. Carpenter et al. (1961) found pre-rigor infusions of various chelating solutions improved the tenderness of beef round as compared to controls injected with water. DeFremery and Pool (1960) observed that in the case of muscles which have been poisoned with sodium monobromoacetate, rigor mortis is characterized by a rapid breakdown of ATP but little or no change in glycogen and pH. The fact that these muscles are as tender as their untreated controls might seem to eliminate the rapid breakdown of ATP as the factor which induced muscle toughness in poultry.

ATP

Lawrie's (1953) data indicate that immediately after death there is a rapid drop in creatine phosphate, a slow drop and then a rapid decrease in ATP, accompanied by a parallel
drop in pH. During these first 24 hours after death, Hamm (1959a) found that the ATP is decomposed to ADP and AMP and finally after deamination to IMP. The post mortem drop of hydration was proportional to the decrease of ATP and he pointed out that two thirds of the loss of water holding capacity was due to the loss of ATP. He postulated that because of its ability to form strong complexes with alkaline earth metals, that it will tie up a part of the bivalent ions. Then as ATP is broken down this releases cations that can attach to the protein structure, thus decreasing the water holding capacity of the meat.

Both glycolysis and the breakdown of creatine phosphate are mechanisms for the resynthesis of ATP from ADP, with one and one half molecules of ATP resynthesized for every molecule of lactic acid formed (Lawrie, 1953). This balance between breakdown and resynthesis of ATP can be maintained only as long as a store of creatine phosphate lasts. However, Bendall (1951) points out that CP plays no direct part in the shortening during rigor because more than 80% of it has disappeared before shortening took place. Lawrie (1953) also showed in working with horse muscle that the initial ATP level begins to fall when the CP had decreased to a value corresponding to 30% of the initial ATP. More recent work by DeFremery and Pool (1960) has shown an extremely rapid breakdown of CP in chicken before any change in muscle texture was noted.

Effects of temperature on rate of ATP disappearance.
Partmann (1963) found that in the freezing range, the reaction velocity of the ATP breakdown starts to fall quickly with decreasing temperature. He showed that the energy-rich nucleotides in beef, chicken, rainbow trout and carp muscle were split in 10-25 days at -8°C., whereas at -24°C., 70-100% of the initial ATP content was normally still present after six months. The rate of ATP disappearance above freezing was greatest at 40°C. but ATP breakdown proceeded at similar rates at 30°, 20° and 10°C. (DeFremery and Pool, 1960).

Relation of ATP to tenderness. The results of these workers were strongly indicative of a correlation between rate of ATP breakdown and muscle tenderness. The most tender readings were observed from cuts stored at 10° to 20°C., while the readings observed from cuts held at 30° to 40°C. were less tender. Results of Bate-Smith and Bendall (1949) have confirmed findings that the disappearance of ATP is related almost linearly to the decrease in extensibility of the muscle, and inversely to the change in modulus of elasticity. The extensibility begins to change rapidly as soon as the ATP level falls below 85% of the initial value and the change is virtually completed when the ATP level has fallen below 15%. Similar results have been reported by Perry (1950), Lawrie (1953), and DeFremery and Pool (1960).

Other factors that affect the rate of ATP disappearance. Bendall et al. (1963) found that the rate of disappearance of ATP differed markedly with different groups of carcasses. In
groups where a slow rate of rigor mortis occurred, the ATP concentration remained high and nearly constant for the first 30 minutes, and then decreased at a constant rate until 3 1/2 hours had elapsed. This was in contrast to carcasses that had a fast rate of rigor mortis, where the ATP decreased rapidly for 2 1/2 hours.

An activation of ATP splitting similar to that occurring with freezing and thawing was obtained by Partmann (1963) when dissected muscle tissue was ground immediately after slaughter and stored at temperatures higher than 0°C. DeFremery and Pool (1960) have shown that rough mechanical handling of chicken before development of rigor mortis accelerated the splitting of energy rich nucleotides. Partmann interpreted this acceleration of ATP splitting as "biochemical injury effect" on the tissue. The reason for its occurrence seemed to be a very quick destruction or inactivation of the relaxing factor. Here again, the actin and myosin filaments associated, forming the highly active actomyosin-ATPase. Apparently the process leading to inactivation of the relaxing factor proceeded more quickly and more completely under such conditions.

Partmann (1957) showed that small concentrations of NaNO₂ greatly inhibited the breakdown of ATP at 20°C in carp muscle. The remarkable fact here is that a concentration of 2% sodium nitrite completely prevented ATP splitting. It was found that pH had no influence on this inhibition at values between 6.2 and 7.0. This worker also inhibited the splitting
of ATP at 20°C. at a pH of 6.2 in carp muscle with various concentrations of NaCl. However, according to Hamm (1959a), ATP is broken down in meat in the presence of salt at the same rate as without added salt. However the association of myosin and actin to form actomyosin, which is considered the course of rigor mortis, happens in the same way as in unsalted meat. But no rigor did occur.

Formaldehyde also inactivated the apyrase system to a large degree when pH was lowered from the neutral point to pH 6.2 (Partmann, 1957). In contrast to the NaCl and NaNO₂, Partmann believed that formaldehyde acted as a denaturing agent on actomyosin.

Bate-Smith and Bendall (1949) deduced that myosin, together with myokinase are the enzymes responsible for the ATP-turnover in muscle post-mortem. Normally the breakdown of ATP and its resynthesis by the glycolytic cycle will take place until the depletion of the glycogen reserve or a pH value of 5.4 in the muscle tissue is reached according to Partmann (1963). March (1954) found the ATP decomposition to be directly related to pH.

Role of Glycolysis in Muscle Quality

The formation of lactic acid from glycogen through glycolysis plays an important part in determining muscle pH and color. Therefore, the ultimate pH which is reached during rigor mortis may be influenced by the reserves of muscle
glycogen at the time of slaughter as suggested by AMIF (1960), p. 33. Briskey et al. (1959) found that muscles which possessed high concentrations of glycogen at time of slaughter reflected the greatest decrease in water holding capacity during rigor mortis. When the fresh muscle glycogen level was lowered, carcasses showed a decreased lactic acid concentration in the chilled muscle along with definite darkening of muscle color, a trend toward a higher ultimate pH, and an increased water binding capacity (Sayre et al., 1963).

**Amount of glycogen present.** Fasting, exhausting exercise and training are among factors that determine quantity of glycogen available at death for the formation of lactic acid, and hence the ultimate pH in a specific muscle according to Lawrie (1958), Bate-Smith and Bendall (1949), Lewis (1961), and Sayre et al. (1961, 1963). Briskey et al. (1958) also found that exhaustive exercise treatment significantly decreased the fresh glycogen concentration. An increase in muscle glycogen was shown to result after feeding rations high in sugar.

**Rate of glycolysis.** Post-mortem glycolysis between the same fixed pH points has been shown to proceed at markedly different rates, even under identical conditions, in the *longissimus dorsi* muscle of the pig, (Lawrie, 1960). This may be explained by the results of Sayre et al. (1963b) that revealed that the rate of glycolysis depended upon the size of the stored glycogen molecule. These workers found that pigs with larger molecules of glycogen had a slow rate of glycolysis as compared to pigs
that had shorter, smaller molecules and a fast rate of glycolysis. Other results of Sayre et al. (1963a) suggest that phosphofructokinase did not act as a regulator of post-mortem glycolysis in muscle because of the lack of association between phosphofructokinase activity and rate of post-mortem glycolysis.

Meyer et al. (1963) postulated that the niacin level may affect the post-mortem metabolism of muscle since he found greater levels of niacin in poor quality muscles as compared to normal muscles.

DeFremery and Pool (1960) observed a rapid breakdown of glycogen content following freezing and thawing of muscle before the normal onset of rigor mortis. An acceleration of glycolysis was also reported with increased temperatures (Briskey et al. 1962). Partmann (1963) found that a pH of 5.3 was generally the limiting value below which glycolysis was completely inhibited, even though glycogen may still be present. Briskey et al. (1959) pointed out that factors which control the rate and amount of glycolysis are more important in controlling the appearance of meat than the exact total amount of glycogen stored at the time of slaughter.

