EVALUATION OF MEAT QUALITY IN COMMERCIAL PIGS IN NEW ZEALAND

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This thesis is dedicated to my beloved father (Atty Sergio Brillantes Gelera) and to my late loving mother (Mrs. Anita Gallano Gelera)

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by

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ABSTRACT

Evaluation was undertaken of 144 carcasses at two abattoirs in the Manawatu region (New Zealand) to study pork quality characteristics. Surveys were made of farmers, transporters and abattoirs on how they handle the pigs before slaughter. Measurements were made of pH_1, pH_u, colour (visual and Hunter LAB), water holding capacity (WHC) by filter paper press, drip loss and protein solubility of the *Semitendinosus* and *Longissimus dorsi* muscles.

The pH_1 was measured at 45 minutes. After 24 hours storage in the chiller, the pH_{24} and WHC were measured and after 30 minutes bloom, the colour measurements (Hunter L A B) and visual colour scores (0 = DFD, 1 = MDFD, 2 = normal, 3 = MPSE, 4 = PSE) were made. The protein solubility was measured within 48 hours postmortem and the drip loss was measured after 48 hours. The carcasses were subjectively classified as DFD (dark, firm, dry), MDFD (mild DFD), normal, MPSE (mild PSE) and PSE (pale, soft, exudative). Sex, breed, age, transport time, distance, last feeding time, weather condition, bruises and laceration/scratches, and stunning time were also recorded.

The total incidence of **PSEo** was *41.98 %* in the **ST** and *72.41 %* in the **LD**, and the **DFDo** incidence was *10.65 %* in the **LD** and *36.05 %* in the **ST**. Almost all the meat quality traits were highly correlated (r = *0.35* to *0.92*) and highly significant ($p < 0.001$) with each other in both muscles used. *pH* (pH_1 and pH_{24}) was the most dependable technique used in this study. There is no obvious relationship between occurrence of pork quality problem in the pigs and the lairage period or transport distance. However, sex had low but significant correlations with pH_1 suggesting a possible advantage in treating sexes differently after they leave the farm.

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Chapter I

INTRODUCTION

The New Zealand Pork Industry Board is in the process of improving the visual and eating quality of pork as a consequence of numerous consumer complaints relating to the extreme variability of pork currently available in the butchery and food stores.

The demand for lean pork has increased slightly in New Zealand in recent years (Anon., 1993). The intensive production of pigs in New Zealand has rapidly moved towards the use of modern intensive fattening units. With this intensification of production, pork quality problems have emerged, especially those attributable to breeds (Pietrain and Landrace). These breeds tend to be more stress susceptible leading to a high incidence of pale, soft, exudative pig meat (MacDougall and Jones, 1975; Evan et al., 1978; Oliver et al., 1991). The occurrence of muscles with PSE (pale, soft and exudative) and DFD (dark, firm and dry) characteristics are undesirable since both give rise to meat of lower quality. PSE and DFD meat are the most important quality defects in pork (Briskey and Wismer-Pedersen, 1961). PSE meat has a pale colour, soft consistency, low initial pH (pH_{45}) less water holding capacity (WHC) and more drip loss. On the other hand, DFD meat has a darker colour, higher ultimate pH (pH), higher WHC and less drip loss than normal meat. Several studies have been performed to find out the causes of these defects (Briskey, 1964; Bendall and Lawrie, 1964; Dildey *et al.*, 1970; Asghar and Pearson, 1980; Honikel and

Kim, 1985 & 1986). Pigs carrying the halothane-gene are generally prone to stress, which may result in a higher incidence of PSE and thus lower meat quality than pigs without this gene (Lundstrom *et al.*, 1989, Archibald, 1991). These genes are genetically conditioned and activated by stress factors associated with the transport and slaughtering procedure (Wismer-Pedersen and Hamm, 1960; Barton-Gade, 1974 & 1979; Fortin, 1974), which leads to abnormal biochemical metabolism in the musculature (Briskey and Wismer-Pedersen, 1961a; Topel *et al.*, 1966; Bendall, 1973; Cassen *et al.*, 1975; Cassens, 1977). The handling of the animals prior to slaughter, as well as too short a resting period at the lairage within the abattoir also influences the development of both PSE and DFD as reviewed by Warris (1987). The incidence of (PSE and DFD) meat in commercial carcasses was recently estimated as high as 70% within the New Zealand industry (Confidential record, Massey University).

In Switzerland, the incidence of PSE is now 4 - 6 % of all pigs slaughtered at registered meat killing facilities (private comm., Dr. Patrick Morrel). Ten years ago the PSE incidence in Switzerland was 20 - 30 %. This reduction in PSe has been achieved by systematic screening and elimination of breeding animals known to carry the genes responsible for PSS and PSE. The Swiss pork industry is now in the enviable position of having less than 6% of slaughtered pigs with PSE meat.

Likewise in Australia, the average incidence of PSE and DFD was 32% and 15%, respectively; this varies from 5 to 65% for PSE and 0 to 45% for DFD (Trout *et al.*, 1991). The Australians are now trying to improve their pork quality by eliminating animals known to bear the genes that makes them susceptible to

stress and also improving their pre-slaughter handling techniques..

PSE development is usually attributed to increased glycolysis rate post-mortem (Briskey and Wismer-Pedersen, 1961). In DFD muscles, the muscle glycogen is already depleted before slaughter (Bendall and Swatland, 1988). This gives less glycogen for the post-mortem glycolysis and the ultimate pH becomes higher than normal (Lawrie, 1991). When PSE develops in a muscle, pH drops to values lower than 5.8 at 45 min post-mortem (Briskey, 1964). Normal muscle in pH decreases from approximately 7 (living muscles) to values between 5.3 and 5.8 after 24 hours post-mortem (Wismer-Pedersen, 1959; Briskey and Wismer-Pedersen, 1961). High carcass temperatures (≥ 35 C) in muscles (particularly in PSE), combined with a low pH values (pH 6.0 or less) in the first hour post-mortem, causes the muscle protein to denature (Wismer-Pedersen, 1959; Penney, 1967; Honikel and Kim, 1986; Offer, 1991). This contributes to the pale colour in PSE muscle (Wismer-Pedersen and Briskey, 1961; Martin et al., 1980; Honikel and Kim, 1986) and also reduces the water holding capacity of the muscles (Wismer-Pedersen, 1959; Offer *et al.*, 1988). Offer (1991) claimed that denaturation of sarcoplasmic proteins in the PSE muscle had a major influence on the increased paleness, while denaturation of the myofibrillar proteins was responsible for the decrease in water holding capacity.

If pigs are exposed to stress prior to slaughter there may be an increased metabolic activity in the muscles (Bendall, 1973; Lister *et al.*, 1981). It is therefore widely accepted that both the rate and the extent of glycolysis of pork muscles after slaughter has a serious effect on pork quality.

Whereas much of the early research on pork quality clearly showed that normal pigs could produce PSE pork (Briskey, 1964; Honikel and Kim, 1986), normal pigs appear to produce far less PSE pork than PSS pigs. The PSE produced from normal (halothane-negative) pigs (i.e., Landrace breed) may have an exceptionally high drip loss (Eikelenboom & Nanni Costa, 1988).

In addition, PSE and DFD pork were recognized as major determinants of fresh pork consumption and in the economics of the manufacture of processed pork products (Hutchings, 1977).

1.1 Goals and Objectives

The goals of this research were; *firstly* to assess pork quality in two abattoir (Longburn and Levin) located in North Island (New Zealand). *Secondly* to evaluate the incidence of PSE and DFD, and to find out whether values for these conditions could be established for the normal population. *Thirdly*, to establish whether any of the following pre-slaughter factors affected the incidence of either PSE or DFD: sex, carcass weight, breed, transport time, distance of travel, time in lairage and time of year. To achieve these goals, a questionnaire was sent to the farmers, transporters and abattoir management and the meat quality traits (pH_1, pH , WHC, drip loss, colour, and protein solubility) were evaluated.

The *final* objective of this study was to established whether there were differences in:

a) the rate of pH fall 45 minutes after slaughter;

b) the final pH after 24 hours post-mortem;

c) water holding capacity (after 24 hours post-mortem);

d) drip loss (after 48 hours post mortem);

e) visual scores (wetness, colour and texture);

f) colourquest hunter L A B values (after 24 hours post mortem);

g) protein solubility (within 48 hours post mortem); and

h) PSE and DFD between Semitendinosus (ST) and Longissimus dorsi (LD) muscles.

Chapter II

LITERATURE REVIEW

2.1 INTRODUCTION

In recent years, the interest in pork quality has been increasing (Jul and Zeathen, 1981). The quality of pork is a very important factor in determining what is a good carcass. This factor is of special significance since it affects the possible uses of the meat. The quality factors include tenderness, flavour, leanness and nutritive value and the pH dependent quality factors, PSE (pale, soft, exudative) and DFD (dark, firm, dry). PSE is regarded by the market as the most serious pork quality problem (Jul and Zeathen, 1981). It is genetically conditioned and activated by stress factors associated with the transport and slaughtering procedure, as it leads to a rapid accumulation of acid products of metabolism in the musculature.

PSE meat is characterized by an abnormally rapid pH fall, low water holding capacity (WHC), high drip loss and a pale colour (high L value) which results in extensive protein denaturation (Briskey, 1964). Whilst DFD meat is characterized by a high pH, high WHC, low drip loss and a dark colour (low L value). However, there are no standardized "*Border*" values for these characteristics due to variations arising from the measuring procedures and equipment, genetics of the animal population, etc. which considerably affect the absolute values (Bendall and Swatland, 1988). The solution of this pork quality

problem might give us a clue as to how we should handle pigs before and after slaughter so as to avoid conditions that would trigger the development of PSE and/or DFD meat conditions.

2.2 *INFLUENCE OF PRE-SLAUGHTER MANAGEMENT ON MEAT QUALITY*

Pre-slaughter management is known to affect pig meat quality (Wismer-Pedersen and Riemann, 1960). The quality of meat is affected by pre-slaughter handling through its influence on the rate and extent of lactic acid production of the muscle after slaughter (Lister *et al.*, 1981). If the rate is rapid (pH drops to 5.8 or less when the temperature of carcass is still warm) PSE pork will result. The extent of the pH fall is determined by the amount of glycogen present in the muscle after death. If this is depleted before slaughter the extent of pH fall is limited and DFD pork will result. The rate of acidification is largely determined by the degree of muscle stress produced before the animal is slaughtered (pre-slaughter) and during slaughter.

There is evidence that pigs which are excited (stress) before they are slaughtered produce poor quality meat compared with those slaughtered with minimum stress (Barton-Gade, 1974). But there is no general consensus as to which factor chiefly influences meat quality, particularly those relating to transport and lairage factors (Warriss, 1987). One possible reason may be the interaction of the different pre-slaughter factors that influences meat quality such that considering one or two of them in isolation leads to a conclusion which may not be valid or

bias analysis.

In general, prolonged or chronic pre-slaughter stress leads to DFD pork and acute stress leads to the PSE pork quality problem. This is a simplified view to several factors that affects the muscle. In fact, it has been known that different pre-slaughter handling factors interact, for example the genetic condition of the pig will influence the response and the effect of a particular factor and may be determined by a range of previous factors. The interaction between genetic condition and pre-slaughter handling seems particularly important. Stress resistant pigs may not produce PSE meat irrespective of poor pre-slaughter handling. Conversely, stress sensitive pigs may produce PSE meat no matter how good the pre-slaughter handling is, the trauma of slaughter alone is sufficient to initiate its development (Nielsen, 1979). Genetic conditions between these extremes will respond more or less favourably to current handling stress. Therefore, the influence of genetic condition and handling stress have a big contribution to the outcome of pork quality (Chadwick and Kempster, 1983).

The incidence of DFD pork in relation to genetic condition is not so clear because of the evidence of breed differences found in the ultimate pH of pork (Warriss and Akers, 1980). But not in pork condition, as Barton-Gade (1987) found a lower incidence of DFD pork in fatter carcasses. However, handling is likely to be much more important than genotype in determining the extent of muscle glycogen depletion (Nielsen, 1979).

Clark (1973) has divided the pre-slaughter handling of pigs into two areas. The first relates to transportation from the farm to abattoir (including loading and

unloading). The second relates to lairage prior to killing. These factors are potentially important in determining the source of defects of pork quality. Other factors are stocking density, group sizes in the truck and holding pens, mixing pigs whether unfamiliar or not, mixing male or female (particularly uncastrated male) and how the pigs are shifted (Lendfers, 1970). This encompasses loading and unloading procedures associated with transport and the movement of pigs within the lairage and immediately before stunning.

2.2.1 Transportation

Cuthberstson and Pomeroy (1970) found that pigs transported over short distances were more stressed than those transported for several hours just prior to slaughter. The incidence of PSE is higher, if pigs are transported for a short period (less than one hour) and then slaughtered upon arrival compared to pigs that travel for a longer period (more than 3 hours) because some pigs appeared to adapt to the transport situation better than others (Butcher, 1975). Extremes of temperatures also increases the incidence of PSE meat (Lambooy, 1988; Warris, 1991). Fasting was effective in reducing PSE but could also reduce carcass yields (Murray *et al.*, 1989) and cause an increase in incidence of DFD meat (Eikelenboom *et al.*, 1991). Stocking density may also affect meat quality. If too many pigs are loaded into the trucks there is an increased risk of hyperthermia resulting in PSE. Lambooy and Engel (1991) recommended a 235 kg/m^2 stocking density for pigs. This seems a reasonable compromise between the animal welfare requirements and the cost of renting a truck as well as meat quality.

Van Putten and Elshof (1978) reported that loading and unloading of pigs is the most stressful part of the transport process, particularly when loading ramps are steep.

