THE EFFECT OF PROCESSING PORK CARCASSES
PRIOR TO RIGOR MORTIS UPON MUSCLE AND FAT QUALITY

by

PHILIP DAVID WEINER

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Approved by:

D. H. Kropf

Major Professor

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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 con-
tinuous 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 filaments 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 splitting, the fibrils are incapable of contracting. Thus, it is found that after this relaxing factor has stopped the actinmyosin interaction, contraction ceases completely.

Observations of Briggs (1963) support the hypothesis that the soluble relaxing factor isolated from muscle is a phospholipid. 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 consistancy 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 sartorious 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 phenomenom 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

than its control.

Kamstra and Saffle (1959) observed that a highly signifi-
cant advantage in tenderness was obtained when sodium hexameta-
phosphate 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 hexametaphos-
phate 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 bivalant 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 effect 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 $0^{\circ}C$. 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 $NaNO_2$ greatly inhibited the breakdown of ATP at $20^{\circ}C$. 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 $NaNO_2$, 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, car-
casses 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 dif-
ferent 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 influenc-
ing 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):

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

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 $CaSO_4$. 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 consistant 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 centri-
fuged 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 per-
centage 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 inten-
sity. 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° 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 desoypentose 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 between 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 im-
proved 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 (1948) 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. How-
ever, 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 transforma-
tion 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° - 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° to 65°C. where reactions
took place to counteract loss of water by proteins. Observa-
tions 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 proce-
dures 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 absorbtion of halogen under conditions selected to promote stoichemetrical 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 ($\pm$ 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 pump-
ing, 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.

Marbling Score	Color Score
1. Slight	1. Extremely light
2.	2.
3. Moderate	3. Normal
4.	4.
5. Abundant	5. Dark

The 9th rib chops were used immediately for expressible
moisture determinations for all loins. Objective color deter-
minations 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
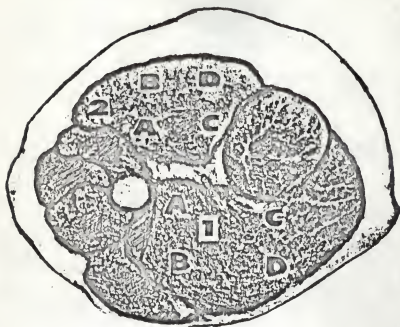ether extract and total moisture.

Fig. 1   Center ham slice showing location of samples from _semimbranosus_ (1) and _biceps femoris_ (2) muscles.
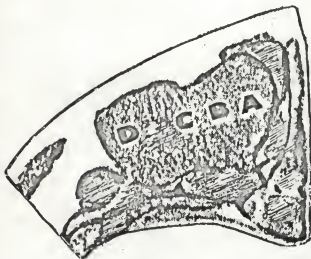

Fig. 2   Rib chop showing location of samples from _long-issimus dorsi_ muscle.

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 modi-
fied 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. Sub-
sequently 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° to $20^\circ C$. 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

	Right side	Left side
Percent cured weight (a)	108.8	110.2
Percent cooking loss (b)	19.5	22.7*
Percent drip loss (c)	3.4	4.8*
Percent evaporation loss (d)	11.7	12.7

    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[a]

	Semimembranosus	Biceps femoris
Barrow	5.60	7.01
Gilt	5.12*	5.89***
Right side	4.95***	6.01***
Left side	5.77	6.88

    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 deminished 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 sartorious 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 3. Longissimus dorsi muscle (loin)

	Shear force[a]	Cooking loss[b]	Expressible moisture[c]	Loin eye area	% fat	% moisture
			LOIN - FROZEN			
Right side	8.43 **	23.4% **	3.52 **	5.20	5.39	74.08
Left side	7.69	25.9%	2.80	4.50	5.05	74.61
			LOIN - 32°F			
Right side	6.97 **	26.1%	3.88	4.20	3.69	73.51
Left side	7.36	27.5%	3.85	4.23	3.80	73.26
Barrow		28.2%	3.84	4.00	4.40 **	73.09
Gilt		25.4% *	3.90	4.44	3.10	73.84 **
Poland		26.5%	4.49 *	4.80	1.90 **	74.30
Duroc		27.1%	3.25	3.62	5.60	72.48 **