Recent work by DeFremery and Pool (1963) eliminated or minimized post-mortem glycolysis on poultry by adrenalin injection, iodoacetate injection or very rapid cooking after slaughter. Results revealed that a rapid disappearance of ATP and consequent rapid onset of rigor were not accompanied
by decreased tenderness. Thus these workers stated that rapid rigor and rapid disappearance of ATP were not a cause of toughening. They also showed that the pattern of tenderization in poultry is such that meat cooked a few minutes after death is more tender than meat allowed to age for an hour before cooking.

With the normal occurrence of glycolysis, poultry rapidly became tough and remained tough until the aging took place. Thus the prevention of post-mortem glycolysis provided evidence that glycolysis caused toughness. It also appears that the faster the glycolysis, the greater the toughness. Evidently this influences the normal post-mortem changes in the muscle fibers. Perhaps it increases the degree of inter and intra-molecular bands that change the muscle from an elastic to an inelastic fiber as related by Defremery and Pool (1963).

Factors Affecting pH

Results of Bate-Smith and Bendall (1949) strongly suggest that the initial pH is determined mainly by the severity of the death struggle. Relaxed animals at time of slaughter had initial pH values of 7.0 as compared to a pH of about 6.5 for animals that struggled violently during slaughtering. Gibbins and Rose (1950) showed that a single twitch of a rats leg caused detectable glycogen losses. Then as the blood supply is rapidly depleted during slaughtering, the lactic acid formed may remain in the muscle. It is this post-mortem-formation of
lactic acid by glycolysis that results in a drop of pH, (Hamm, 1959b). The lactic acid formed isn't broken down further because the muscles of a carcass go into rigor essentially under anaerobic conditions (Scaife, 1955).

According to Bate-Smith and Bendall (1949), the relation between production of lactic acid and fall in pH is nearly linear. Thus, they point out, the higher the initial pH the higher the ultimate pH. However, Marsh (1954), Briskey et al. (1959) and Briskey and Wismer-Pedersen (1962) observed no obvious relationship between initial and ultimate pH values. These workers found different ultimate pH levels in various quality groups. This was contrary to the results of Bendall et al. (1963) that show the ultimate pH is the same in both poor quality carcasses and acceptable quality carcasses. The total lactic acid formation in these two groups corresponded to the pH values.

Scaife (1955) found that the ultimate pH of muscle is affected by the surrounding atmosphere only in the outer few mm. of surface. The ultimate pH of this surface area exposed to oxygen is approximately .3 of a pH determination higher than the interior of the muscle or the surface area exposed to nitrogen in this work.

Extreme variations in the rate of decrease in pork muscle pH during the immediate post-mortem period has been noted by Briskey and Wismer-Pedersen (1961b); Briskey et al. (1959, 1960); Wismer-Pederson (1959); Bendall and Wismer-
Pedersen (1959) and Bendall et al. (1963). On the basis of comparisons between muscles, Briskey and Wismer-Pedersen (1961a) suggested that in addition to chemical composition, the chilling rate of the individual muscle may also be an important factor in determining pH pattern and ultimate muscle structure.

A rapid decrease in temperature of meat samples reduced the rate at which the pH declined as found by Wismer-Pedersen and Briskey (1961) and Bendall and Wismer-Pedersen (1962). Then an increase in temperature increased the rate of acid formation, thereby increasing the rate at which the pH declined, Marsh (1954) and Bendall and Wismer-Pedersen (1962). Beecher and Briskey (1962) showed that pigs that had been skinned showed a faster rate of chilling and as expected, a slower pH drop. Briskey and Wismer-Pedersen (1961b) pointed out that the rapid chilling of sections with low initial pH values prevented continuation of the severe depression and elevation in pH.

These various chilling rates tend to alter the rate of lactic acid formation, however they had no significant effects on the total lactic acid produced (Wismer-Pedersen and Briskey, 1961).

Relation of Color to Pork Quality

The color or degree of pigmentation is a factor influencing the consumers acceptance of meat. The color of meat has been found to be highly correlated to the pH by Bate-Smith
(1948), Gibbins and Rose (1950), Wismer-Pedersen (1959) and
Briskey and Wismer-Pedersen (1961b). Kamstra and Saffle
(1959) observed that a high pH value was related to a dark
colored muscle and that color intensity was decreased when
lactic acid was added.

A number of workers have observed the effect of physical
structure on the depth of color in meat. The "closed" struc-
ture of meat at a high pH permits reflected light to pass
through a deep layer of pigment and the color appears to be
deep red. This condition exists in dark cutting beef. If the
light is scattered by superficial layers as occurs in low pH
values, the color will appear much paler even though the pig-
ment content is unchanged as postulated by Bate-Smith (1948),
Lawrie (1958), and Wismer-Pedersen and Briskey (1961). Hamm
(1953) postulated that at a low pH, water would be released
from the muscle allowing the structure to become dense. This
change in denseness of structure would result in the reflection
of shorter wave lengths of light and produce a lighter color.

Conditions related to color. Judge (1959) found that the
relation between muscle color and breeds of swine was highly
significant as certain breeds tended to produce loin muscles
of a lighter color while others produced darker loins. The
incidence of pale, soft exudative ham muscle was found to be
higher during periods of atmospheric conditions with high
temperatures or wide temperature fluctuations immediately prior
to slaughter (Forrest, 1963).
Briskey et al. (1958, 1959, 1960) and Lewis et al. (1961) showed that stress prior to slaughter significantly decreased the two-toned score of hams, giving a darker overall color.

**Water Holding Capacity in Meat**

The expression, "water holding capacity", means the ability of meat to hold fast to its own or added water during the application of any physical change such as force or heat. This property of muscle affects the quality of meat during almost all processing operations after slaughter; i.e. transport, storage, aging, grinding, salting, curing, heating, freezing and thawing (Hamm, 1960).

The charges present on muscle proteins are responsible for the binding of water to meat. The hydrophilic group responsible for the fast binding of water consists of two types. One group includes the polar groups of the side chains of proteins, such as the carboxyl, amino, hydroxyl and sulfhydryl groups. The other type is made up of undissociated carbonyl and amino groups of the peptide bonds, in which binding of water is due to the dipolar character of water. The water molecule is a dipole because the negative charge of oxygen and positive charge of hydrogen do not coincide, and therefore water can act as a molecular magnet. It is assumed then that water is bound to certain of these hydrophilic groups between the peptide chains. This can be referred to
tightly "bound" water. From research in this field, it is evident that changes in the water holding capacity of meat during normal storage and processing do not affect the tightly bound water.

The remainder of the water, sometimes referred to as "loose" water, is retained within the protein structure, but can be forced out by the application of very slight physical changes or heat. The ability of muscle protein to hold this "loose" water is influenced by changes in protein charges and by attraction or repulsion of charged groups.

When the positive charges on a protein are equal to the negative charges, a situation referred to as the "isoelectric" point, the protein has its lowest water binding capacity. The isoelectric point for meat is in the pH range of 5.0-5.3 according to Hamm (1959b) and Wismer-Pedersen (1960). The addition of an acid or a base at this point will increase the water binding capacity of meat as this will make more ions available. This means that at higher pH values above the isoelectric point, meat will have an increased water holding capacity.

**Methods of determining water holding capacity.** Grau and Hamm (1956) transformed the press method for determining water holding capacity to a quantitative technique by using filter paper. The more loosely the water is bound to the protein, the more is absorbed by the filter paper.

In this method a 300 mg. sample of meat tissue is placed on a filter paper between two Plexiglas plates. It is then
pressed, under uniform pressure, till a round thin film occurs as the water squeezed out is absorbed by the filter paper. After a set length of time, the pressure is removed and the meat film is traced before being removed from the filter paper. The inside meat area, which contains practically no moisture is then subtracted from the total area to give the moisture area. These areas can be measured by the use of planimeter. The moisture area or expressed juice absorbed by the filter paper is then proportional to the amount of loose water in the meat sample.

These workers pointed out that the type and uniformity of the filter paper is extremely important as regards the spreading of the pressed fluid. They also obtained a uniform moisture content of these filter papers by storing them in a desiccator over a saturated solution of KCl for a period of two or three days. This method is not applicable to samples with a high fat content.