2.2.2 Lairage

The development of the two pork quality defects (PSE and DFD) counteract one another. If muscle glycogen is depleted by fasting and/or exhaustive activity, the development of PSE meat will be prevented because there is insufficient glycogen for adequate production of lactate. Nielsen (1979) illustrated this by placing the pigs in the lairage from 0 to 22 hours. He determined that as the holding time increases (6 hours above) the PSE incidence decreases. However the number of pigs showing DFD meat increases after two hours stay in the lairage. It is presumed that lairing allows for the recovery from the stressors associated with transportation and results in a decrease in the incidence of PSE. Glycogen depletion by stressors, may eventually give rise to a greater incidence of DFD meat. This work confirms the result of Moss and Robb (1978), in which they found that the incidence of PSE meat was reduced slightly by overnight lairage but DFD incidence increased significantly.

The mixing of unfamiliar pigs (Smulder and van Laack, 1992), over crowding and weather conditions (Fortin, 1989) may also be important factors that can influence meat quality. Mixing large unfamiliar pigs has been shown to increase the incidence of PSE meat. Whilst pigs from small unmixed groups developed a moderate ultimate pH (Gallway and Tarrant, 1979). Mixing pigs initiated

fighting within the group resulting in bruises and wounds on the pigs (Wismer-Pedersen and Riemann, 1960).

Design of the lairage also appeared to affect meat quality (Grandin, 1983 & 1992). Large pens containing more than 60 pigs produced an increased incidence of DFD compared to pigs placed in smaller pens with less number. This is because pigs of different origin and sex when placed together tend to fight. The problem is worsened if the pen walls are not solid which allows pigs in adjacent pens to fight.

Therefore, good pre-slaughter handling will improve meat quality in pigs except those of stress-susceptible breeds. Loading and unloading are very stressful to pigs but one hours rest will help then recover from this stress. Laired pigs should ideally be kept in small, unmixed groups to prevent fighting and consequently avoid bruising and wounds in the carcass.

2.3 INFLUENCE OF HYDROGEN ION (pH) ON MEAT QUALITY

After death, glycolysis occurs in the muscles of an animal and results in a gradual reduction of glycogen, creatine phosphate and later adenosine triphosphate (Lawrie, 1991). Biochemical changes are accompanied by the formation of lactic acid and a resultant fall in the muscle pH (Bendall, 1973). The rate and extent of post-mortem glycolysis can be assessed by measuring changes in the amounts of these chemical components. However, in studies involving large numbers of animals, estimation of the various glycolytic intermediates

become's impractical and most workers therefore rely on pH values alone when estimating the rate and extent of post-mortem glycolysis.

The pH is important to meat because it influences its quality factors i.e., its colour, water holding capacity, and drip loss, and sensory properties i.e., its flavour and tenderness and ultimately the shelf-life. The speed and extent of the decline in pH after slaughter, determined by acidification in the muscle which is known as glycolysis, has a particular influence on the processing properties of meat. If the pH drops very quickly the meat will be PSE, and a very slow and incomplete drop in pH will result in DFD meat. On the other hand the normal meat undergos a gradual and complete drop in pH.

Environmental temperature has a marked effect upon the rate of post-mortem pH fall (McCarthy and Mackintosh, 1953). The rate of pH decline is closely related to temperature, with high temperatures enhancing and low temperatures inhibiting the rate of pH drop. The effect on pH changes are a direct result of temperature upon the rate of glycolysis. This interrelation of pH and temperature can have a marked effect on the case of PSE pork.

The pH of meat has tremendous effect upon its physical properties, being responsible for dark, firm, dry (DFD) and pale, soft, exudative (PSE) pork muscle. Generally, high pH values (6.2 or higher) result in an increase in water holding capacity, giving a darker colour and coarser texture, and provide conditions more favourable to spoilage. Whereas low pH values (5.4 or less) tend to have the reverse effect (Bendall, 1973). Apparently, both high and low pH values have advantages and disadvantages such that one must compromise

to make maximum use of pH in producing meat or meat products. The physical effects of pH are closely associated with the isoelectric points of the major mat proteins. So, when pH declines to about 5.4 or less, the isoelectric point of myosin is being approached (Briskey and Wismer-Pedersen, 1961a). This results in shrinkage of fibrils, with a subsequent loss in the ability to bind water and a looser structure (Offer and Trinick, 1983).

2.3.1 Initial pH

The fall in pH of meat is the result of acid production. In a normal case, glycolysis takes place slowly and the pH in the pig drops during the course of 24 hours to a final pH of 5.8 or lower. If glycolysis takes places very quickly, the pH could drop to 5.8 within 45 minutes (initial pH) after post-mortem, and would indicate the presence of PSE meat.

Fast glycolysing PSE meat (45 minutes after death) shows very low levels of ATP (adenosine triphosphate) and glycogen, low pH_1 values but an elevated level of inosine monophosphate (IMP) and lactate. On the other hand, the DFD muscles (45 minutes post mortem) show low levels of ATP, glycogen and lactate as well as high pH_1 values. After 24 hour post mortem, the pH is higher and the level of lactate is lower than in normal muscle. There exists a high relationship between low pH_1 and appearance of pork (Bendall and Swatland, 1988).

Potthast and Hamm (1976) found that at 45 minutes post-mortem high levels of ATP and glycogen and low levels of lactate ions and H^+ ions could be found in

the muscle meat of stress resistant pigs. The pH_1 value is therefore high. Breakdown of ATP and glycogen in the muscle tissue of normal pigs is completed within the first 24 hours after slaughter, the glycogen and lactate concentrations scarcely altering in the initial phase of glycolysis.

At pH_1 values of less than 5.8 the meat is generally described as PSE and at pH_1 values above 6.2 as DFD. Accelerated glycolysis induced by very rapid ATP breakdown determined the low pH_1 value in PSE pork (Fisher and Augustini, 1977). This process begins during slaughter and is complete about one hour after the animal is slaughtered. Rapid glycolysis results in high lactic acid contents 45 minutes post mortem. In the case of stress susceptible animals, if exposed to stressors e.g., transportation, breakdown of ATP and glycogen may begin some time before slaughter. The breakdown products of glycogen, i.e., lactate and hydrogen ions (lactic acid) enter the bloodstream before or during slaughter. Therefore, the initial pH values are a good indicator in evaluating the meat quality especially of PSE meat. Several authors have refuted the claim that low pH value early post mortem necessarily result in PSE (Vada, 1977; Vada-Kovacs *et al.*, 1982; Smulders *et al.*, 1983; Severini *et al.*, 1984; Barton-Gade, 1980, 1987; Bendall and Swatland, 1988). Nevertheless, the close correlation between initial pH value and colour brightness, water holding capacity, ATP, glycogen and lactate concentration shows that the pH_1 value is a particularly suitable indicator for determining pork quality.

2.3.2 Ultimate pH

The pH resulting either from the lack of glycogen reserves or from the inhibition of glycogen breakdown, is referred to as ultimate pH (Lawrie, 1991). Ultimate pH seems to be determined mainly by muscle glycogen concentration at slaughter as this is the major source of energy for post-mortem glycolysis (Pearson, 1971). However, the relationship between ultimate pH and muscle glycogen concentration is nonlinear, with the main effects on ultimate pH being at glycogen concentrations lower than 8 mg/g of muscle (Warris *et al.*, 1984). Enhancing the rate of glycogen breakdown could result in increasing the rate of pH fall, but not the extent of pH fall (Pearson, 1971). Both the rate and the extent of post-mortem pH fall are influenced by the genotype of the animal; pre-slaughter stress i.e., transportation, environmental condition of animal before slaughter; muscle fibre type; and stunning procedures.

The rate of glycolysis in post mortem muscle and the ultimate pH influence the meat quality in various ways, that is, its colour (Lawrie, 1952), water holding capacity (Hamm, 1960), and shelf-life (Pearson, 1971; Egan and Shay, 1988). All these findings suggest that a relatively slow rate of glycolysis and a moderately low ultimate pH (about 5.4) are characteristic of normal muscle. High ultimate pH (about 5.8) results in dark coloured and close structured meat with poor keeping quality, and if used for curing results in the slow penetration of salt. Normal ultimate pH meat (about 5.6) has an open structure and is bright red in colour. It is also known that a slow rate of glycolysis results in high quality meat (Lawrie, 1985), whereas a rapid drop of pH (from 7.0 to 6.0 within 20 minutes) and a very low ultimate pH (about 5.3), tend to disrupt the structure of muscle

causing the meat to appear pale and watery (Briskey, 1964). Precipitation of the sarcoplasmic protein on the myofilaments may also occur. The evidence of this has been shown by Wismer-Pedersen, 1959; Bendall and Wismer-Pedersen, 1962; and Bendall, 1973.

The rate of post mortem pH decline is faster in porcine muscle than in bovine muscle; ultimate pH values are reached within 3 hours in pork compared to bovine in which it takes more than 24 hours (Greaser, 1986). The rate of pH change reflects both extent and intensity of post mortem metabolism. The rate and the extent of post mortem pH changes in pig muscles largely determine pork quality. Fast pH fall combined with low ultimate pH and extensive protein denaturation leads to pale soft exudative (PSE) meat. Limited pH change combined with a high ultimate pH leads to dark firm dry (DFD) meat (Bendall and Wismer-Pedersen, 1962).

The ultimate pH measurement can provide valuable information as to the quality of the meat in a carcass and also on subsequent meat products. If pH values differ from normal values one can usually assume that there will either be a reduction in quality or even increased tendency to spoilage. Conversely the presence of a normal pH provides some assurance that the product fulfils certain quality expectations.

Measurements of the pH 45 minutes or 24 hours post-mortem (pH_1 or pH_{24}) to determine PSE or DFD characteristics in pig carcasses has been used for more than a decade in scientific investigations and in fattening and carcase performance testing.

2.4 *INFLUENCE OF WATER HOLDING CAPACITY (WHC) ON MEAT QUALITY*

Muscle contains about 20% protein and 70 to 75% water (Lawrie, 1991), wherein myofibrillar proteins play a dominant role in water holding and/or binding capacity of the muscle. Water holding capacity (WHC) is the property of the meat to hold its own water or is the ability of the muscle proteins to bind water (Hamm, 1986). The immobilized or entrapped water is bound in varying degrees, however, part of the water is bound so tightly that it can only be driven off by heating (Hamm and Deatherage, 1960). The mechanism restricting the mobility of water in muscle is poorly understood but is apparently determined by the spatial arrangement of the muscle protein. Myosin is known to have an important function in binding of water (Penney, 1967). Offer *et al.* (1984) have clarified WHC on the basis of the swelling and shrinking of the myofibrils which are associated with expansion or shrinking of the filament lattice.

2.4.1 Role of protein in WHC

It has long been known that proteins are the principal water binding substances in meat. Proteins are capable of binding large amounts of water because of the hydrogen bonding of water molecules to polar groups on the protein chains (Miller *et al.*, 1968). The following protein chain groups are involved: amino, carbonyl, carboxyl, guanidino, hydroxyl, imidazol, and sulfydryl. The water binding potential is diminished as polar groups are blocked (Penny, 1969). The binding of water to proteins by hydrogen bonding produces flexible molecules

(Morrissey *et al.*, 1982). In muscle, the water binding of the tissue is greatly influenced by the solubility and state of its myofibrillar and sarcoplasmic proteins (Briskey and Wismer-Pedersen, 1961b; Bendall and Wismer-Pedersen, 1962; Sayre and Briskey, 1963).

The pH of this muscle is about 7.0 and its physiological salt concentration allows the muscle proteins to bind about 90% of the water intracellularly. Eighty five to ninety five percent of water is held within the fibres in equilibrium with the remaining 5 to 15% (plasma fluid) outside the fibre. Inside the fibre walls, the water is distributed between the intrafibrillar space i.e., between the spaces of myofibril (Offer and Trinick, 1983). The balance of water is so perfect, that it allows movement of the proteins within the fibre during contraction and exchange of metabolites in and out of the fibre without altering the overall amount of water held (Morrissey *et al.*, 1982). Thus, the muscle protein has a principal role on water holding in meat. The myofibrillar proteins are considered to be the main water holders, the quantity being proportional to the space between the filaments (Offer and Trinick, 1983). This is in turn related to the changes on the surfaces of the fibrillar proteins and to pH (Sayre and Briskey, 1963). Hence, any change in WHC is of concern, and is a good indicator of changes in the muscle protein and the structure of myofibrillar proteins (Hamm, 1960 & 1975).

2.4.2 Effect of pH on WHC

After the death of the animal the pH starts to fall to its ultimate value of about 5.5 (Lawrie, 1991). This pH fall reduces the ability of the muscle proteins to hold the water and as a consequence the WHC of the muscles decreases (Hamm, 1971). Hamm (1975) also reported that meat has a very high WHC immediately after slaughter but decreases very rapidly during the first 24 to 48 hours post-mortem. The formation of lactic acid, which in turn decreases the pH, has some effect on decreased WHC. However, the WHC of meat increases upon longer storage of meat due to proteolytic enzyme activity cleaving peptide bonds, thereby making more polar groups available for hydration (Judge *et al.*, 1989).

As the declining pH of the muscle approaches the isoelectric point, the myofibrillar proteins (pH 5.5) and the actin-myosin attachment (rigor mortis) change causing the water holding capacity to decrease (Asghar and Pearson, 1980). The development of rigor mortis in muscle, which is caused by cross linkage between actin and myosin filaments, causes a tightening of the protein network which eventually leads to a considerable decrease in the water holding capacity of meat during the first 24 hours of post-mortem changes. Bouton et al. (1972) found that increased shortening of muscle fibres, i.e., contracted muscle, was accompanied by a decrease in WHC.

So, if the post mortem pH of muscle does not decline to the normal ultimate value of 5.4 to 5.6 and instead remains at 6.0 or higher, the water holding capacity of the meat does not decline either (Bendall, 1973). This relationship was confirmed in beef by Bouton *et al.* (1973), in lamb/mutton by Bouton *et al.*

(1971 and 72), and in pork (Honikel and Hamm, 1974). In such circumstances the mobile water will remain protein bound and the meat appear dry and firm (DFD meat). This high WHC of DFD meat is ideal for sausage making (Hamm, 1973). Changes in WHC also contributes to changes in colour and flavour of pork (Honikel, 1987a). Likewise, WHC influences the palatability and tenderness of meat. It has also a direct effect on shrinkage (drip loss) during storage. When muscle has poor WHC, loss of moisture and consequently loss of weight during storage is great. WHC not only affect raw meat but also the behaviour of meat during cooking in relation to juiciness (Gault, 1985). Juiciness of cooked meat is related to the WHC of the meat as it produces a rapid release of meat fluids when first chewed. However, grinding also increases the meat WHC by increasing the number of polar groups available for binding with the water molecule. Water is bound better when added after the meat is ground (Hamm, 1975).