a) Expressed in pounds as measured by the Warner Bratzler Shear using 1/2 inch cores.
b) Expressed as % of uncooked weight.
c) Expressed as ave. sq. in expressible juice/gm. sample.
d) 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 <u>longissimus
dorsi</u> muscle was cooked, the smaller the loin eye area, the higher
ratio of exposed surface would be present. This may tend to in-
crease 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 find-
ings of Perry (1950), DeFremery and Pool (1960) and Partmann
(1963). Perry (1950) showed that "thaw rigor" in the <u>sartorious</u>
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. pro-
duced 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 signifi-
cant 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 signifi-
cant 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 $32^{\circ}F$.

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

	Location*			
	A	B	C	D
Biceps femoris	5.83[a]	6.70[ab]	6.70[b]	6.86[b]
Semimembranosus	4.65[a]	5.00[a]	5.74[b]	6.04[b]
L.D. - Frozen	7.84[a]	7.62[a]	8.09[a]	8.71[b]
L.D. - 32°F.	7.38[a]	7.14[a]	6.98[a]	7.20[a]

*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 denaturization 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

	Iodine number	% free fatty acid
Poland	68.70 ✱✱✱	1.17
Duroc	61.06	1.02
Right side	64.37	1.11
Left side	65.39	1.08
Time A	67.0 ✱	.74 ✱
B	64.7 ✱	1.12
C	62.9	1.43

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 by products 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

Figure 3
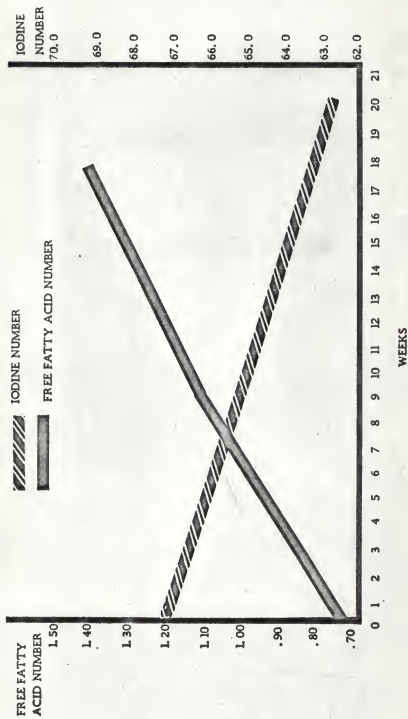
IODINE AND FREE FATTY ACID NUMBERS

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

	Right side (Treated)	Left side (Control)
Marbling of loin[a] vs Ether Extract of longissimus dorsi muscle[b]	.912**	.871**
Color of loin[c]	.770**	.808**
Expressible moisture[d]	-.564*	-.811**
Iodine number	-.679**	-.787**
Shear force - longissimus dorsi[e]	-.579*	-.458
Shear force - biceps femoris[e]	.252	.066
Shear force - semimembranosus[e]	-.143	-.214
Cooking loss - loin[f]	.325	-.149
Cooking loss - ham[f]	.018	-.057
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 -.811**). 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 per-
cent 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

	Right side (Treated)	Left side (Control)
Iodine number - Time A vs		
Iodine number - Time B	.717**	.816**
Iodine number - Time C	.415	.857**
% free fatty acid - Time A	.622*	.478
% free fatty acid - Time C	.052	.315
Iodine number - Time B vs		
Iodine number - Time C	.527*	.663**
Iodine number - Time C vs		
% free fatty acid - Time C	-.427	-.152
% free fatty acid - Time A vs		
% free fatty acid - Time B	.042	.070
% free fatty acid - Time C	.046	-.118
% free fatty acid - Time B vs		
% free fatty acid - Time C	.874**	.536*

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 signifi-
cantly 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 signifi-
cantly 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 hold-
ing 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 sig-
nificantly 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

PHILIP DAVID WEINER

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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 $32^\circ - 36^\circ F$. 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.