Briskey et al. (1960) measured expressible water by modifying the rapid method proposed above by Grau and Hamm. The modified apparatus consisted of Plexiglas plates which were placed between two 1/4-inch aluminum sheets connected to a steel frame, hydraulic-jack and pressure gauge. A sample (0.3 gm.) was placed on the mid portion of a sheet of filter paper removed singularly from a humidifier and placed between the Plexiglas plates. Four thousand pounds per square inch of pressure was then applied for a 5 minute period. The muscle
and water juice areas were subsequently measured with a compensating polar planimeter and the amount of expressible water was recorded as a percentage of the total water. The formula used to express percentage of expressible water when 44.07 mg. of water were absorbed per sq. in. of filter paper was the following according to Kauffman and Carl (1960):

\[
\% \text{ Expressible Water} = \frac{(\text{Total area} - \text{Meat film area}) \times 44.07}{\% \text{ water in sample} \times 300 \text{ mg}}
\]

Topel (1962) also modified the rapid method of expressible moisture as proposed by Grau and Hamm. He used Whatman #1 filter paper dried 12 hours at 110°F. in a conventional oven. The filter paper was then placed in a desiccator over CaSO₄. He then placed the Plexiglas plates with (0.3 gm.) sample on a filter paper in a Carver Press for five minutes at 10,000 p.s.i. The muscle and water areas were subsequently measured with a polar planimeter and the relative amount of expressible water was recorded as a ratio of muscle area to water area.

In working with these methods, Urbin et al. (1962) obtained more consistent results by using an electrically driven centrifugal pump in place of a hand operated pump. These workers also indicated the desirability of using samples within a narrow weight range of a selected sample weight.

Deatherage (1957) described a method to determine the water holding capacity of meat that was developed by workers at Ohio State. This method involves placing a weighed portion of ground or unground meat in the upper portion of a calibrated tube resting on a loose fritted glass disc. The tube then is
placed in a water bath at a temperature desired for 30 minutes and then cooled to 30-35°C. Following this, the tube is centrifuged and then the amount of juice present is read from the calibrations (Wierbicki and Deatherage, 1958).

In comparing this tube method and the press method of Grau and Hamm, Deatherage (1957) reported excellent agreement on fresh meat. However, these two methods did not agree on cooked meat. It was pointed out that the press method has the advantage that it requires less time than does the tube method.

Relation of expressible moisture to various quality characteristics. Briskey et al. (1958) and Wismer-Pedersen (1959) found that as the pH of meat approached the isoelectric point there was a definite increase in the amount of expressible water. A similar relationship was shown for eight different muscles studied by Briskey et al. (1960). The four muscles which had the lowest pH values also possessed the greatest percentage of expressible water. The reverse was true for the four muscles with the highest pH values.

Briskey and Wismer-Pedersen (1961) and Meyer et al. (1963) found a highly significant correlation between loose water and color. They revealed that muscles with large quantities of loose water are inclined to be especially pale in color intensity. Karmes (1963) observed similar results as darker pork muscles tended to have higher moisture-protein ratio than lighter colored muscles.

Briskey et al. (1959a) reported that there was no
significant difference in expressible water between four classes of muscle in the fresh stage. However, the amount of expressible water increased significantly during the chilling process. Results of Lawrie (1960) show that a slow rate of pH fall during rigor is associated with greater fluid retention whereas a fast rate of glycolysis tends to be associated with a greater degree of exudation. He want on to point out that since the ultimate pH is the same, pH 5.5, for all rates of pH fall, the effect of ultimate pH on fluid retention can be disregarded.

Effect of chill rate on water-holding capacity of muscle. The rate of heat removal from 40°C to 20°C was of great importance in determining the effect of lactic acid production on water-binding capacity of meat as stated by Wismer-Pedersen and Briskey (1961). These workers placed 1/2 of a pork carcass in a polyethylene bag and submerged this in cold brine at -2°C. The other side acted as a control and was placed in a cooler (3°C) at the same time the first side was placed in brine. The chilling rates in the ham centers were only moderately accelerated by submersion. However, the ham surface, loin and belly were chilled much faster in the submersion chilled sides. Data imply that there was no substantial difference in ultimate (24 hr.) lactic acid concentrations or pH values. Yet the loose-water values were significantly decreased in the submerged sides, and the color intensity values were significantly increased.

Bendall and Wismer-Pedersen (1962) showed that meat going
into rigor at 20°C. had more grams water retained per gram of protein than the control held at 37°C. Bendall et al. (1963) showed that meat going into rigor at a constant temperature of 37°C. became watery and pallid in appearance. These workers postulated that the reason for this pale and watery appearance of the meat is the combination of high temperature and low pH, and that this could be prevented if the carcass was cooled fast enough to below 30°C.

Other factors affecting water-binding capacity of muscle. Comparison of two experiments by Sayre et al. (1961) indicates that factors other than fresh glycogen content, chilled pH and rate of glycolysis are important in determining the water-binding capacity of muscle. Wismer-Pedersen (1960) found that as a rule the concentration of desosympentose nucleic acid phosphorus (DNAP) is a little higher in the press fluid from meat with watery structure. After additional work Wismer-Pedersen drew the conclusion that the cell membranes in watery pork were somewhat more permeable to DNA than the membranes in normal meat, but by and large they were still intact.

The patent of Turner and Olsen (1959) describes a method for preventing the loss of ATP activity and myosin solubility to retain water binding properties of meat intended for use in sausage. By freezing meat within three to four hours of slaughter and defrosting the meat in the presence of salt, they have been able to incorporate meat into an emulsion in a pre-rigor state. Under these conditions the soluble protein
content remains at a maximum and the emulsifying and water
binding properties are greatest.

Deatherage and Hamm (1960) showed that quick freezing
and thawing of meat in rigor mortis had a small effect on water
holding capacity. This process did not cause any shift of
isoelectric point or any marked changes of available protein
charges.

Lockett (1962) and Bendall and Wismer-Pedersen (1962)
found that chloride content and water to protein ratio are
among the components conforming to pattern and having a direct
statistically significant relation to water holding capacity.

A direct, highly significant correlation was found be-
tween water retention and zinc content of beef muscles excised
before chilling. This is contrast to the inverse relation
found between water retention and either calcium or magnesium
content (Swift and Berman, 1959).

Additives That Influence Pork Quality

Bivalent metallic cations are in meat by nature and
have an important influence on the water holding capacity in
spite of their relatively low concentrations. Hamm (1959)
found that Magnesium (25 mg. %) and Calcium (5 mg. %), and
perhaps even Zinc (3 mg. %) decrease the water holding capacity
of muscle. If he removed a part of the natural calcium from
the muscle by treatment with a cation exchanger (resin), then
a strong increase in water holding capacity was noted. Hamm
explained these results by the fact that in removing metallic cross bridges, more charged groups become available for water binding. The addition of sodium chloride to meat increases the water holding capacity. This effect is due to the influence of chloride ions rather than to the influence of sodium ions. Salt cross linkages between peptide chains may be split off by binding of chloride ions and thus increase the meat hydration by both net charge effect and stereo effect.

Hamm prevented the rapid loss of water holding capacity after slaughter by salting of the ground or cut meat during the first hours after death. The additive effect of salt and ATP gives this meat an extremely high water holding capacity. Here the distance between the protein chains is too great for the bivalent cations released by the breakdown of ATP to connect the chains. Thus no drop in meat hydration was observed. Sherman (1961) and Wierbicki et al. (1957) also showed an improved hydration effect due to the addition of sodium chloride.

The influence of water holding capacity in curing. Hamm (1959) and Wismer-Pedersen (1960) found that a good correlation exists between water holding capacity of meat and the amount of pickle absorbed. These workers observed that the normal cuts absorbed less pickle than did soft, pale, watery cuts. Hamm (1959a) mentioned that the interaction between meat proteins and water causes these effects.

Results of Bate-Smith (1943) pointed out that at high pH values salt will not penetrate as readily into muscle from the
curing pickle. Wismer-Pedersen (1960) found that generally speaking, when watery pork is cured, the meat juices diffuse into the meat to a greater extent than when normal meat is cured. Additional results appear to indicate that water absorbed during cure is more loosely bound in the meat with soft, pale, watery structure than in meat of normal structure. Studies on the flow of K, Na and DNA indicated a more thorough penetration of the pickle into the meat cells of the watery meat as compared to the normal meat.