If the pH declines to an abnormally low value of 5.4 or less, water holding capacity decreases (Briskey, 1964). Such water is expelled from the fibrillar protein due to its excess positive charges at low pH values. This leads to an inccrease in repulsion between myofibrils and so more space for the free water molecules (Bendall and Wismer-Pedersen, 1962; Offer and Trinick, 1983). Thus, low pH is extremely deleterious to water holding and/or water binding capacity of meat, especially if the temperatures in meat are above 20°C. This change in meat also influences the colour and juiciness of meat (Fjelkner-Modig and Persson, 1986).

2.4.3 Effect of ions (cations) on WHC

Calcium and magnesium are the principal cations found in meat (Lawrie, 1991). They are bound in three ways; tight bound at the isoelectric point of myosin at pH 5; pH dependent bonding that is relatively strong at neutral pH (pH 7); and by loose electrostatic bonding to negatively charged proteins (Hamm, 1960). Ions bound by electrostatic bonds are usually extractable by water (Wismer-Pedersen, 1971). The release of calcium and magnesium by muscle during and immediately after the onset of rigor is the result of pH decline (Hamm, 1960). These divalent cations, thus lower the WHC of meat by reducing the electrostatic repulsion between negatively charged groups. This causes the tightening of myofilaments resulting in meat shrinkage (Offer and Trinick, 1983).

With sodium chloride, shrinkage does not occur because the chloride ions mark the effect of cations on WHC. On the other hand, removal of cations increases WHC (Hamm, 1986). The effect of cations is minimal at the isoelectric point of myosin but increases as the pH increases because of the strength of cation binding to the myofibrillar proteins is increasing. Therefore, cations in muscle reduce its WHC at pH's above the isoelectric point of myosin, whereas removal of cations at these pH's increases WHC.

WHC becomes one of the most important qualitative characteristics of meat, as it affects the appearance of the product (colour), its behaviour on cooking, tenderness and its juicy sensation on chewing. Since water is a universal medium of reaction, its availability affects greatly the changes occurring in meat during chilling, storage and processing (Hamm, 1960).

Thus, water holding, which is directly related to exudation and the amount of water in meat, should be evaluated as PSE and DFD meat can be detected by using this technique.

2.5 INFLUENCE OF DRIP LOSS ON MEAT QUALITY

During refrigeration, meat loses moisture from its surfaces resulting in weight loss called drip loss or meat shrinkage. Thus, drip loss is simply defined as the water lost in meat after a certain period of storage. Water found on the surface of raw meat is usually called "weep" by consumers, as "drip" in thawed raw meat and as "shrink" in cooked meat. Other than the economic losses associated with weight loss, the loss of moisture during the first few days in refrigerated storage seldom decreases meat acceptability. However, the physical changes occurring in meat during prolonged refrigeration as a consequence of drip include surface discolouration and dehydration, and here, there is a lowering in the quality of the meat.

The factors which affect the drip loss include the shape and size of the muscle, and various treatments during the conditioning period e.g., rapid chilling of pre-rigor muscles which may lead to cold shortening and so increased drip. For instance, a linear relationship between sarcomere length and drip loss in pork muscle (Honikel, 1987a).

2.5.1 Effect of pH on drip loss

Slow pH fall and rapid temperature decrease induces cold shortening with an increased drip loss. Whereas, slow pH fall at very low chilling rates causes rigor shortening, again with an increased drip loss (Hamm, 1982; Honikel *et al.*, 1986). Fast glycolyzing muscles at prevailing high temperatures result in PSE muscles with a rapid release of exudate from the meat (Honikel, 1987c). Thus, drip loss of meat is clearly affected by pH, temperature and time. The relationship between ultimate pH of meat and drip loss was shown to be non-linear (Honikel, 1987b). At pH's above 6.0 there is little pH influence but below pH 6.0, there was a sharp increase in drip loss (Warriss, 1982). In the case of temperature, Honikel (1984) found that a significant decrease early post-mortem influenced the drip loss of PSE meat substantially. Nevertheless, Woltersdor and Troeger (1989) reported that PSE pork can be improved by using rapid chilling techniques. Honikel (1987c) also found that fluid loss in PSE pork longissimus dorsi increased 23% compared with normal pork after storing at 0°C for 17 days. The differences between normal and PSE pork during the first 3 to 5 days after post-mortem, could be explained by the damage to the muscle fibres and not solely to protein denaturation (Offer *et al.*, 1984; Offer *et al.*, 1988).

DFD meat lost much less water during the first 24 hours of storage (Kauffman, 1986) compared with PSE meat which released water much faster within the first 24 hours of storage (Honikel, 1987c). Whilst normal meat had little drip over the first 24 hours this increased between day 1 and 5. After 17 days of storage the difference in drip loss had diminished (Honikel, 1987a). Therefore, drip loss of meat depends on the time of measurement post-mortem; the chilling

temperature of the meat after the ultimate pH is reached; and the method of packaging used. Surface tight (heat shrunk) vacuum packaging give rise to less exudate from the meat during storage than vacuum packaging with vacuum holes at the corners of the meat sample (Ramsbottom, 1971; Apple and Terrilizzi, 1983).

Pork quality problems (PSE and DFD) can be detected using drip loss techniques without using sophisticated and expensive instruments. Therefore, drip loss measurement is one of the most suitable ways of assessing juice holding capacity (drip loss) in fresh meat.

2.6 *INFLUENCE OF COLOUR ON MEAT QUALITY*

Colour is important in meat because the consumer usually relates meat colour to the freshness of meat (Jul and Zeuthen, 1981). Colour is the major criterion for consumers when purchasing meat and meat products from supermarket. The purchaser usually expects a standard colour from each product i.e., fresh meat to be bright red to cherry red and cured meat to be pinkish red. As a result, if the products do not conform to consumer's visual expectations e.g., PSE or DFD meat, then they will discriminate against the product.

Humans judge colour on the basis of a combination of three factors; Lightness, Saturation and Hue (MacDougall, 1982). Lightness or luminosity is an indication of overall light reflectance (brightness) of colour, paler colours have greater lightness than the dark colours; Saturation or purity describes the intensity of a

fundamental colour with respect to the amount of white light that is mixed with it, pale or pastel colours have a low saturation and the deep and vivid colours have high saturation; and Hue (yellow, green, blue and red) describes the wave length of light radiation, black, white and grey are colours devoid of hue (King, 1980).

2.6.1 Meat pigments

The colour of fresh meat is mainly dependent on the concentration and chemical state of meat pigments (myoglobin and haemoglobin) and on the physical characteristics of meat, such as its light scattering and absorbing properties (Lawrie, 1985).

Lawrie *et al.* (1963) found muscle pigment (myoglobin) concentration in pork to be low (0.06%) compared with other animals. Age also affects the concentration of myoglobin, as a general rule, as the age of the animal increases the myoglobin concentration increases. The change in myoglobin content of a muscle with advancing age is due to increased deposition of myoglobin in existing red fibres (Lawrie *et al.*, 1964). Beecher *et al.*(1968) found that myoglobin in the muscle is concentrated in the red fibre and in the red muscles contain more red fibres compared to white fibre (Moody and Cassens, 1966) as they have a more intense colour. But some muscles i.e., ST in pigs, definitely have a light and a dark portion (Beecher *et al.*, 1968). The outer light portion in muscle contains only a fraction of the red fibres and myoglobin of the dark inner portion (Beecher *et al.*, 1968).

In addition to concentration, the type and chemical state of the myoglobin also influences muscle colour (Livingston and Brown, 1981). These include deoxymyoglobin, oxymyoglobin and metmyoglobin. These three pigments are in a dynamic state with each other and the dominant pigment form depends on localized conditions.

Deoxymyoglobin, commonly referred as myoglobin or reduced myoglobin, contains iron in a ferrous state (Fe^{2+}) and is characterized by its purplish-red colour and is visible in freshly cut meat.

Oxymyoglobin, which is characterized as a bright pink in pork, forms very quickly after exposure of deoxymyoglobin to oxygen. The pigment must be in the ferrous state for oxygenation to occur (Livingston and Brown, 1981). Oxymyoglobin is stable under high partial pressure of oxygen but at lower oxygen tension at some of the oxygmyoglobin is converted to deoxymyoglobin which becomes more susceptible to oxidation (Stewart *et al.*, 1965).

Once oxidation occurs, metmyoglobin (oxidised pigment) replaces other forms unless reducing mechanisms are available, this is called Metmyoglobin-reducing activity (Gidding, 1977). Metmyoglobin has iron in the ferric state (Fe^{2+}) and gives an undesirable brown colour which consumers associate with old, contaminated or off meat. Oxidation occurs more readily at a lower muscle pH and is directly dependent on hydrogen ion concentration (Brown and Mebine, 1969).

All three forms are reversible and in a state of dynamic equilibrium with each

other. Conditions in the muscle at any given location may drive the pigment reaction largely to one form (Kropf, 1993). When the new cut surface is formed, oxymyoglobin quickly forms at the surface and gradually penetrates more deeply as oxygen diffuses into the muscle resulting in the gradual *blooming* of meat colour. The depth of oxygen penetration into muscle is dependent primarily on oxygen tension, which is influenced by temperature as well as pH (MacDougall, 1982). Although oxygen diffusion is more rapid at a higher temperature, net oxygen penetration is greatest at temperatures close to 0°C, where activity of enzymes that uses oxygen is minimal (Stewart *et al.*, 1965b).

Due to the rapid discolouration of meat, which is influenced by the three biochemical factors; myoglobin autoxidation, enzyme ferrimyoglobin reduction and oxygen consumption rate (Lawrie, 1985), it is sensible to measure meat colour directly rather than undergo a long measuring procedure (Kefford, 1963).

Measurement of colour requires three attributes known as hue, chroma and value (Judge *et al.*, 1975). In general, this task will be done by the use of *Tristimulus colorimetry*, whereby a colour is defined as a point in three dimensional colour space. Hue describes the kind of colour whether blue, green red or yellow and this is represented by the perimeter. Chroma or saturation indicates the depth of colour or the extent to which the hue is diluted with white and this represented by the distance out from the central core. Value or lightness describes the overall light reflectance of the colour and this represented by the central vertical core.

2.6.2 Effect of pH on muscle colour

Muscle pH also greatly influences the colour of the muscle. PSE and DFD are the muscle colour variations which are associated with pH. PSE, which results from a rapid decline of pH while the muscle is still warm, is paler in colour than normal muscle because the muscle structure (myofibril) opens and scatters the light that enters the meat (Briskey, 1964). These changes are usually accompanied by a marked denaturation of protein (sarcoplasmic and myofibrillar) and a severe loss of water binding properties of the proteins. DFD is darker in colour than normal muscle because the muscle fibres are swollen and tightly packed together forming a barrier to the diffusion of oxygen and of light (Lawrie, 1950), and plenty of water is retained in the muscle. In general, meat discolours if the meat pH is above or below normal. If the muscle pH is greater than 6.0, the meat appears dark (DFD); and if the muscle is lower than 5.5, the meat appears pale (PSE).

2.6.3 Colour variability in the carcass

Colour variability is often evident throughout the pork carcasse (Briskey, 1969). A particular muscle may be pale on the outside and dark at the centre. In some carcasses, the entire muscle becomes PSE immediately or between 30 to 90 minutes post-mortem. In other cases, the carcass may exhibit two different qualities, the white muscles becoming PSE and the red fibres showing a varying degree of firmness and colour (Beecher *et al.*, 1966). This variability in muscle colour is prominent in pigs due to their pigment variation (Beecher *et al.*, 1965)

and low saturation in pig muscles (Monin and Sellier, 1985). Barton-Gade (1981) separated the muscle into two types; whiter muscles and red muscles. Whiter muscles have predominantly anaerobic metabolism and these are more susceptible to the PSE condition i.e., longissimus, semimembranosus, bicep femoris, and gluteus. Red muscles are aerobic and less susceptible to become PSE i.e., semispinalis capitis, serratus ventralis and quadriceps.

Colour is important in identifying pork quality for the following reasons. The first is the need for standardization of the colour of pork and/or pork products, as consumers usually become suspicious if the same type of meat or brand shows wide variation in colour. The second is the use of colour as a measure of economic worth. The third is the use of colour to measure either natural pigments present or some colour ingredient that is being added to the pork or product. Therefore, colour becomes one of the most important quality factors affecting consumer decisions and hence can affect the profit of all those people involved in the pork industry. It must be noted, that colour can be adversely influenced at all stages of production > processing > and in the marketing chain. Though colour is a subjective phenomenon, it is important in the field of meat quality assessment (Hood, 1978).

2.7 INFLUENCE OF PROTEIN SOLUBILITY ON MEAT QUALITY

Protein solubility is the amount of protein (%) that goes into solution or colloidal dispersion under specified conditions and is not sedimented by moderate centrifugal forces (Bailey, 1982). Solubility at saturation represents an

equilibrium between the solid and soluble phases.

Solubility is usually affected by environmental conditions such as pH, temperature, salts and mixture with other food component (Kinsella, 1982 & 1984). Solubility is a very important functional property of proteins and its determination can be affected by a variety of environmental conditions (pH and ionic strength). It can give valuable information on the processing of the product and on its potential value in applications involving foam and emulsion formation. Isolation of major proteins of the myofibril are based initially on cell disintegration and rupture of the sarcolemma in order to free the myofibril, followed by extraction of the various proteins on the basis of solubility in solutions containing, potassium chloride (KCl) and phosphate.

In animals, there are more than 600 identified skeletal muscles (some large, some small, some fast twitch and others slow twitch) which represents 35 - 60% of the animal carcass weight (Pearson and Young, 1989). Except for water, proteins are the major constituent of lean meat (Lawrie, 1991). The composition of adult mammalian muscle is about 75% water, 19% protein, 2.5% lipid 1.2% carbohydrates and 2.3% non-nitrogenous soluble substance (Lawrie, 1991). From an anatomical viewpoint, muscle consists of a mass of contractile fibres that generally lie parallel to the long axis of the muscle and are bound together in a network of connective tissue which emerges at each end to form tendons and adhesions connected directly or indirectly to bone (Guyton, 1989)

In muscle, proteins are generally classified as myofibrillar, sarcoplasmic and connective tissue proteins. The myofibrillar proteins account for around 50 - 55%

of the total protein, whilst the sarcoplasmic proteins contribute 30 - 34% of the total protein content and the remaining 10 - 15% is connective tissue protein which is composed of collagen (about 40-60%) and elastin (around 10 - 20%) (Greaser, 1986).

2.7.1 Myofibrillar proteins

The myofibrillar proteins are those which participate directly in the process of muscle contraction. The major proteins, which comprises 50% of the total myofibrillar protein, are myosin, actin, tropomyosin, troponin, and ∝-actinin (Lawrie, 1991). Myofibrillar protein is now known to be composed of about 12 to 14 significant proteins (Tarrant, 1982; Greaser, 1986).

Myosin, which comprises about 47.83% of myofibrillar protein, is readily soluble in 3-5% salt and has a unique hydrophobic binding site located in the head region (Pearson and Young, 1989). Myosin undergoes conformational changes and protein-protein interaction during heating, it may be the component related to the structural integrity of processed meat systems. In the presence of salt, myosin has the greatest binding power, however sarcoplasmic proteins seem to exert a deleterious effect on the binding power of myosin. This effect was attributed to the adsorption of denatured sarcoplasmic proteins onto the myofibrillar proteins, resulting in decreased extractability as in the case of PSE muscle (Schmidt *et al.*, 1981).

Actin, which comprises about 21.74% of myofibrillar protein, has a synergistic

effect in gelling and binding, where the gel strength and binding properties being influenced by the ionic strength of the medium (Lawrie, 1985).

2.7.2 *Sarcoplasmic proteins*

The sarcoplasmic proteins consist of those proteins which are soluble in solutions of low ionic strength ($M < 0.1$) and include the water soluble albumins, such as myoglobin and the myogen fraction, this latter group comprises most of the glycolytic enzymes. This protein fraction is now classified as nuclear, mitochondrial, microsomal and cytoplasmic (Scopes, 1970). The proteins in this group are globular or rod shaped and have low viscosity, low water binding capacity, a molecular weight of 20000 - 100000 and an isoelectric point between pH 6.0 and 7.0 (Lawrie, 1985).

2.7.3 *Effect of pH on protein solubility*

Muscle pH and temperature are the major factors that affect protein solubility (Sayre and Briskey, 1963). In normal porcine muscle, the pH falls to ultimate values in the range of 5.8 to 5.4 after 24 hours (Bendall, 1973). The pH drop is gradual in that the muscles on the carcass have cooled well before the ultimate pH is attained. In DFD pork, the pH fall is so small that the muscles have reached their ultimate pH long before the muscles have cooled (Lawrie, 1991). In PSE pork, the rate of glycolysis and pH drop are so rapid (three or more times faster than the normal rate) that the muscles have had no time to cool

down before the pH has fallen below 6.0 (Briskey and Wismer-Pedersen, 1961). This condition induces the occurrence of protein denaturation (roughly 20% of sarcoplasmic and myofibrillar proteins) thereby reducing the ability of muscle protein to hold water. This is manifested in increased drip (10% of its weight) formation. This protein denaturation also affects the colour of meat (Offer and Knight, 1989). These facts explains the pale colour of PSE meat but not its watery nature (Honikel and Kim, 1986). The pale colour could be explained by the 20% reduction in sarcoplasmic and myofibrillar proteins (Bendall and Wismer-Pedersen, 1962). Increased drip in PSE meat would seem to be a result of ruptures in the cell membrane through which fluid can pass (Offer *et al.*, 1984).

2.7.4 Different solubility of muscle protein

The muscles consist of about 19% of protein (Lawrie, 1991). The soluble sarcoplasmic protein makes up to about a third of this. Thus, 5.5% (55 mg protein/g) are present in solution. Whilst the salt soluble myofibrillar protein fraction makes up about 11.5% (115 mg protein/g) of the total muscle weight.

Sarcoplasmic proteins are readily extractable in water or low ionic strength buffer (0.15 or less). Whilst the myofibrillar protein requires intermediate to high ionic strength buffers (0.3 or higher) for their extraction (Pearson and Young, 1989). Stromal proteins that constitute connective tissue and associated fibrous proteins by comparison are insoluble. Sarcoplasmic protein includes myoglobin and enzymes associated with glycolysis, the tricarboxylic acid cycle, and the

electron transport chain. The latter two enzyme groups are contained within the mitochondria but are readily extractable. Myofibrillar proteins constitute the proteins associated with the thick and thin filaments and are commonly referred to as salt soluble proteins.

Muscle proteins are classified on the basis of their solubility into sarcoplasmic, myofibrillar or stromal (connective tissue) protein. Muscle protein solubility is altered during the first few hours after death. The solubility of sarcoplasmic and myofibrillar proteins has been used to characterize protein changes during animal maturity (Dickerson and Widdowson, 1960) and compare protein compositions of different muscles (Lawrie, 1961).

Sarcoplasmic protein solubility after 24 hours is 55% less soluble than at the onset of rigor if the muscle exihibited a high temperature and rapid glycolysis. Conversely, only a 17% reduction of sarcoplasmic protein solubility is noted during the first 24 hours after slaughter if the pH remained high at the onset of rigor mortis. The 24 hour pH of the muscle appeared to have an influence on sarcoplasmic protein solubility (Sayre and Briskey, 1963). The extractability of the actomyosin from PSE meat is less than 50% of that of meat allowed to go into rigor at lower temperatures. It has been suggested by Bendall and Wismer-Pedersen (1962) that this arises because of the deposition of denatured sarcoplasmic protein on the myofilaments, without necessarily any denaturation of actomyosin itself. Scopes (1964 & 1965) showed that creatine kinase was the most easily denatured of the sarcoplasmic proteins under PSE conditions, whereas most of the other proteins retained their natural form. Denaturation usually means that these proteins become insoluble.

Bendall and Wismer-Pedersen (1962) have suggested that rapid glycolysis, which results in PSE directly affects only the solubility of sarcoplasmic proteins. These workers (Bendall and Wismer-Pedersen, 1962) postulated that sarcoplasmic protein denatured and precipitated on the myofibrillar proteins and thereby reduced the myofibrillar protein solubility. Muscle protein appeared to be one of the major factors affecting the water retaining properties of muscle.

Barton-Gade (1974) noted that protein solubility increased as the meat became less exudative (DFD) whilst with low protein solubility the meat become exudative (PSE). Therefore, the protein solubility can be used in the determination of the PSE and DFD muscle.

Chapter III

MATERIALS AND METHODS

3.1 INTRODUCTION

The aim of this study was to determine the incidence of PSE and DFD (two major pork quality defects) amongst pigs slaughtered at two abattoirs, one at Longburn and the second site just outside the city limits of Levin.

Pre-slaughter stress may be one possible cause of the appearance of PSE and DFD meat. This was investigated by sending questionnaires to the pork producers, trucking companies, and abattoir management. These questionnaires are included in Appendix C.

The pigs used in this study were chosen at random from the abattoirs at Longburn and Levin during the period of August 1993 to January 1994. The pigs were kept under standardized or normal condition of feeding, housing and slaughtering. The pork quality was measured using the following criteria; initial pH (*45* to *1* hour after slaughter), ultimate pH (after *24* hours slaughter); water holding capacity (after *24* hours slaughter); colour (after *24* hours slaughter); protein solubility (within *48* hours after slaughter); and drip loss (after *48* hours slaughter).

3.2 PRE-SLAUGHTER ASSESSMENT AND MUSCLE PREPARATION

Two major abattoirs were selected for this study. They were visited on a regular (*weekly*) basis for 6 months. Six (*6*) pigs were chosen randomly from each particular batch for testing. Before the testing, the following data was collected: Name of the pig supplier; method of transportation; length of time off feed; loading and unloading procedure (time, number of workers and equipment used to drive the pigs); trucking distance; weather conditions (temperature); length of time in the lairage; and stunning procedure (data shown in Appendix A). All this data was recorded to establish if the incidence of PSE and DFD could be attributed to these pre-slaughter factors.

The muscles used in this study were *Semitendinosus* (ST) and *Longissimus dorsi* (LD). At forty five (*45*) minutes after slaughter, pH_1 values were measured. On the same day the muscles were collected and placed in plastic bags, sealed and transported to the laboratory, muscles were placed in the chiller (*2° - 4°C*) to await further testing. The two muscles from the right side of the carcass were cut from the median portion of the ST and between the 13^{th} / 14^{th} ribs of the LD 24 hours after slaughter. In addition to pH_1, the following were measured for each muscle: ultimate pH (pH); water holding capacity (WHC); colour (visual and colourquest hunter L A B); protein solubility (PS); and drip loss (DL).

3.3 pH MEASUREMENT

3.3.1 Initial pH measurement (pH_1)

The initial pH was measured forty five (45) minutes to one (1) hour after slaughter, using an Orion pH meter and a direct insertion probe electrode (Orion Research Incorporated, USA, 1990). Before measuring, the Orion pH meter was calibrated against buffers of pH 7.0 and pH 4.0 at ambient temperature. The pH_1 was measured by inserting the electrode in the median part of the muscles.

3.3.2 Ultimate pH measurement (pH_{24})

Approximately 100 grams of muscle tissue were excised from the inside of the medial portion of Semitendinosus and Longissimus dorsi were minced and used to evaluate the ultimate pH. Two (2) grams of the minced muscles were placed in a beaker and homogenized with 10 ml of 5 mM neutralised sodium iodoacetate (Bendall, 1973). The sample was left to equilibrate at 20°C, and the ultimate pH was measured using an Orion SA250 pH meter fitted with a 91-04 combination electrode (Watson Victor, Auckland). The electrode was dipped into homogenate, shaken gently and read when the pH value had stabilized. The electrode was rinsed thoroughly with distilled water and blotted between measurements. Three pH readings were made on each sample and the mean of these was used.

3.4 MEASUREMENT OF WATER HOLDING CAPACITY

3.4.1 Filter paper press (FPP) method

Water holding capacity was measured in terms of expressible water using a filter press method (Hamm, 1960). Approximately *0.3* grams of a muscle sample was weighed exactly and placed onto a pre-weighed (Whatman's No. 1 11.0 cm diameter) filter paper which had been stored over saturated KCl. This was placed between plexiglass plates and a 9.625 kg weight was applied for five minutes.

The filter paper was re-weighed. The difference between this weight and pre-tested weight was computed and used to give a measure of the WHC.

This filter paper press method was well documented as a measurement technique in determining PSE properties. The differences observed in the first hour after slaughter were based on pH value differences between normal and PSE meat and not directly on the increased wateriness of PSE muscle.

3.5 MEASUREMENT OF DRIP LOSS

Drip loss (DL) was determined by a modified method of Honikel (1987) in which samples were placed in a plastic bag (polyethylene film) to simulate retail display conditions.

A slice of semitendinosus and longissimus dorsi muscle, approximately 2.5 cm thick (about *100* g) was removed (preferably from the median part of semitendinosus and between 13^{th}/ 14^{th} rib, and having a fresh cut surface), and used for drip loss measurement. Adipose tissue, other muscles and bits of collagen were removed. The fascia in the longissimus dorsi, however, was left on the piece of meat. When the sample was cut, the temperature of the room and of the piece of meat were almost the same, to avoid either surface drying or condensation on the meat surface. The prepared slice of meat was weighed accurately and immediately sealed in a plastic bag under normal pressure or put into a vessel with a tight seal and a grating at the bottom of it. Extra care was taken to ensure that the expressed drip did not come into contact with the piece of meat. In the plastic bag this was achieved by running a cotton thread through the meat and enclosing it in the seal; the meat could then be hung suspended above the tray within the bag.

The muscles were stored between 0°C - 4°C for 48 hours to give accurate results. After 48 hours, the slice of meat was removed from the container, the muscle was dried off carefully with an absorbing tissue paper and re-weighed. The drip loss was calculated as the difference between the initial weight and the re-weighed weight, and expressed as percent drip loss.

3.6 MEASUREMENT OF COLOUR

Muscles (ST and LD) samples for assessment were 40 by 10 mm thick slice. They were cut perpendicular to the fibres and the connective tissue and external fatty tissue were trimmed off. Before the muscle cuts were evaluated for colour, they were packed into polyethylene bags, chilled and stored for twenty four (24) hours at 0 to 4°C after slaughter. Initially, the meat was assessed by visual examination (visual scores) and with Hunter LAB Colorquest spectrophotometry (Hunter Associates Laboratory, Inc. Reston, Virginia, USA).

3.6.1 Visual scores (wetness, colour and texture)

The visual scores were based on the Forrest *et al.* (1963) five point scale. This is the modified form of five point scale wherein; the five point scale for wetness was (*0*: dry, *1*: slightly dry, *2*: normal, *3*: slightly wet, *4*: wet) for colour (*0*: dark, *2*: normal, *3*: slightly pale, *4*: pale) and for texture (*0*: firm, *1*: slightly firm, *2*: normal, *3*: slightly loose, *4*: very loose texture). The three sets of visual scores were combined in an overall score for meat quality *0* (DFD), *1* (mild DFD), *2* (normal), *3* (mild PSE) and *4* (PSE). Meat colour was also quantified against a set of standard pork colours at the same time. The muscle samples were evaluated by two female panellists and the mean of three readings were used.