Wismer-Pedersen and Briskey (1961) found no significant difference in salt content or gelatin percentage of canned products between slowly chilled and fast chilled pork. However, definite trends toward decreased salt and gelatin in the treated (fast chilled) produce were quite apparent. The sausage emulsions from the submerged sides contained about 4% less gelatin than their respective controls. Organoleptic evaluations showed no significant differences in saltiness, taste, and texture as a result of treatment.

The Role of Quality During Cooking

Wismer-Pedersen (1960b), Lewis et al. (1961) and Meyer et al. (1963) showed that pale, soft, watery muscle had a significantly higher cooking loss.

The average total cooking losses during braising 1/2 inch pork chops were about 33% of the raw weight, Murphy and Carlin (1963). Of this cooking loss the volatile losses
amounted to 23 to 28% while the drip losses accounted for 3.5 to 7%. Onate and Carlin (1963) observed an average cooking loss of 21% for pork rib roast. The volatile loss amounted to 15% while the drip loss was only 6%.

Sherman (1961) observed that variations in fluid retention on heating can be explained in terms of the colloidal transformation that occurs in the soluble meat proteins. It appears that the absorption of ions open up the meat structure by breaking the loose bonds with the tissues, permitting faster absorption of water. This swelling of proteins - particularly actomyosin - within the meat prior to heating appears to be the most important factor in water retention.

The results of Wierbicki et al. (1957) indicate that heat denaturation of muscle proteins begins at about 40°C. and is essentially finished at 70°C. In this 40°C - 70°C. range, dynamic shifts involving potassium, calcium, and magnesium take place in such a manner as to promote hydration of meat proteins, and thus tend to counteract the dehydration usually associated with heat denaturation. This tendency is promoted by adding sodium chloride which increased the absorption of potassium and magnesium ions by the meat with almost no effect on calcium ions. The amount of moisture lost increases with increasing temperature, except in a range from 55°C to 65°C. where reactions took place to counteract loss of water by proteins. Observations of Wierbicki (1957) and Hamm (1959a) revealed that pH of meat shows a relatively uniform increase with increased
temperatures up to 75° to 80°C.

Role of marbling in pork. Murphy and Carlin (1961) showed that intermingling of fat within the lean had a significantly positive effect on both tenderness and juiciness of braised pork chops. Similar results have also been reported by Batcher and Dawson (1959) and Harrington and Pearson (1962).

Measurement of tenderness in pork. Pearson (1963) reviewed the many types of chemical, histological and mechanical procedures that have been used in attempting to evaluate tenderness. In his conclusions, he pointed out that the mechanical methods appear to be most useful at the present time. Although many mechanical devices have been used, the Warner-Bratzler shear and Kramer shear test afford the best relationships to sensory means of measuring tenderness. The relation between mean chew counts and shear values were highly significant \( r = 0.92 \) as reported by Harrington and Pearson (1962). Several other workers have also found a high relationship between the Warner- Bratzler shear test and panel scores for tenderness including Klose (1959), Cobb et al. (1961), Burrill et al. (1962), Bratzler and Smith (1963), and Mathews and Bennet (1963).

Analysis of variance of different locations within the longissimus dorsi indicated a significant tendency for shear values to be higher on the distal cores than on proximal cores in both fresh and cooked muscles (Onate and Carlin, 1963). Similar results were reported for raw samples by Murphy and Carlin (1961). Conflicting results by Urbin et al. (1962)
found shear values to be higher for the proximal cores than for distal cores for both raw and cooked muscles of pork *longissimus dorsi*.

**Quality of Lard**

**Free fatty acids.** The direct effect of the free fatty acids themselves on flavor and aroma depends on the kind of acids liberated (Hall *et al.* 1962). These workers showed that the metabolic liberation of fatty acids to supply energy in the depleted live pig was related to a rise in desirability of flavor of the cooked fat. This relation was reversed when increased acidity was brought about by post-mortem autolysis.

Harrison *et al.* (1962) reported that acid numbers for lard held at room temperature were affected significantly by including ethanolamine in the ration. This work also found that refrigerator storage appeared to have no advantage over room temperatures for acid numbers.

**Iodine values.** The determination of the iodine value of fats containing isolated double bands is based on the absorption of halogen under conditions selected to promote stoichemetical results (Mehlenbacher 1960). The general procedure involves the addition of an excess of halogen to the sample, reduction of the excess halogen with potassium iodide and finally titration with standard sodium thiosulfate using a starch solution as an indicator. The Wijs and Hanus methods are the most widely used, with the Wijs results closely approaching theoretical
values for fats containing only isolated double bonds.

With these observations reviewed in the literature in mind, work was undertaken to study the effect on pork quality due to various changes in processing carcasses before rigor mortis sets in. The principle objective was to note if various cooling methods, rate of cooling and injection of curing solutions alter pork quality.

EXPERIMENTAL METHODS

History of Animals

Eight Duroc and eight Poland China swine were placed on a pelleted ration under the same environmental conditions at an average weight of 63.8 pounds (+ 11.3). Four gilts and four barrows of each breed were used. One Duroc gilt died of Septicemia after 11 weeks so carcass data were not obtainable. Six additional swine from the University farm were obtained at slaughter weight at a later date for an additional study which will be called the frozen loin study. These swine were of various breeding backgrounds and included both barrows and gilts.

Slaughter Procedure

The animals were slaughtered in the Kansas State University meat laboratory by normal slaughter procedures. Four slaughter dates were set up for the first 15 swine so that the average slaughter weight would be approximately 200
to 210 pounds. The heaviest remaining barrow and gilt from each breed were slaughtered at each of these dates. The hogs were delivered to the meats laboratory approximately 15 hours before slaughter. At time of slaughter, each hog was stunned with an electrical stunner and then shackled. The right hind leg was used for shackling on the first and third kill date and the left hind leg at the second and fourth kill date so any effect due to shackling could be removed. A fifth kill date was selected for the six swine used for the frozen loin study. These six swine weighed 200 to 250 pounds at the time of slaughter.

These hogs were dressed essentially packer style with head off, leaf fat removed and hams unfaced. The dressed carcass weight was recorded before the right and left side were separated. The left sides were chilled at a temperature of 32° - 36°F. for 24 to 48 hours and acted as a control in this experiment. The right sides were cut and processed within one hour of stunning. The cutting procedure used followed that described at the 1952 Reciprocal Meat Conference.

Procedure for Treatment

The regular skinned ham of the right side was weighed and artery pumped up to a 10 percent increase in weight over the green weight. If this weight wasn't obtained with artery pumping, an additional stitch pumping was used. The pickle used was made with 8 pounds salt, 3 pounds sugar, 1 1/2 oz. sodium
nitrate and 1 oz. sodium nitrite for every six gallons of water. This pickle showed a temperature of 37°F. at the time of pumping. Pumped weight was then recorded before the ham was placed in a vat and cooled to 37°F. with iced cover pickle. It remained in this vat 16 days at 37°F.

The regular skinned ham from the control side was weighed and pumped with similar brine at a similar percentage as the ham from the right side. It was then placed in the same vat as the hams from the right side and held 14 days at 37°F. The remainder of the procedure is exactly the same for both hams.

The hams were removed from cure and the cured weight recorded. A two inch center ham slice was removed by following cuts located one inch and three inches toward the shank from the aitch bone. All external fat and fat in the area of the stifle were removed. The weight of the center ham slice was recorded.

Following this, the two-inch slice from both the left and right hams were placed on racks in separate aluminum trays and simultaneously cooked at 350°F. in a rotary oven until an internal temperature of 75°C. was attained. The roasts were then removed and cooked weights and drip loss were recorded.

Warner Bratzler Shear values were determined on four 1/2 inch cores of each the biceps femoris and semimembranosus as illustrated in Fig. 1. All roasts were cooled to 40°C. before these cores were removed.
Loin

The trimmed regular loin from the right side was weighed and placed in a chill room at 32 - 36°F. After 48 hours the loin was removed from the cooler and weighed. In the frozen loin study, the trimmed loin from the right side of the six carcasses was wrapped in freezer paper and placed in a blast freezer at -10 to -20°F. and frozen. After 48 hours these loins were removed from the freezer and weighed.