3.6.2 Tristimulus colour (Hunter L A B) values

Before evaluation, the muscle cuts were exposed to the atmosphere for at least one (*1*) hour to allow the muscles to "bloom". Tristimulus colour parameters, Hunter LAB (L = lightness / darkness, 100 for white and 0 for black; a = red +, green; and b = yellow +, blue -) values, of the meat surface were determined using a colorquest spectrophotometer (Hunter LAB). A white plate with specification L = 94.5, a = -1.0, and b = 0.0 was used for calibration. Three reading (III D65, III A and III C) were recorded and the mean of these were used. Data reduction of Hunter *A* and *B* colour yielded chroma $(A^2 + B^2)^{1/2}$ and Hue $(Tan^{-1}\ (B/A)$ parameters were computed to be used as possible indices of meat quality (Joseph and Connolly, 1977).

3.7 MEASUREMENT OF PROTEIN SOLUBILITY

Sarcoplasmic and myofibrillar proteins were extracted from the muscle within forty eight (*48*) hours after they were excised from the semitendinosus and longissimus dorsi.

3.7.1 Measurement of total protein

The total protein was analyzed using Kjeldal method. The Kjeldal method consists of three stages: digestion, distillation and titration.

Digestion

A weighed sample was digested with concentrated sulphuric acid, this converts nitrogenous compounds to ammonium sulphate whilst carbonaceous matter is oxidised. To increase the speed of the reaction, catalyst such as mercuric oxide, copper sulphate or selenium can be used, and sodium sulphate or potassium sulphate is added to raise the boiling point of the acid.

Distillation

The ammonium sulphate formed by digestion of the sample is treated with excess alkali, this liberates ammonia which is distilled into excess boric acid.

Titration

The ammonia absorbed by the excess boric acid is titrated directly with standard acid.

The following procedure was carried out using Kjeldal method. Fifty (50) grams of ground pork muscle were weighed accurately and placed into the digestion tube. Two (2) Kjeltabs (containing 3.5 g Potassium sulphate K_2SO_4 and 3.5 mg Selenium *Se*) and 15 ml concentrated sulphuric acid were added. The sample was digested in an electric digestion unit (Buchi 435, Switzerland) at 420°C for 40 minutes. After digestion, the samples were removed carefully and allowed to cool for about 30 minutes.

The digested sample was placed in the distillation unit (Buchi 323, Switzerland). The liberated ammonia was collected in a 30 ml boric acid solution.

When distillation was completed, the samples were titrated in the titrator unit (Mettler DL25, Switzerland) with standardized 0.1 *M* HCl to pink end point. The calculated percent nitrogen was multiplied by 6.25 to get the total protein.

3.7.2 Measurement of soluble sarcoplasmic protein

Ten (*10*) grams of minced pork muscle was weighed accurately, placed into a 50 ml centrifuge tube (Nalgene centrifuge ware, USA) and homogenized in 10 ml of **0.1** *M* KCl. The sample was centrifuged in refrigerated centrifuge (Sorvall^{R} RC-5C superspeed refrigerated centrifuge, USA) at 18,000 rpm for 15 minutes. The supernatant was accurately weighed and transferred to a digestion tube for protein (Kjeldal method) evaluation. The calculated percent nitrogen was multiplied by 6.25 to get the percent total sarcoplasmic protein.

3.7.3 Measurement of soluble myofibrillar protein

Ten (*10*) grams of minced pork muscle was weighed accurately, placed into a 50 ml centrifuge tube (Nalgene centrifuge ware, USA) and homogenized in 10 ml of **0.5** *M* KCl. The sample was centrifuged in a refrigerated centrifuge (Sorvall^{R} RC-5C superspeed refrigerated centrifuge, USA) at 18,000 rpm for 15 minutes. The supernatant was accurately weighed and transferred to a digestion tube for

protein (Kjeldal method) evaluation. The calculated percent nitrogen was multiplied by 6.25 to get the percent total protein.

3.7.4 Measurement of protein solubility

The protein solubility was carried out using two different ionic strength solutions (0.1 *M* KCl and 0.5 *M* KCl). The method used was similar to that described by Lundstrom *et al.* (1988) except that the protein was analyzed using Kjeldal method. The protein solubility was computed using this formula.

$$\frac{\text{Supernatant (0.5 } M\text{) x TP of 0.5 } M \text{ - Supernatant (0.1 } M\text{) x TP of 0.1 } M}{\text{Sample wt. x Total protein}}$$

Supernatant = fluid after mixing minced meat and 0.5 or 0.1 *M* KCl; TP = total protein after the supernatant fluid undergoes Kjeldal method; Sample wt. = weight of the minced meat (without KCl) that undergoes Kjeldal method; Total protein = total protein of sample without KCl.

3.8 STATISTICAL ANALYSIS

The initial pH (pH_1), ultimate pH (pH), water holding capacity (WHC), drip loss (DL), visual score (wetness, colour, and texture), colourquest spectrophotometer (*L A B*), protein solubility (PS) the measurements were divided into (DFD, MDFD, Normal, MPSE, PSE) on the basis of the border values shown in Table 1.

Statistical analysis were performed using the Statistical Analysis System (SAS) package (SAS, 1982). Mean values, standard error and standard deviations were taken for the various characteristics of each of the pork quality categories. Frequency (%) was calculated in order to differentiate percentage of DFD (severe DFD), MDFD (mild DFD), Normal, MPSE (mild PSE), and PSE (severe PSE). Total percentage of DFD and MDFD (DFD_o) and of PSE and MPSE (PSE_o) were also computed. Overall correlation between pork quality characteristics were determined. The correlation between pH_1 and pre-slaughter variables were also determined.

Table 1. "Border" values for the different category measured of ***ST*** and ***LD***.

	DFD	MDFD	Normal	MPSE	PSE
pH_{45} min	> 6.41	6.21 - 6.40	6.01 - 6.20	6.00 - 5.81	< 5.80
pH_{24} hrs	> 6.41	6.21 - 6.40	6.20 - 5.81	5.80 - 5.41	< 5.40
WHC (%)	> 66.0	61.0 - 65.0	56.0 - 60.0	51.0 - 55.0	> 50.0
Drip loss	< 1.0	1.01 - 2.0	2.01 - 3.0	3.01 - 4.0	> 4.01
OVS	0	1	2	3	4
Colour					
L	< 25.0	25.1 - 30	30.1 - 35.0	35.1 - 40.0	> 40.1
A	> 18.1	16.1 - 18	14.1 - 16.0	12.1 - 14.0	< 12.0
B	< 05.0	05.1 - 06	06.1 - 07.0	07.1 - 08.0	> 08.1
PS	> 60.1	55.1 - 60	50.1 - 55.0	45.1 - 50.0	< 45.0

DFD = severe dark firm dry; MDFD = mild DFD; PSE = severe pale soft exudative; MPSE = mild PSE; WHC = water holding capacity; OVS = overall visual score (wetness, visual colour, texture); L = lightness; A = redness; B = yellowness; PS = protein solubility.

Chapter IV

RESULTS

The raw data and statistical analysis are shown in Appendix A and B, respectively. The "*border*" values used during the research are shown in Table 1. Pork quality parameters are subjectively assessed as DFD (dark, firm, dry), MDFD (mild DFD), normal, MPSE (mild PSE) or PSE (pale, soft, exudative), and are based on the "*border*" values. The typical PSE and DFD pork, found in the study, are shown in Photos 1 and 2.

The results show high variability on the semitendinosus (ST) and longissimus dorsi (LD) muscle in this study (shown in Table 2). In the abattoir A, there were *9.10%* PSE, *18.28%* MPSE, *33.46%* normal, *29.75%* MDFD and *9.42%* DFD on **ST**; and *37.62%* PSE, *32.14%* MPSE, *19.78%* normal, *7.17%* MDFD and *3.31%* DFD on **LD**. In abattoir B, there were *28.50%* PSE, *28.08%* MPSE, *10.51%* normal, *25.97%* MDFD and *6.95%* DFD on **ST**; and *35.93%* PSE, *39.11%* MPSE, *14.18%* normal, *9.28%* MDFD and *1.52%* DFD on **LD**. The mean percentage for both abattoirs is illustrated in Figure 1a. If all the parameters were considered, the percentages of normal carcasses within the "*border*" values were not high and the PSE incidence was higher in LD while the DFD was higher in ST (shown in Table 3). Figure 1b and 1c displays the overall percentages of ST and LD for each meat quality category in all the parameter used in the evaluation period.

Table 2. Summary of meat quality category for both abattoirs.

Abattoir	Type of Muscle	N	Meat Quality Category				
			DFD (%)	MDFD (%)	Normal (%)	MPSE (%)	PSE (%)
A	ST	78	9.42	29.75	33.46	18.28	9.10
	LD	78	3.31	7.17	19.78	32.14	37.62
B	ST	36	6.95	25.97	10.51	28.08	28.50
	LD	66	1.52	9.28	14.18	39.11	35.93

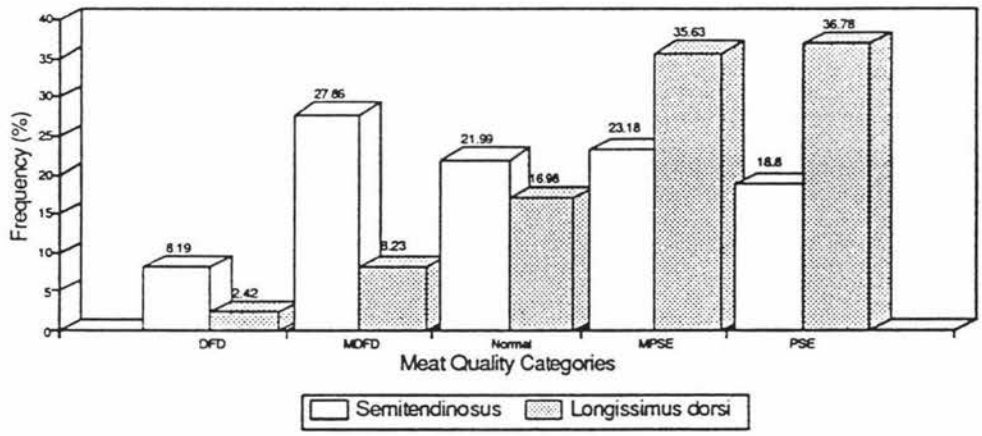


Figure 1a. Mean percentage of ST and LD for each meat quality category at both abattoirs.

Table 3. Summary of DFDo, Normal and PSEo at abattoirs A and B.

Abattoir	Type of Muscle	N	Meat Quality Category		
			DFD_o (%)	Normal (%)	PSE_o (%)
A	ST	78	39.17	33.46	27.38
	LD	78	10.48	19.78	69.76
B	ST	36	32.92	10.51	56.58
	LD	66	10.80	14.18	75.04

DFD_o = total percentage of severe DFD & MDFD; PSE_o = total percentage of severe PSE & MPSE.

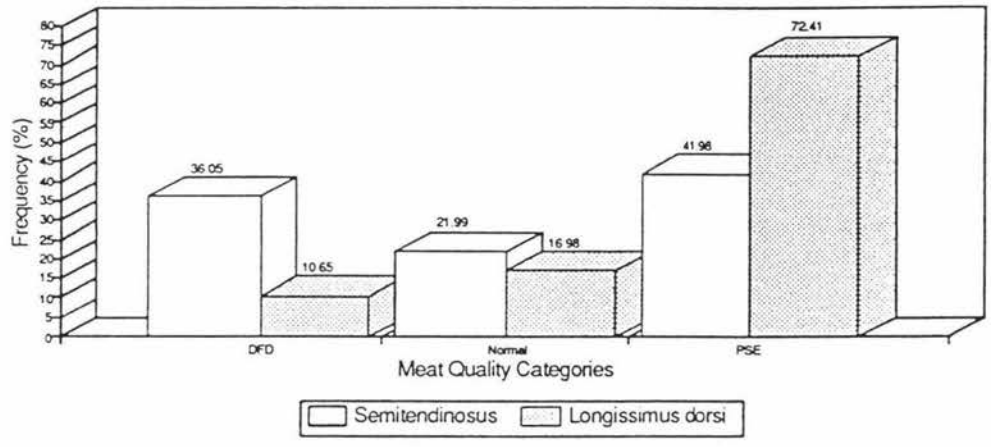


Figure 1b. Overall result of the DFDo, Normal and PSEo meat on ST and LD at both abattoirs.

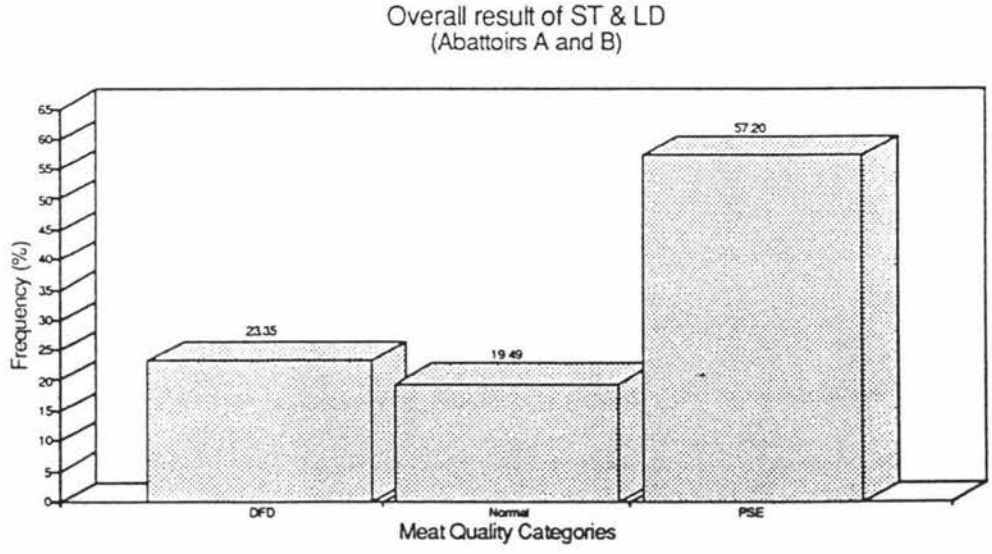


Figure 1c. Overall result of the DFDo, Normal and PSEo meat on both muscle at both abattoirs.

The correlation coefficients between pork quality parameters are shown in Table 11. Generally, a correlation coefficient of 1 represent perfect agreement between a pair of parameters, whereas a coefficient of 0 indicates that no relationship exists between the parameters. Therefore, the results show that all the parameters are all interrelated except in the case of tristimulus colour A.

Multiple regressions did not furnish useful information because the muscle characteristics were found to be highly interrelated, that is, the correlations were significantly greater than zero. This is shown in Appendix B.

4.1 PRE-SLAUGHTER EFFECTS ON PORK QUALITY

As shown in Table 4a, the 78 pigs slaughtered at abattoir A comprised *51.28* % males and *48.72* % females, with an average carcass weight of 69.24 kgs. At abattoir B, 66 pigs were slaughtered, *51.52* % were male and *48.49* % were females, with an average carcass weight of 58.37 kgs. All the pigs at abattoir A are slaughtered after overnight holding. Whilst at abattoir B, some of the pigs were slaughtered within two to three hours of arrival at the abattoir.

The incidence of bruising in the loin and rumps were between *14.10 to 28.21* % and *1.52 to 22.73* % at abattoirs A and B, respectively. Wounds occurring on the shoulder were between *15.39 to 20.51* % and *3.03 to 22.73* % at abattoirs A and B, respectively. This is shown in Table 4b. Photo 3 shows the bruises and scratches of some carcass that were slaughtered. Photo 4 shows some probable causes of bruising, lacerations and scratches.

Table 4a. Summary of pre-slaughter data at abattoirs A and B that could affect pork quality.

	N	Sex		CW (Mean)		Breed	Age (Mean)	TT	Dist. (Km)	LFT (BL)
		M	F	M	F					
A	78	40	38	68.96	69.51	CB[1]	22.67	18.33	17	1 h
B	66	34	32	57.45	59.29	CB[2]	21	*	*	1 h

N = number of observation; M = male; F = female; CW = carcass weight; TT = transport time; Dist = distance; Km = kilometre; LFT = last feeding time; BL = before loading; CB = crossbreed; [1] = Large white, Landrace and Duroc; [2] = Large white and Landrace.

Table 4b. Incidence of bruises and wounds on all carcass sampled at abattoirs A and B.

Abattoir	Location	Bruises		Wounds	
		Light (%)	Heavy (%)	Light (%)	Heavy (%)
A (N = 78)	Shoulder	7.69	2.56	20.51	15.39
	Loin	28.21	14.10	-	5.13
	Rump	23.10	16.67	5.13	6.41
	Ear/Head	-	-	-	7.69
	Abdomen	-	-	-	10.26
B (N = 66)	Shoulder	13.64	-	22.73	3.03
	Loin	22.73	4.55	-	1.52
	Rump	22.73	1.52	3.03	1.52
	Ear/Head	-	1.52	-	1.52
	Abdomen	-	1.52	4.55	1.52

4.2 pH A TOOL TO ASSESS PORK QUALITY

The mean values of pH_1 and pH_{24} were different in the two muscles used. The value for the ST (*6.28* pH_1 and *5.98* pH_{24}) was higher than LD (*5.99* pH_1 and *5.62* pH_{24}). This is shown in Appendix B.

4.2.1 Initial pH

Table 5a and Figures 2a and 2b shows for ST and LD the percentages in each meat quality category for pH_1 throughout the evaluation period at abattoirs A and B. The incidence of the severe PSE condition was higher at abattoir B than at abattoir A. The percentage was *11.54* % in ST and *35.90* % in LD at abattoir A and *22.22* % in ST and *37.89* % in LD at abattoir B. Correlations between pH_1 values to other parameters were in good agreement (Table 11). The results show firstly in the ST that the pH_1 readings were highly correlated with the pH_{24} readings (+0.90) (shown in Figure 9), also in good agreement with WHC (+0.78), overall visual score (-0.78), drip loss (-0.65) and colour L (+0.51) but in less agreement with protein solubility (+0.49), colour B (-0.44) and colour A (+0.35). While in LD, the pH_1 was in good agreement with all of the parameters except for colour A. The values were pH_{24} (+0.89), WHC (+0.89), overall visual score (-0.84), protein solubility (+0.78), drip loss (-0.72), colour L (-0.69) and colour B (-0.67).

Table 5a. Meat quality categories of the ST and LD using pH_1 as parameter.

	Meat Quality Category									
	DFD		MDFD		Normal		MPSE		PSE	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
A	*42.30*		*20.51*		*15.39*		*10.26*		*11.54*	
ST	(6.58)	0.14	(6.30)	0.06	(6.11)	0.06	(5.91)	0.07	(5.72)	0.07
LD	*12.82*		*10.26*		*17.95*		*23.08*		*35.90*	
	(6.59)	0.14	(6.30)	0.07	(6.08)	0.05	(5.89)	0.07	(5.71)	0.08
B	*13.89*		*38.89*		*16.67*		*8.33*		22.22	
ST	(6.55)	0.08	(6.33)	0.06	(6.08)	0.06	(5.94)	0.04	(5.67)	0.10
LD	*3.03*		*16.67*		*15.15*		*27.27*		*37.89*	
	6.44	0.02	(6.28)	0.04	(6.08)	0.05	(5.93)	0.06	(5.68)	0.08

a= n (78); b = n (66); DFD = severe DFD; MDFD = mild DFD; PSE = severe PSE; MPSE = mild PSE; ST = semitendinosus; LD = longissimus dorsi; SD = standard deviation.

Table 5b. Frequency (%) distribution, mean value and standard deviation of DFDo, Normal and PSEo for pH_1.

		DFDo		Normal		PSEo	
Abattoir	Muscle	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
A[a]	ST	*62.81* (6.49)	0.18	*15.39* (6.11)	0.06	*21.80* (5.81)	0.12
	LD	*23.08* (6.46)	0.19	*17.95* (6.08)	0.05	*58.98* (5.79)	0.12
B[b]	ST	*52.78* (6.39)	0.11	*16.67* (6.08)	0.06	*30.55* (5.75)	0.15
	LD	*19.70* (6.30)	0.07	*15.15* (6.08)	0.05	*65.16* (5.78)	0.14

a= n (78); b = n (66); DFDo = total percentage of severe DFD and mild DFD; PSEo = total percentage of severe PSE and mild PSE; ST = semitendinosus; LD = longissimus dorsi; SD = standard deviation.

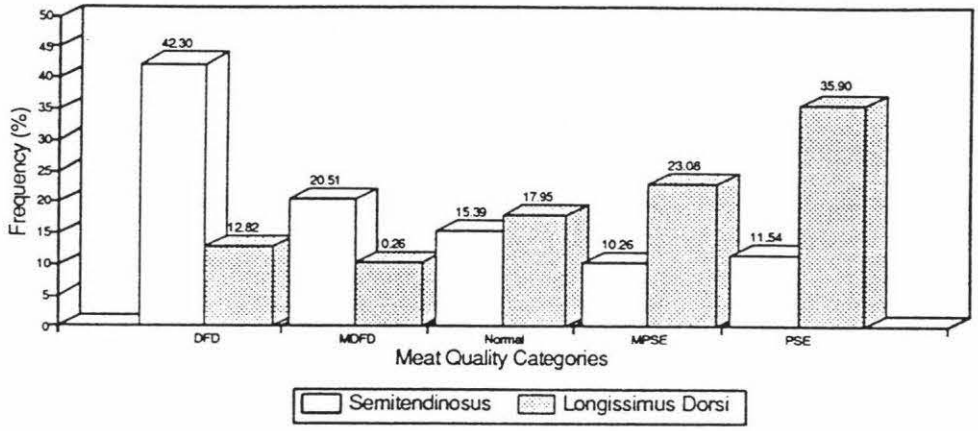


Figure 2a. Frequency (%) distribution of the initial pH of the ST and LD at abattoir A.

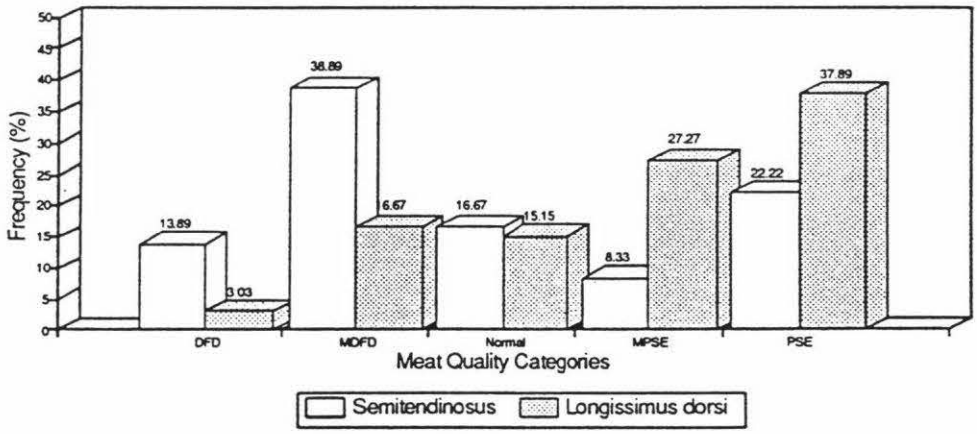


Figure 2b. Frequency (%) distribution of the initial pH of the ST and LD at abattoir B.

4.2.2 Ultimate pH

Percentages of ST and LD in each meat quality category for pH_1 throughout the evaluation period at abattoirs A and B are shown in Table 6a, and Figures 3a and 3b. The overall incidence of the PSEo condition was higher at abattoir B than at abattoir A. The percentage was *26.93* % of ST and *73.08* % of LD at abattoir A, and *82.61* % of ST and *84.90* % of LD at abattoir B. Abattoir B had a lower overall incidence of DFDo compared to abattoir A. This is shown in Table 5b. The result also shows that the PSE incidence was higher in LD than ST at both abattoirs, though the ST muscle had higher incidence of DFD than the LD.

Correlation between pH_{24} values to other parameters were in good agreement except in colour A for both the ST and LD. The result shows (Table 11) in the ST that WHC (+0.81), OVS (-0.87), and drip loss (-0.74) had the highest correlations compared to other parameters. Whilst in the LD, all the parameters had high correlation values; WHC (+0.92), OVS (-0.92) drip loss (-0.84), colour L (-0.82), protein solubility (+0.77) and colour B (-0.73). This relationship of pH_{24} to other parameters were illustrated in Figures 10, 11, 12, and 13.

Table 6a. Meat quality category in ST and LD using pH_{24} as parameter.

	Meat Quality Category									
	DFD		MDFD		Normal		MPSE		PSE	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
A* ST	*10.26* (6.47)	0.05	*21.79* (6.29)	0.05	*41.03* (5.97)	0.10	*23.08* (5.60)	0.13	*3.85* (5.35)	0.03
LD	*2.56* (6.60)	0.11	*8.97* (6.35)	0.07	*15.39* (5.92)	0.09	*43.59* (5.56)	0.11	*29.49* (5.28)	0.10
B[b] ST	- -	-	*13.04* (6.27)	0.04	*4.35* (6.06)	-	*47.83* (5.58)	0.12	*34.78* (5.35)	0.04
LD	- -	-	*1.89* (6.29)	-	*13.21* (5.94)	0.12	*50.94* (5.62)	0.11	*33.96* (5.34)	0.05

MDFD = mild DFD; MPSE = mild PSE.

Table 6b. Mean and standard deviation of DFDo, Normal and PSEo for pH_{24}.

Abattoirs	Muscle	DFDo		Normal		PSEo	
		% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
A*	ST	*32.05* (6.34)	0.10	*41.03* (5.97)	0.10	*26.93* (5.57)	0.15
	LD	*11.53* (6.40)	0.13	*15.39* (5.92)	0.09	*73.08* (5.45)	0.18
B[b]	ST	*13.04* (6.27)	0.04	*4.35* (6.06)	-	*82.61* (5.48)	0.15
	LD	*1.89* (6.29)	-	*13.21* (5.94)	0.12	*84.90* (5.51)	0.16

a= abattoir A with n (78); b = abattoir B with n (66); - = no value; DFDo = total percentage of severe DFD & mild DFD; PSEo = total percentage of severe PSE & mild PSE; SD = standard deviation.

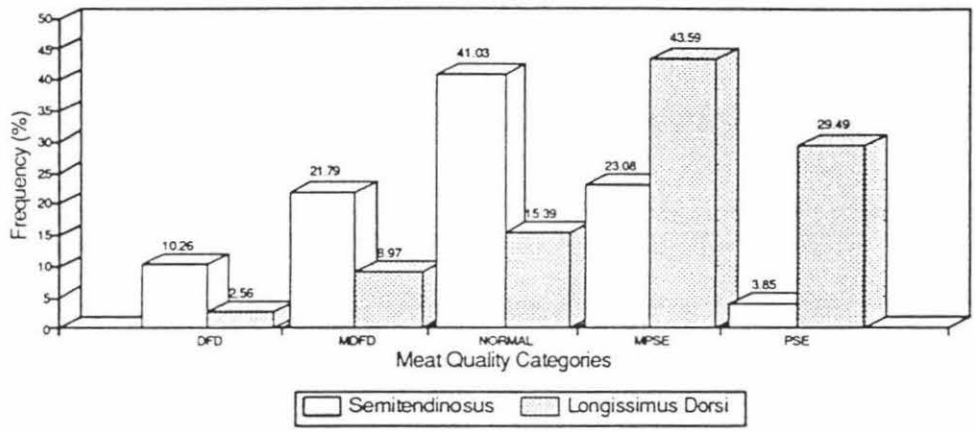


Figure 3a. Frequency (%) distribution of the ultimate pH of the ST and LD at abattoir A.