After 48 hours, three one inch chops were removed at the 9th, 10th and 11th rib from all loins. A visual marbling score and color score were recorded at this time. A tracing of the longissimus dorsi at the 10th rib was also obtained. The following standards were used to evaluate color and marbling.

<table>
<thead>
<tr>
<th>Marbling Score</th>
<th>Color Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Slight</td>
<td>1. Extremely light</td>
</tr>
<tr>
<td>2.</td>
<td>2.</td>
</tr>
<tr>
<td>3. Moderate</td>
<td>3. Normal</td>
</tr>
<tr>
<td>4.</td>
<td>4.</td>
</tr>
<tr>
<td>5. Abundant</td>
<td>5. Dark</td>
</tr>
</tbody>
</table>

The 9th rib chops were used immediately for expressible moisture determinations for all loins. Objective color determinations using the Photovolt colorimeter were also made of the 9th rib chops of the last six carcasses. However, the 9th rib of the right loin of these last six carcasses had to be thawed out overnight in a cooler before the determination could be made. The remaining longissimus dorsi was ground three times through a fine plate of an Oster food grinder. From this composite, a sample was taken for determination of ether extract and total moisture.
Fig. 1  Center ham slice showing location of samples from semimbranosus (1) and biceps femoris (2) muscles.

Fig. 2  Rib chop showing location of samples from longissimus dorsi muscle.
The 10th and 11th rib chops from the first 15 carcasses and from the control side of the last six carcasses were immediately boned, wrapped and frozen at -10 to -20°F. The chops from the right side of the last six loins were wrapped and placed back in the freezer. All chops were removed from the freezer 24 hours before cooking and placed in a chill room to thaw.

All external fat was removed from the loin chops before the weight of the longissimus dorsi muscle was recorded. The chops from both the left and right loins were then placed on racks in separate aluminum trays and cooked at 400°F. in a rotary oven until an internal temperature of 75°C. was obtained. The samples were then removed and weights recorded.

Warner Bratzler Shear values were recorded on four 1/2 inch cores of the longissimus dorsi as illustrated in Fig. 2. All chops were cooled to 40°C. before these cores were removed.

Fat

A 150 gm. sample of fat was removed from the fatback of each side at time of cutting, cubed and then rendered immediately in a rotary oven at a temperature of 280°F. The fat was rendered in a beaker and the lard was then filtered through cheese cloth in a funnel into storage jars. The weight of lard rendered and time were recorded.

The lard was frozen until iodine number and free fatty acid determinations could be made. At that time the samples
were stored at 65°F. for the remainder of the storage period. Free fatty acid determinations were made 3 times over an 18 week period. Iodine numbers were also determined 3 times, but over a 21 week period.

Expressible Moisture Determinations

Measurement of expressible moisture was made by modifying the rapid method proposed by Grau and Hamm (1956). This modified procedure utilized Whatman #1 filter paper stored in a desiccator over a saturated solution of KCl for a period of one or two days. When the sample was prepared for measurement, filter paper was singularly removed from the desiccator and placed on a Plexiglas plate. Immediately, a weighed meat sample of 300 mg. (± 10 mg.) was placed on the mid portion of the filter paper. Following this, a second Plexiglas plate and a 1000 gm. weight, Plexiglas plate and meat sample were then removed. Subsequently the moisture area was measured with a compensating polar planimeter and the relative amount of expressible water recorded as moisture area per gram of sample and as moisture area per gram of water in sample.

Ether extract and moisture were determined using methods outlined by the Official Methods of Analysis (Assoc. Offic. Agr. Chemists, 1960). Results are expressed as percent of original sample weight.
Color Determination

The green tristimulus filter of the Photovolt colorimeter was used to determine percent reflectance from muscle samples. Lower values represent the darker colors and higher values represent the lighter colored muscle samples.

Iodine Number

The iodine number of lard was determined by the Wijs Method as designated in the Official Method of Analysis (Assoc. Offic. Agr. Chemists, 1960). Results are expressed as Iodine Number, Wijs Method.

Free Fatty Acid Number

The free fatty acid of lard samples was determined using the Official Methods of Analysis (Assoc. Offic. Agr. Chemists, 1960). Results are expressed as percent free fatty acids.

Statistical Analysis

Data from the eight Duroc and eight Poland China swine were subjected to analysis of variance using a 4 x 4 Latin Square Design. Mean values for the Duroc gilt population were substituted for the individual that died. Data from the frozen loin study were also subjected to analysis of variance. When more than two means were compared, Duncans multiple range test was used for comparing means.

Correlation coefficients were calculated between various
criterion of product quality in the group of 15 swine. Levels of significance were used as indicated by Snedecor (1956).

RESULTS AND DISCUSSION

Cooking Values for the Hams

Mean values for various factors of the hams studied are listed in Tables 1 and 2. These data indicate no significant difference in percentage cured weight between the hams from the right side and the hams from the left side.

When cooking data from the treatment and control were compared, differences attributable to treatment were observed. Significantly lower cooking losses and drip losses were obtained from the right hams, these hams were removed within one hour of slaughter and pumped with curing solution, than the left hams or control hams. The drip loss from the left hams appeared to be considerably more viscous than the drip loss from the right hams. No significant difference was noted in evaporation loss due to treatments.

Temperature recordings of these hams during the chilling process showed that there was a faster rate of heat removal in the treated hams than in the control hams. Wismer-Pedersen and Briskey (1961) found that the rate of heat removal from 40°C to 20°C. was of great importance in determining the effect of lactic acid production on water-binding capacity of meat. Thus a fast decrease in temperature would slow down the rate of lactic acid production. Results of Lawrie (1960) show that a
### Table 1. Ham curing and cooking values

<table>
<thead>
<tr>
<th></th>
<th>Right side</th>
<th>Left side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent cured weight (a)</td>
<td>108.8</td>
<td>110.2</td>
</tr>
<tr>
<td>Percent cooking loss (b)</td>
<td>19.5</td>
<td>22.7*</td>
</tr>
<tr>
<td>Percent drip loss (c)</td>
<td>3.4</td>
<td>4.8*</td>
</tr>
<tr>
<td>Percent evaporation loss (d)</td>
<td>11.7</td>
<td>12.7</td>
</tr>
</tbody>
</table>

* a) Expressed as % of green weight.
  b) Expressed as % of uncooked weight.
  c) Weight of drip in pan expressed as % of uncooked weight.
  d) % cooking loss - % drip loss

* P = .05

### Table 2. Ham shear force values

<table>
<thead>
<tr>
<th></th>
<th>Semimembranosus</th>
<th>Biceps femoris</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrow</td>
<td>5.60</td>
<td>7.01</td>
</tr>
<tr>
<td>Gilt</td>
<td>5.12</td>
<td>5.89</td>
</tr>
<tr>
<td>Right side</td>
<td>4.95</td>
<td>6.01</td>
</tr>
<tr>
<td>Left side</td>
<td>5.77</td>
<td>6.88</td>
</tr>
</tbody>
</table>

a) Shear force values expressed in pounds as measured by the Warner Bratzler Shear using 1/2 inch cores.

* P = .05
*** P = .001
slow rate of pH fall during rigor is associated with greater fluid retention whereas a fast rate of glycolysis tends to be associated with a greater degree of exudation. Therefore the difference found in this study may be in part due to the increased rate of heat removal in the treated hams.

It may be postulated that the decreased cooking loss and drip loss in the treated hams may be due to the addition of the curing solution, and thereby the reaction of the salts, before rigor mortis occurred. Hamm (1959a) prevented the rapid loss of water holding capacity after slaughter by salting of the ground or cut meat during the first hours after death. He also observed that an animal injected with sodium chloride before being dressed out, had muscle tissue that had "100 percent ability" to hold water. Hamm explained that this effect is due to the influence of the chloride ions as the salt cross linkages between peptide chains may be split off by binding of these chloride ions, thus more charged groups become available for water binding. Therefore this increased water holding capacity would mean that the treated hams would have increased ability to hold fast its own or added water during the application of heat.

Tenderness of Hams

The results of this study indicate that tenderness of the ham can be influenced by the sex of the live animal and by the treatment. Average shear values of the two ham muscles studied are listed in Table 2.
Highly significant differences were observed between barrows and gilts from the shear values of the *semimembranosus* and *biceps femoris* muscles. The barrows had significantly higher shear values than gilts in both muscles studied.

A highly significant difference was noted in shear values between the muscles from the hams from the right side and the hams from the left side. Significantly lower shear values were found from both the *semimembranosus* and *biceps femoris* muscles of the treated hams.

Again it may be postulated that improved tenderness in the muscles of the treated hams may be due to either, or both, the increased rate of heat removal from the treated hams and/or the addition of the curing solutions, and thereby the reaction of the salts, before rigor mortis occurred. Bate-Smith and Bendall (1949) demonstrated that lower temperatures in rabbit muscle resulted in less shortening of the muscle fibers. More recent work by DeFremery and Pool (1960) with chicken muscle and Briskey et al. (1962) with pork muscle have shown that the total time for completion of rigor mortis was markedly increased by lowering the temperature. Marsh (1953) found a relationship to exist between shortening and extensibility which indicates diminished cross-bond formation is present with increased shortening. In working with the *longissimus dorsi* muscle of beef cattle, Wang (1956) revealed the existence of a positive correlation between muscle fiber extensibility and shear force values. Locker (1960) also found that shortened muscles were
judged less tender by a sensory panel.

Partmann (1963) postulated that if the interaction between actin and myosin during rigor mortis could be wholly or partly impeded, this might improve tenderness. In work with strips of diaphragm muscle excised immediately post mortem from beef cattle, Partmann showed that shortened muscles were significantly less tender than the stretched strips after the same amount of time. However, Briggs (1963) showed that the presence of calcium ions inhibits the relaxing factor, thus preventing the relaxation of fibrils and resulting in contraction. The removal of calcium by injection of a chelating agent, EDTA, delayed the onset of rigor mortis according to Howard and Lawrie (1956), as described by Partmann (1963).

Hamm (1959a) observed that an animal injected with sodium chloride before being dressed out, had muscle tissue that was extremely tender. He explained this phenomenon as a shift in the ionic balance. Results of Weber (1963) show that binding of exchangable calcium by myofibrils was highest in KCl solution. A highly significant advantage in tenderness was also obtained by Kumstra and Saffle (1959), when sodium hexametaphosphate was injected into hams removed 15 minutes after slaughter, as compared to the control which was injected with water at the same time. The salts added in the curing solution could combine with calcium ions as they are freed, thereby preventing this calcium from inhibiting the relaxing factor. This could then possibly result in decreased contraction and
decreased shortening of the muscles which seems to be associated with the improved tenderness that was observed.

Shear Values of Loin Samples

Mean values for various factors of the loins studied are listed in Table 3. Significantly different shear force values were observed due to treatments. Those loins that were removed from the carcass before rigor mortis set in and cooled in a 32° - 34°F. cooler were found to have significantly lower shear force values than the control loins. However the loins that were frozen immediately after removal from the carcass had significantly higher shear force values than the control loins.

The lower shear values noted for the loins cooled at 32° - 34°F. may be explained much in the same manner as proposed for the lower shear values of the treated hams. It may be postulated that the opposite results obtained for the frozen loins parallel the phenomenon of "thaw rigor" as described by Perry (1950). He observed definite shortening in the sartorius muscle of the frog during "thaw rigor". DeFremery and Pool (1960) also found that "thaw rigor" induces a highly significant decrease in tenderness of cooked poultry.

Expressible Moisture and Cooking Loss of Loin

The results of this study indicated that there is a significant difference in the water holding capacity between the frozen loin and control, but no significant difference in
<table>
<thead>
<tr>
<th></th>
<th>Shear force&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Cooking loss&lt;sup&gt;b&lt;/sup&gt;</th>
<th>LOIN - FROZEN</th>
<th>LOIN - 32°F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expressible moisture&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Loin eye area</td>
</tr>
<tr>
<td>Right side</td>
<td>8.43</td>
<td>23.4%</td>
<td>3.52</td>
<td>5.20</td>
</tr>
<tr>
<td>Left side</td>
<td>7.69</td>
<td>25.9%</td>
<td>2.80</td>
<td>4.50</td>
</tr>
<tr>
<td>Barrow</td>
<td></td>
<td></td>
<td>3.88</td>
<td>4.20</td>
</tr>
<tr>
<td>Gilt</td>
<td></td>
<td></td>
<td>3.85</td>
<td>4.23</td>
</tr>
<tr>
<td>Poland</td>
<td></td>
<td></td>
<td>4.49</td>
<td>4.80</td>
</tr>
<tr>
<td>Duroc</td>
<td></td>
<td></td>
<td>3.25</td>
<td>3.62</td>
</tr>
</tbody>
</table>

<sup>a</sup> Expressed in pounds as measured by the Warner Bratzler Shear using 1/2 inch cores.
<sup>b</sup> Expressed as % of uncooked weight.
<sup>c</sup> Expressed as ave. sq. in expressible juice/gm. sample.
<sup>d</sup> Expressed as % of uncooked weight.

* P = .05
** P = .01
water holding capacity between the chilled loin and its control. Significantly higher expressible moisture values were found for the frozen loins than from its control. Yet when cooking data from the treatment and controls where compared, no significant difference in cooking loss were observed. The data show that the frozen loin had a slightly lower cooking loss than its control even though it has a significantly lower water holding capacity. One factor that could influence the cooking loss here is the difference in loin eye area. Since just the longissimus dorsi muscle was cooked, the smaller the loin eye area, the higher ratio of exposed surface would be present. This may tend to increase the cooking loss in the loin from the left side.

Total cooking loss could also be influenced by the large drip loss that had already occurred after thawing and before cooking these samples. Again these results parallel the findings of Perry (1950), DeFremery and Pool (1960) and Partmann (1963). Perry (1950) showed that "thaw rigor" in the sartorius muscle of frog was accompanied by a 35% loss in weight.

These data indicate that freezing prior to rigor mortis and then thawing adversely affects tenderness and water holding capacity. Yet, the rapid chilling of the loin to 32°F produced lower shear force values and no significant difference in water holding capacity. Therefore it appears that rapid chilling is beneficial because it slows down the rate of rigor mortis, thereby decreasing the shortening of the muscle fibers.

In comparison, Partmann (1963) points out that when
muscle tissue is frozen immediately after the death of warm-blooded animals, the glycolytic processes slow down and become almost completely inhibited at a low enough temperature. The ATP still present at that moment will persist. Then, when the temperature increases sufficiently during thawing, the ATP will be split quickly as contraction of the tissue occurs, producing "thaw rigor", followed by a high degree of drip loss.

Water holding capacity was also affected by the breed of swine as indicated by significantly lower expressible moisture areas from the Durocs than from the Poland Chinas. No significant differences in water holding capacity were observed due to sex. Breed of swine shows no effect on cooking loss, but the data indicate a significant difference in cooking loss due to sex. Significantly lower cooking losses were obtained from gilts than from barrows.

Where significant differences were found in water holding capacity due to breed, no significance was observed in cooking loss due to breed. However the loin eye area for the Poland China group was significantly larger than from the Duroc group. Thus the lower ratio of exposed surface in the Poland China group may tend to decrease the cooking losses. These data also indicate highly significant differences due to breed X sex interactions when comparing shear force values of the loin samples.
Ether Extract and Total Moisture

The ether extract content and total moisture of the longissimus dorsi muscle showed no significant differences due to treatment in either loin study. However, these data indicate a highly significant difference in ether extract content and total moisture between breeds and sex. The Poland China group had a significantly lower ether extract and higher total moisture content than the Duroc group. Samples from gilts had a significantly lower ether extract and higher total moisture content than those from barrows.

Effect of Location on Shear Force Values

The results of this study indicate that the location of the core sample within the muscle can influence the shear force values. An average value for the four locations (Fig. 1 and 2) for each muscle studied are listed in Table 4. Highly significant differences were observed between various sample locations of the biceps femoris and semimembranosus muscles of the ham and the longissimus dorsi muscle from the loins in the frozen loin study. However, these data show no significant difference in the location of the core samples of the loin study where the loins were chilled to 32°F.