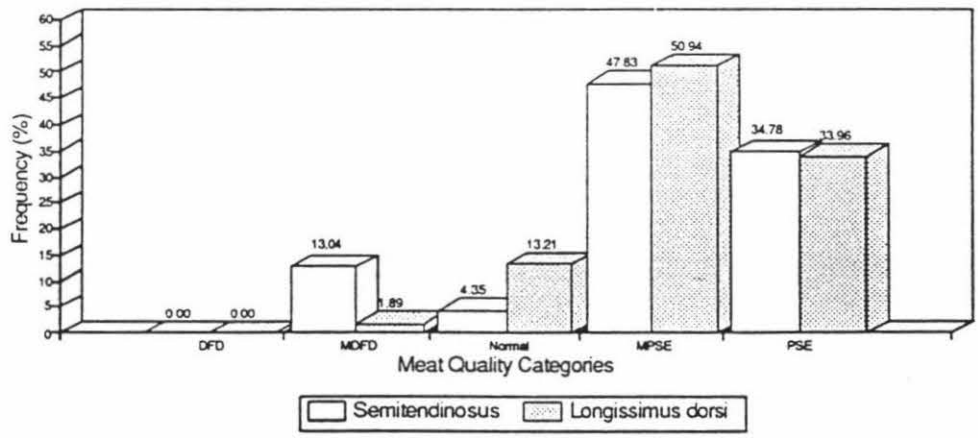


Figure 3b. Frequency (%) distribution of the ultimate pH of the ST and LD at abattoir B.

4.3 WHC A TOOL TO ASSESS PORK QUALITY

The FPP (filter paper press) method at 24 hour post mortem indicated a high of *51.28* % of the ST muscle to be DFDo and *65.38* % of the LD to be PSEo. The results are shown in Tables 7a, 7b and Figure 4.

As shown in Table 11, WHC values in the ST muscle correlated highly with; drip loss (-0.83), overall visual score (-0.77), and protein solubility (+0.57) but not with colour L, A and B. In LD, WHC correlated highly with overall visual score (-0.89), drip loss (-0.85), protein solubility (+0.82), colour L (-0.78) and colour B (-0.68) except with colour A. The correlation of WHC to drip loss and colour L (brightness) are illustrated in Figures 14 and 15.

Table 7a. Mean and standard deviation of meat quality category in relation to *WHC.*

	Meat Quality Category									
	DFD		MDFD		Normal		MPSE		PSE	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
ST	*6.41* (67.97)	1.71	*44.87* (63.00)	1.48	*37.18* (57.75)	1.20	*8.97* (53.89)	0.63	*2.56* (49.08)	1.34
LD	*5.13* (69.12)	2.20	*6.41* (63.31)	2.07	*23.08* (58.06)	1.56	*24.36* (53.25)	1.54	*41.02* (48.94)	1.90

MDFD = mild DFD; MPSE = mild PSE; SD = standard deviation; ST = semitendinosus; LD = longissimus dorsi.

Table 7b. Mean and standard deviation of DFDo, Normal and PSEo in relation to *WHC*.

Muscle	DFDo		Normal		PSEo	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
ST	*51.28* (64.11)	2.45	*37.18* (57.75)	1.20	*11.53* (57.22)	5.91
LD	*11.54* (65.89)	3.65	*23.08* (58.06)	1.56	*65.38* (50.55)	2.74

DFDo = total percentage of severe DFD and mild DFD; PSEo = total percentage of severe PSE and mild PSE; SD = standard deviation; ST = semitendinosus; LD = longissimus dorsi.

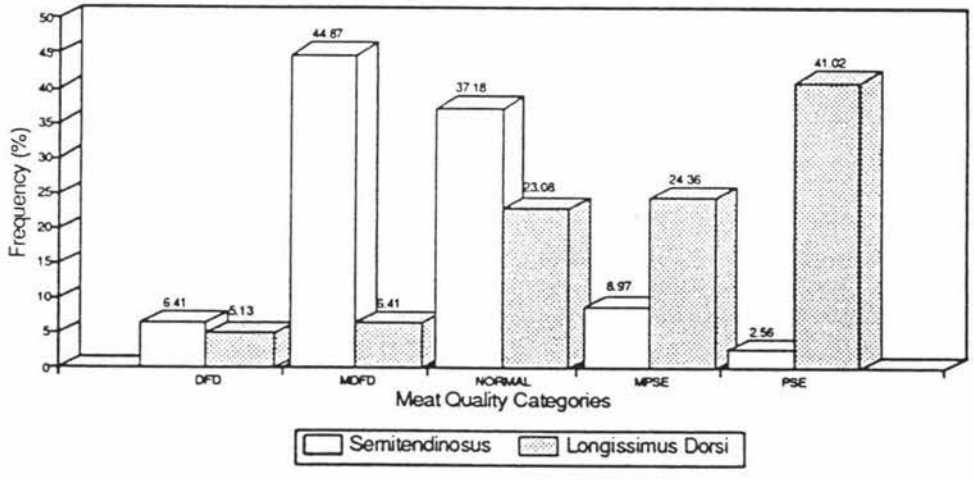


Figure 4. Frequency (%) distribution of WHC of the **ST** and **LD** at abattoir A.

4.4 DRIP LOSS A TOOL TO ASSESS PORK QUALITY

Each meat quality category in relation to drip loss observations are shown in Tables 8a, b and Figure 5. The incidence of the MPSE and PSE were *7.69* % and *65.39* % with a standard deviation of 1.23 and 0.75 in the ST and the LD, respectively. While the incidence of MDFD and DFD were higher for the ST were higher *52.56* % (with standard deviation of 0.25) than in LD (*11.54* %).

In the ST, the drip loss was only highly correlated with the overall visual scores (+0.73) and protein solubility (-0.65). However with the LD, all the parameters except colour A were highly correlated. Respective correlation values are as follows; -0.95, +0.86, +0.75 and +0.63 for protein solubility, overall visual score, colour L and colour B, respectively. These results are shown in Table 11. Figure 16 illustrate the correlation of drip loss and colour L (brightness).

Table 8a. Meat quality category in ST and LD using *drip loss* as parameter.

	Meat Quality Category									
	DFD		MDFD		Normal		MPSE		PSE	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
ST	*7.69* (0.88)	0.07	*44.87* (1.32)	0.32	*39.74* (2.32)	0.24	*2.56* (3.42)	0.25	*5.13* (4.72)	0.41
LD	*1.28* (0.96)	- -	*10.26* (1.40)	0.21	*23.08* (2.44)	0.32	*14.10* (3.49)	0.26	*51.29* (5.73)	0.89

SD = standard deviation; - = no value; DFD = severe dark firm dry; MDFD = mild DFD; PSE = severe pale soft exudate; MPSE = mild PSE.

Table 8b. Mean and standard deviation of DFDo, Normal and PSEo for *drip loss*.

Muscle	DFDo		Normal		PSEo	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
ST	*52.56* (1.35)	0.25	*39.74* (2.44)	0.32	*7.69* (5.25)	1.23
LD	*11.54* (1.26)	0.33	*23.08* (2.32)	0.24	*65.39* (4.29)	0.75

SD = standard deviation; DFDo = total percentage of severe DFD and mild DFD; PSEo = total percentage of severe PSE and mild PSE .

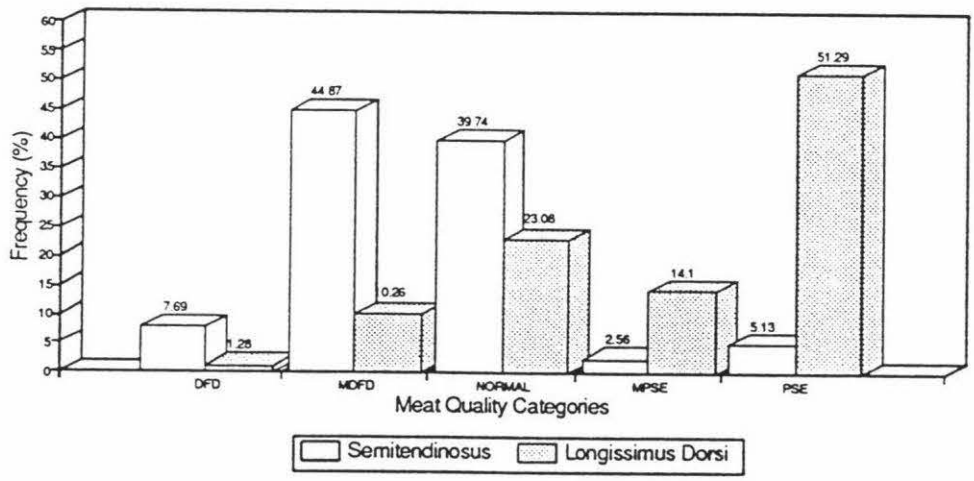


Figure 5. Frequency (%) distribution of drip loss of the ST and LD at abattoir A.

4.5 COLOUR A TOOL FOR ASSESSING PORK QUALITY

Tables 9a and 9b contains the percentages of ST and LD in each meat quality category for all colour observations throughout the evaluation period. The results show that there was a high incidence of the DFDo (*41.03 %*) of ST muscle and PSEo (*69.24 %*) of LD muscle in overall visual colour score. Likewise in colour L (brightness), the result shows a high incidence DFDo (*51.29 %*) of ST muscle and PSEo (*65.39 %*) of LD muscle.

When the colour scores were grouped in three general categories DFDo, normal and PSEo (as shown in Table 9b), it can be seen that nearly *69 %* of the LD colour observations were undesirable in that they were PSE. Conversely, *21.48 to 39.75 %* of LD and ST were within the normal range of visual colour scores and colour hunter LAB, whereas only *9 %* would have been considered DFD in LD muscle.

The overall visual score and colour L (brightness) showed higher correlation coefficients for all parameters unlike colour A and B. This is shown in Table 11.

Table 9a. Colour characteristics of DFD, MDFD, Normal, MPSE and PSE.

	Meat Quality Category									
	DFD		MDFD		Normal		MPSE		PSE	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
L ST	*10.26* (23.30)	1.55	*41.03* (27.90)	1.33	*37.18* (32.64)	1.33	*11.54* (37.39)	1.59	-	-
LD	*3.85* (23.53)	1.56	*5.13* (28.43)	1.24	*23.08* (33.43)	1.22	*14.10* (37.62)	1.55	*51.29* (42.01)	2.13
A ST	*5.13* (20.10)	1.63	*20.51* (16.65)	0.62	*42.31* (15.07)	0.50	*26.92* (13.28)	0.58	*5.13* (11.22)	0.29
LD	*1.28* (19.14)	-	*1.28* (16.73)	-	*5.13* (14.92)	0.72	*42.31* (12.78)	0.48	*50.00* (11.11)	0.78
B ST	*2.56* (4.77)	0.26	*24.36* (5.68)	0.29	*41.03* (6.51)	0.29	*25.64* (7.44)	0.29	*6.41* (8.27)	0.27
LD	*3.85* (4.74)	0.16	*10.26* (5.54)	0.40	*37.18* (6.49)	0.31	*38.46* (7.46)	0.28	*10.25* (8.55)	0.41

Table 9b. Mean and standard deviation of DFDo, Normal and PSEo for *colour*.

Colour Traits		Meat Quality Category					
		DFDo		Normal		PSEo	
		% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
OVS	ST	*41.03*	-	*38.46*	-	*20.51*	-
	LD	*10.25*	-	*20.51*	-	*69.24*	-
L	ST	*51.29* (26.98)	2.30	*37.18* (32.64)	1.33	*11.54* (37.39)	1.59
	LD	*8.98* (26.33)	2.90	*23.08* (33.43)	1.22	*65.39* (39.44)	2.83
A	ST	*25.63* (17.34)	1.65	*42.31* (15.07)	0.50	*32.05* (12.95)	0.94
	LD	*2.56* (17.94)	1.70	*5.13* (14.92)	0.72	*92.31* (11.88)	1.06
B	ST	*26.92* (5.59)	0.39	*41.03* (6.51)	0.29	*32.05* (7.61)	0.44
	LD	*14.11* (5.32)	0.51	*37.18* (6.49)	0.31	*48.71* (7.69)	0.54

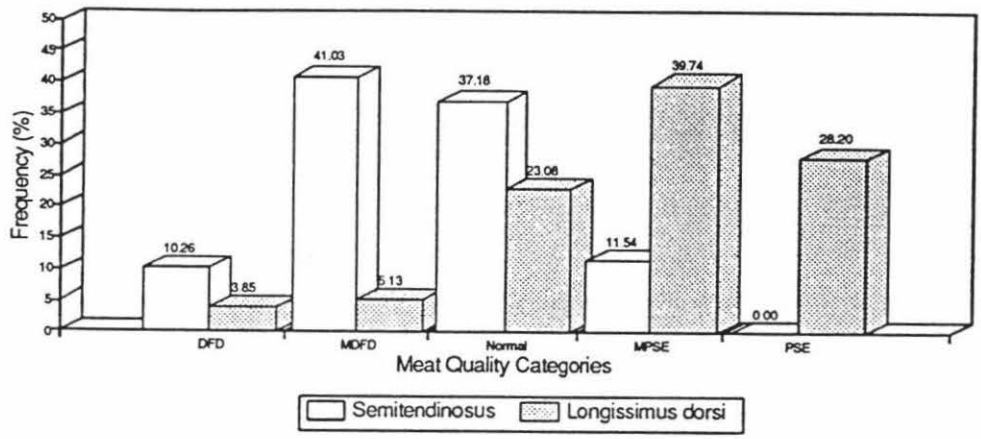


Figure 6. Frequency (%) distribution of colour L (brightness) of the ST and LD at abattoir A.

4.6 PROTEIN SOLUBILITY A TOOL FOR ASSESSING PORK QUALITY

Table 10a contains the percentages of ST and LD in each meat quality category for protein solubility. The percentage of LD muscles in the MPSE and PSE categories were higher than for the ST muscles. The mean percentage of PSE and MPSE were *54.76* % and *23.81* %, respectively. Conversely, the mean percentage of ST and LD with normal protein solubility were *54.76* % (ST) and *21.43* % (LD), respectively. This is shown clearly in Figure 7. When they were grouped in three general categories DFDo, normal and PSEo (shown in Table 9b), it can be seen that nearly *78.57* % of the LD had an undesirable protein solubility in that they were PSEo. Conversely, *21.43* % of LD and *54.76* % of ST

were within the normal range of protein solubility, whereas *21.43* % of ST would have been considered as MDFD.