The core samples located proximal to the femur bone, of the two ham muscles, had significantly lower shear force values than did core samples located distal to the femur bone. Core samples from the medial location of the longissimus dorsi muscle
Table 4. Effect of location on shear force value

<table>
<thead>
<tr>
<th>Location*</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biceps femoris</td>
<td>5.83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.70&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.70&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.86&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Semimembranosus</td>
<td>4.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.74&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.04&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>L.D. - Frozen</td>
<td>7.84&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.62&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.09&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.71&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>L.D. - 32°F.</td>
<td>7.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*All values for a given muscle with same superscript are not significantly different at .05 level.

of the loin showed a significantly lower shear force value than the laterally located samples. This is in agreement with work reported by Murphy and Carlin (1961) and Onate and Carlin (1963) where they found a significant tendency for shear values to be higher on the lateral cores than on the medial cores. However these results are conflicting with work of Urbin et al. (1962) where shear values were found to be higher for the medial cores than for lateral cores for cooked muscles of pork *longissimus dorsi*.

Yield of Lard

In the lard phase of this study, the yield of lard from fat samples during rendering was not significantly affected by the treatments or by the breed or sex of the swine. However this may not be a true picture of the possible differences because there was a wide range in sample size and rendering time
which resulted in an exceedingly wide range of yields. Observations during the rendering process revealed that the cubes of fatty tissue from the treated side appeared to nearly maintain their original shape and size during the rendering process. In comparison, the samples from the control side were shriveled to some degree upon completion of rendering. Cracklings from the left side also appeared to exhibit a darker brown color.

The shriveled appearance and darker color of the cracklings from the control side may not have been present in the cracklings from the treated side because of the possible difference in the state of denaturation of the proteins in the connective tissue of the fat samples.

Chemical Analysis of Lard

Iodine number and percent free fatty acid were determined for the lard samples at three stages of storage. The mean values for these results are listed in Table 5. These data indicate a highly significant difference in iodine number due to breed of swine and stage of storage.

Samples from the Poland Chinas had a significantly higher iodine number than those from Durocs. The lower iodine number for the Durocs may be partly explained by the composition of the original fat sample used for rendering. According to White et al., 1959, p. 456, variations in the composition of the depot lipid have been noted as one progresses from the outermost layers of depot fat toward the innermost layers; the melting
Table 5. Chemical analysis of lard

<table>
<thead>
<tr>
<th></th>
<th>Iodine number</th>
<th>% free fatty acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poland</td>
<td>68.70</td>
<td>1.17</td>
</tr>
<tr>
<td>Duroc</td>
<td>61.06</td>
<td>1.02</td>
</tr>
<tr>
<td>Right side</td>
<td>64.37</td>
<td>1.11</td>
</tr>
<tr>
<td>Left side</td>
<td>65.39</td>
<td>1.08</td>
</tr>
<tr>
<td>Time A</td>
<td>67.0</td>
<td>.74</td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>B</td>
<td>64.7</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>C</td>
<td>62.9</td>
<td>1.43</td>
</tr>
</tbody>
</table>

A - first analysis - control.
B - first analysis after storage.
C - final analysis after storage.

* P = .05
### P = .01

Point of the lipid progressively increases and the iodine number decreases. It was noted that the Duroc group had a much thicker fat covering and therefore would have a lower percentage of the outermost layers of fat than did the samples from the Poland China group. No significant breed difference in percent free fatty acid was obtained.

Treatment had no significant influence on the iodine number or the free fatty acid number of the lard samples in this study. The treatment used in this study had no significant effect on the original quality of the lard or on the quality after storage.
The average iodine number of the lard samples, as shown in Table 5, was significantly lower at each stage of storage. This would mean that fewer double bonds are present in this lipid sample after set times of storage due to possible oxidation at the double bond. In comparison, these data show a highly significant increase in the percent free fatty acids during storage.

The relationship between the iodine number and the percent free fatty acids from this study is shown in Figure 3. Thus, the corresponding decrease in iodine number and increase in free fatty acid number would tend to agree with the idea that oxidation of lard occurs at double bonds. This would then decrease the number of double bonds present as the percent free fatty acid number increases because of the byproducts of this oxidation.

These data indicate no significant interaction between treatment and time for iodine number or percent free fatty acid number.

**Correlation Coefficients**

Correlation coefficients between various subjective and objective evaluations of quality are listed in Table 6.

**Marbling**

Ether extract of the *longissimus dorsi* muscle was used as an objective determination of marbling. The correlation
Table 6. Correlation coefficients between various subjective and objective evaluations of quality

<table>
<thead>
<tr>
<th></th>
<th>Right side (Treated)</th>
<th>Left side (Control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marbling of loin* vs Ether Extract of longissimus dorsi muscle b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color of loin c</td>
<td>.912**</td>
<td>.871**</td>
</tr>
<tr>
<td>Expressible moisture d</td>
<td>.770**</td>
<td>.808**</td>
</tr>
<tr>
<td>Iodine number</td>
<td>-.564*</td>
<td>-.811**</td>
</tr>
<tr>
<td>Shear force - longissimus dorsi e</td>
<td>-.679**</td>
<td>-.787**</td>
</tr>
<tr>
<td>Shear force - biceps femoris c</td>
<td>-579*</td>
<td>-.458</td>
</tr>
<tr>
<td>Shear force - semimembranosus e</td>
<td>.252</td>
<td>.066</td>
</tr>
<tr>
<td>Cooking loss - loin f</td>
<td>.325</td>
<td>-.149</td>
</tr>
<tr>
<td>Cooking loss - ham f</td>
<td>.018</td>
<td>-.057</td>
</tr>
</tbody>
</table>

| Color of loin vs                  |                      |                     |
| Expressible moisture              | -.495                | -.880**             |
| Iodine number                     | -.682**              | -.775**             |
| Shear force - longissimus dorsi   | .454                 | .379                |
| Shear force - biceps femoris      | .268                 | .155                |
| Shear force - semimembranosus     | .092                 | .066                |
| Cooking loss - loin               | .175                 | .041                |
| Cooking loss - ham                | -.012                | .060                |

| Expressible moisture              |                      |                     |
| Iodine number                     | .164                 | .620*               |
| Shear force - longissimus dorsi   | .581*                | .426                |
| Shear force - biceps femoris      | -.083                | .103                |
| Shear force - semimembranosus     | -.097                | -.039               |
| Cooking loss - loin               | .190                 | .054                |
| Cooking loss - ham                | .222                 | .014                |

a) 1=devoid    5=abundant  
b) Expressed as % of raw weight 
c) 1=light (pale), 3=normal, 5=dark  
d) Expressed as ave. sq. in. expressible juice/gm. sample  
e) Values expressed in pounds as measured by the Warner Bratzler Shear using 1/2 inch cores  
f) Expressed as % of uncooked wt.  

# P = .05  
## P = .01
coefficients observed between this and the subjective marbling score (.912** and .871**), indicate that the subjective evaluation of marbling is a consistent and accurate method of determining the amount of intramuscular fat, when it is done by trained personnel. This is in agreement with results reported by Judge et al. (1960) and Forrest (1962).

Subjective marbling scores were significantly correlated with subjective color scores (.770** and .808**) and expressible moisture determinations (-.564* and -.311**). Increased marbling in a muscle was associated with a darker color and improved water holding capacity. The correlation coefficients between marbling and iodine number were -.679** and -.787**. This suggests that increased marbling scores would be associated with a decreased number of double bonds present in a lard sample from that swine carcass.

The correlation coefficients between marbling and shear force values of the muscles studied for treated and control sides, respectively, were: longissimus dorsi (-.579* and -.458), biceps femoris (.252 and .066) and semimembranosus (-.143 and -.214). Marbling was significantly related to shear force values for the treated longissimus dorsi muscle and approached significance for the control side. However these data show no relationship between the marbling of the loin and the shear force values of the two ham muscles studied. This suggests that marbling of a muscle is related to tenderness of that muscle, but not necessarily associated with tenderness of
another muscle in that carcass. Correlation coefficients between marbling and cooking losses from the loin (.325 and -.149) and ham (.018 and -.057) were not significant.

**Color**

Subjective color scores were significantly correlated with expressible moisture determinations (-.495 and -.880**) only for the control side. A dark color tended to be associated with less juice per gm. tissue, therefore with greater water holding capacity. This suggests that the color was an indicator of water holding capacity in the control loins, but color was not as good an indicator of water holding capacity in the treated loins. Treatment may have had an effect on expressible moisture which could not be detected in observing muscle color. The correlation coefficients between muscle color score and iodine number were (-.682** and -.775**) which would indicate that light colored muscles are associated with higher iodine number values of lard samples from the same carcass.

No significant correlation was observed between color of longissimus dorsi muscle and shear force values of the muscles studied or cooking losses of the loin and ham samples.

**Expressible Moisture**

Expressible moisture of longissimus dorsi muscle as determined by the modified filter paper method and expressed as average square inches expressible juice per gm. sample was
not significantly correlated with shear force values of the ham muscles studied or cooking losses from the loin and ham samples. Apparently factors other than expressible moisture influenced cooking losses. Correlation coefficients of .581* and .426 were observed between expressible moisture and shear force values of the longissimus dorsi muscle. This suggests a slight improvement in tenderness with lower expressible moisture values.

Chemical Analysis of Lard

Data from lard samples which were analyzed for iodine number three times over a 21 week storage period and for percent free fatty acid number three times over the first 18 weeks of this storage period are shown in Table 7.

The correlation coefficients between the original iodine number of the lard samples and the iodine number at first analysis after storage (.717** and .816**) and final analysis after storage (.415 and .857**) indicates that the decrease in iodine number during storage occurs proportionally to the original iodine number. The significant correlation between the iodine number obtained at the first analysis after storage and final analysis after storage (.527* and .633*) verify this.

Correlation coefficients of .622* and .478 between the original iodine number and the original free fatty acid number suggest some degree of relationship. However, no significant correlation was noted between original iodine number and final
Table 7. Correlation coefficients between iodine numbers and percent free fatty acid number at various times

<table>
<thead>
<tr>
<th></th>
<th>Right side (Treated)</th>
<th>Left side (Control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iodine number -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time A vs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iodine number - Time B</td>
<td>.717**</td>
<td>.816**</td>
</tr>
<tr>
<td>Iodine number - Time C</td>
<td>.415</td>
<td>.857**</td>
</tr>
<tr>
<td>% free fatty acid - Time A</td>
<td>.622*</td>
<td>.478</td>
</tr>
<tr>
<td>% free fatty acid - Time C</td>
<td>.052</td>
<td>.315</td>
</tr>
<tr>
<td>Iodine number -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time B vs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iodine number - Time C</td>
<td>.527*</td>
<td>.663**</td>
</tr>
<tr>
<td>Iodine number -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time C vs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% free fatty acid - Time C</td>
<td>-.427</td>
<td>-.152</td>
</tr>
<tr>
<td>% free fatty acid -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time A vs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% free fatty acid - Time B</td>
<td>.042</td>
<td>.070</td>
</tr>
<tr>
<td>% free fatty acid - Time C</td>
<td>.046</td>
<td>-.118</td>
</tr>
<tr>
<td>% free fatty acid -</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time B vs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% free fatty acid - Time C</td>
<td>.374**</td>
<td>.536*</td>
</tr>
</tbody>
</table>

A - first analysis - control
B - first analysis after storage
C - final analysis after storage

# P = .05
## P = .01
percent free fatty acid. The negative, but non significant correlation between iodine number at final analysis after storage and percent free fatty acid at final analysis may tend to show that a decrease in double bonds is associated with increased fatty acid formation in lard during storage.

Correlation coefficients between the original percent of free fatty acids and free analysis after storage (.042 and .070) and final analysis after storage (.063 and -.118) were not significant. Yet correlation coefficients of .874** and .536** between the first percent free fatty acid analysis after storage and final analysis after storage were highly significant. These results are hard to explain, but may suggest that certain oxidizing agents or antioxidants may be present in some of these lard samples that could influence the rate of fatty acid formation soon after storage. However after a certain period of time, fatty acid formation appeared to occur at a relatively constant rate in all samples.

SUMMARY

Eight Duroc and eight Poland China swine including four gilts and four barrows of each breed were placed on feed under the same environmental conditions. Six additional swine were slaughtered to study effect of freezing loins before rigor mortis. All animals were slaughtered at a weight of approximately 200 pounds. The left side (control) of the dressed carcass was chilled at a temperature of 32° - 36°F. for 48
hours before being cut and processed by regular methods. The right sides (treated) were cut and processed within one hour of bleeding.

The treated hams had significantly lower cooking losses and drip losses than the control hams. Significantly lower shear values were found from both the semimembranosus and biceps femoris muscles of the treated hams. The barrows had significantly higher shear values than gilts in both ham muscles studied. These two ham muscles also showed significantly lower shear force values for core samples located proximal to femur bone than distal core samples.

Loins removed before rigor mortis and chilled had significantly lower shear values than the control loins. However the loins removed before rigor mortis and frozen had significantly higher shear force values than its control loins. Significantly higher expressible moisture values were found for the frozen loins, but no significant difference in expressible moisture was noted between chilled loins and controls. When cooking losses, ether extract and total moisture of the loin studies were compared, no significant difference was observed due to treatment.

Treatment had no significant influence on the iodine number or the free fatty acid number of the lard samples in this study, regardless of length of storage.

Increased marbling of the loin was significantly related to increased ether extract, darker color, improved water holding capacity and lower shear values of the longissimus dorsi
muscle and lower iodine numbers of lard. A dark color of longissimus dorsi muscle tended to be associated with improved water holding capacity and lower iodine numbers, but not significantly correlated to shear force values and cooking losses.
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THE EFFECT OF PROCESSING PORK CARCASSES PRIOR TO RIGOR MORTIS UPON MUSCLE AND FAT QUALITY

by

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This study was undertaken to determine the effect on the muscle and fat characteristics of pork due to processing carcasses before rigor mortis. In addition it seemed important to study the relationship between various criterion of pork quality.

Eight Duroc and eight Poland China swine including four gilts and four barrows of each breed were placed on feed under the same environmental conditions. Six additional swine were slaughtered to study effect of freezing loins before rigor mortis. All animals were slaughtered at a weight of approximately 200 pounds. The left side (control) of the dressed carcass was chilled at a temperature of 32° - 36°F. for 48 hours before being cut. The right sides (treated) were cut and processed within one hour of bleeding.

After cutting the right hams were pumped with regular pickle and cooled in a vat with iced cover pickle. The right loins were either placed in a chill room or in a blast freezer after cutting. The control ham and loin were processed by regular methods. Roasts removed from the hams and chops from the loin were cooked in a rotary oven.

Lard samples obtained by rendering fat samples after cutting, were analyzed for iodine number and percent free fatty acid over a period of 21 and 18 weeks respectively.

The treated hams had significantly lower cooking losses and drip losses than the control hams. Significantly lower shear values were found from both the semimembranosus and biceps femoris muscles of the treated hams. The barrows had
significantly higher shear values than gilts in both ham muscles studied. These two ham muscles also showed significantly lower shear force values for core samples located proximal to femur bone than distal core samples.

Loins removed before rigor mortis and chilled had significantly lower shear force values than the control loins. However the loins removed before rigor mortis and frozen had significantly higher shear force values than its control loins. Significantly higher expressible moisture values were found for the frozen loins, but no significant difference in expressible moisture was noted between chilled loins and controls. When cooking losses, ether extract and total moisture of the loin studies were compared, no significant difference was observed due to treatment.

Treatment had no significant influence on the iodine number or the free fatty acid number of the lard samples in this study, regardless of length of storage.

Increased marbling of the loin was significantly related to increased ether extract, darker color, improved water holding capacity and lower shear values of the longissimus dorsi muscle and lower fat, iodine numbers. A dark color of longissimus dorsi muscle tended to be associated with improved water holding capacity and lower fat iodine numbers, but not significantly correlated to shear force values and cooking losses.