Table 10a. Meat quality category in ST and LD using *protein solubility* as parameter.

	Meat Quality Category									
	DFD		MDFD		Normal		MPSE		PSE	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
ST	- -	-	*21.43* (57.25)	1.09	*54.76* (52.65)	1.47	*16.67* (49.45)	0.56	*7.14* (42.88)	0.32
LD	- -	-	- -	-	*21.43* (52.09)	1.34	*23.81* (47.59)	1.50	*54.76* (32.17)	4.45

SD = standard deviation; - = no value; DFD = severe dark firm dry; MDFD = mild DFD; PSE = severe pale soft exudate; MPSE = mild PSE.

Table 10b. Mean and standard deviation of DFDo, Normal and PSEo for *protein solubility*.

Muscle	DFDo		Normal		PSEo	
	% (Mean)	SD	% (Mean)	SD	% (Mean)	SD
ST	*21.43* (57.25)	1.09	*54.76* (52.65)	1.47	*23.81* (47.48)	3.21
LD	- -	-	*21.43* (52.09)	1.34	*78.57* (36.51)	8.01

DFDo = total percentage of severe DFD; PSEo = total percentage of severe PSE; SD = standard deviation; - = no value.

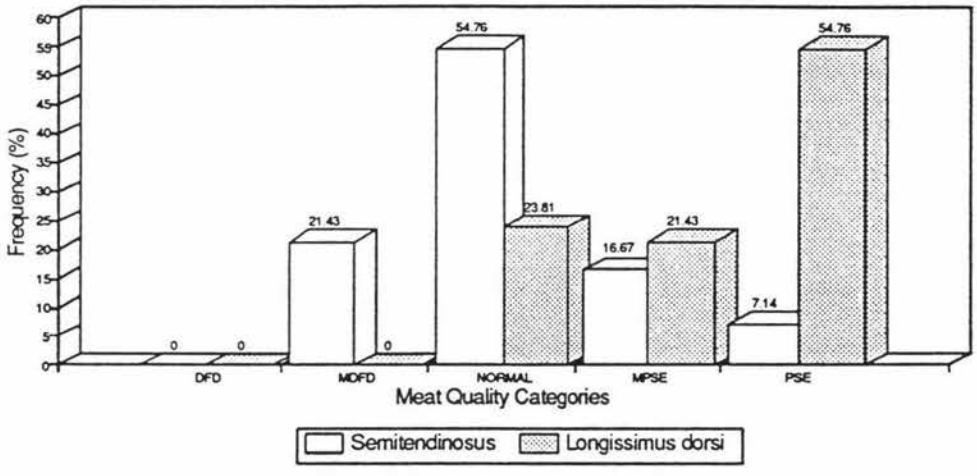


Figure 7. Frequency (%) distribution of protein solubility of the ST and LD at abattoir A.

Table 11. Correlation between the pork quality parameters of *ST* and *LD*.

MQV	Type of Muscle	Meat Quality Parameters												
		pH_1	pH_{2u}	WHC	DL	CL	CA	CB	Chr	Hue	Wet	VCS	TEXT	VS
pH_{2u}	ST	+.90***	-	-	-	-	-	-	-	-	-	-	-	-
	LD	+.89***	-	-	-	-	-	-	-	-	-	-	-	-
WHC	ST	+.78***	+.81***	-	-	-	-	-	-	-	-	-	-	-
	LD	+.89***	+.92***	-	-	-	-	-	-	-	-	-	-	-
DL	ST	-.65***	-.74***	-.83***	-	-	-	-	-	-	-	-	-	-
	LD	-.72***	-.84***	-.85***	-	-	-	-	-	-	-	-	-	-
CL	ST	-.51***	-.59***	-.43***	+.41***	-	-	-	-	-	-	-	-	-
	LD	-.69***	-.82***	-.78***	+.75***	-	-	-	-	-	-	-	-	-
CA	ST	+.35***	+.41***	+.25*	-.22*	-.74***	-	-	-	-	-	-	-	-
	LD	+.14	+.21	+.23*	-.13	-.45***	-	-	-	-	-	-	-	-
CB	ST	-.44***	-.58***	-.40***	+.45***	+.78***	-.47***	-	-	-	-	-	-	-
	LD	-.67***	-.73	-.68***	+.63***	+.72***	-.08	-	-	-	-	-	-	-
Chr	ST	-	+.32**	+.17	-.13	-.65***	+.97***	-.30*	-	-	-	-	-	-
	LD	-	-.03	+.01	+.07	-.22	+.93***	+.22	-	-	-	-	-	-
Hue	ST	-	+.41**	+.16	-.21	-.65***	+.53***	-.62***	-.57***	-	-	-	-	-
	LD	-	+.65***	+.63***	-.52***	-.79***	+.70***	-.74***	+.49***	-	-	-	-	-
Wet	ST	-	-.82***	-.72***	+.68***	+.60***	-.44***	+.55***	-.35**	-.36**	-	-	-	-
	LD	-	-.87***	-.85***	+.81***	+.79***	-.21	+.61***	-.02	-.58***	-	-	-	-
VCS	ST	-	-.71***	-.58***	+.54***	+.83***	-.70***	+.68***	-.61***	-.55***	+.70***	-	-	-
	LD	-	-.87***	-.86***	+.81***	+.86***	-.35**	+.66***	-.15	-.70***	+.85***	-	-	-
Text	ST	-	-.81***	-.72***	+.67***	+.49***	-.30*	+.52***	-.20	-.29*	+.81***	+.63***	-	-
	LD	-	-.88***	-.81***	+.79***	+.81***	-.20	+.67***	-.01	-.62***	+.82***	+.83***	-	-
VS	ST	-.78***	-.87***	-.77***	+.73***	+.62***	-.48***	+.56***	-.39**	-.38**	+.93***	+.77***	+.87***	-
	LD	-.84***	-.92	-.89***	+.86***	+.84***	-.18	+.67***	+.02	-.61***	+.92***	+.91***	+.92***	-
PS	ST	+.49***	+.57***	+.57***	-.65***	-.32*	+.10	-.39*	+.04	+.25	-.43**	-.27	-.53**	-.50***
	LD	+.78***	+.77***	+.82***	-.95***	-.72***	-.01	-.62***	-.23	+47***	-.77***	-.76***	-.69***	-.84***

MQT = meat quality traits; WHC = water holding capacity; DL = drip loss; CL = tristimulus colour L; CA = tristimulus colour A; CB = tristimulus colour B; Chr = chroma; Wet = wetness; VCS = visual colour score; text = texture; OVS = overall visual score; PS = protein solubility;
* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

4.7 OVERALL RESULT FOR ALL PARAMETERS

A summary of all the results of this study for all parameters is shown in Table 12. It is observed that values were different for all parameters, both muscles and abattoirs.

All parameters predicted *14.10 to 50.94%* MPSE and *10.25 to 54.76%* PSE meat for the LD muscle, *13.04 to 44.87%* MDFD and *0 to 12.82%* DFD meat for the ST muscle, and *5.13 to 54.76%* normal meat for both muscles. Abattoir A had a higher incidence of DFD meat than at abattoir B but the abattoir B had a higher incidence of PSE meat compared with abattoir A.

The pH_1 (*20.51%* and *42.30%* at abattoir A; *38.89%* and *13.89%* at abattoir B), pH_{24} (*21.79%* and *10.26%* at abattoir A and none at abattoir B) and colour hunter L (*41.03%* and *10.26%*) predicts MDFD and DFD meat on ST muscle. The WHC (*24.36%* and *41.02%*), drip loss (*14.10%* and *51.29%*), visual evaluation (*28.21%* and *41.03%*) and protein solubility (*21.43%* and *54.76%*) predicts MPSE and PSE meat on LD muscle.

Therefore, the result shows that the LD muscle is very susceptible to PSE and ST muscle to DFD quality defects. Those techniques that can accurately predict PSE were WHC, drip loss, visual evaluation, and protein solubility while the pH_1, pH_{24} and colour hunter L can precisely predict DFD. The abattoir B shows a higher percentages PSE on both muscles.

Table 12. Summary of the results for different pork quality parameters subjectively assessed as DFD, MDFD, normal, MPSE or PSE.

Pork Quality Parameters	Meat Quality Category				
	DFD (%)	MDFD (%)	NORMAL (%)	MPSE (%)	PSE (%)
pH_1[a]					
ST	42.30	20.51	15.39	10.26	11.54
LD	12.82	10.26	17.95	23.08	35.90
pH_{24}[a]					
ST	10.26	21.79	41.03	23.08	3.85
LD	2.56	8.97	15.39	43.59	29.49
pH_1[b]					
ST	13.89	38.89	16.67	8.33	22.22
LD	3.03	16.67	15.15	27.27	37.89
pH_{24}[b]					
ST	0.00	13.04	4.35	47.83	34.78
LD	0.00	1.89	13.21	50.94	33.96
WHC					
ST	6.41	44.87	37.18	8.97	2.56
LD	5.13	6.41	23.08	24.36	41.02
Drip loss					
ST	7.69	44.87	39.74	2.56	5.13
LD	1.28	10.26	23.08	14.10	51.29
Colour L					
ST	10.26	41.03	37.18	11.54	0.00
LD	3.85	5.13	23.08	39.74	28.20
Colour A					
ST	5.13	20.51	42.31	26.92	5.13
LD	1.28	1.28	5.13	42.31	50.00
Colour B					
ST	2.56	24.36	41.03	25.64	6.41
LD	3.85	10.26	37.18	38.46	10.25
OVS					
ST	5.13	35.90	38.46	19.23	1.28
LD	2.56	7.69	20.51	28.21	41.03
PS					
ST	0.00	21.43	54.76	16.67	7.14
LD	0.00	0.00	23.81	21.43	54.76

N = number of observation; [a] = abattoir A (N = 78 carcasses); [b] = abattoir B (N = 66 carcasses); WHC = water holding capacity; L = brightness; A = redness; B = yellowness; OVC = overall visual colour; PS = protein solubility; DFD = severe dark firm dry; MDFD = mild DFD; PSE = severe pale soft exudative; MPSE = mild PSE .

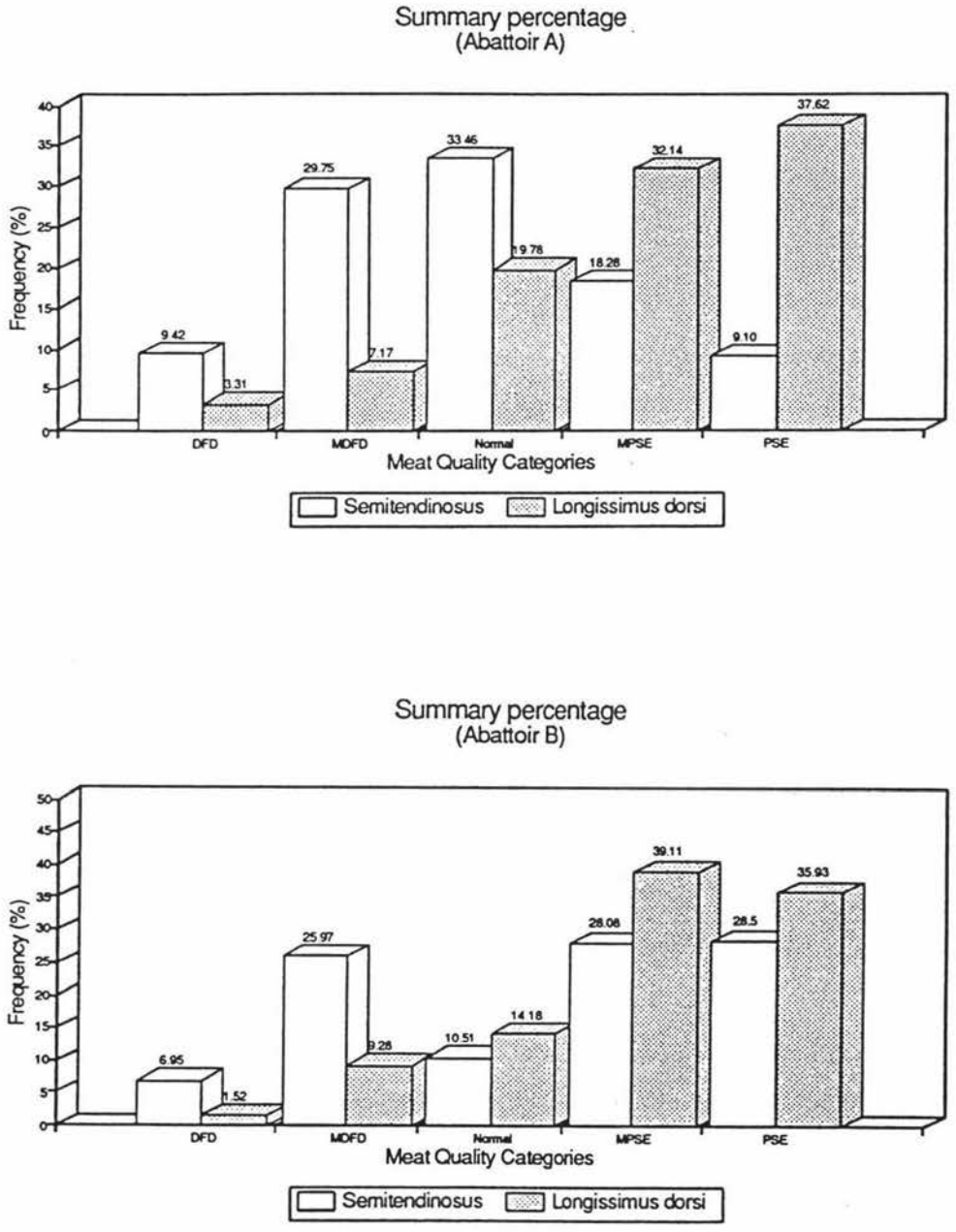
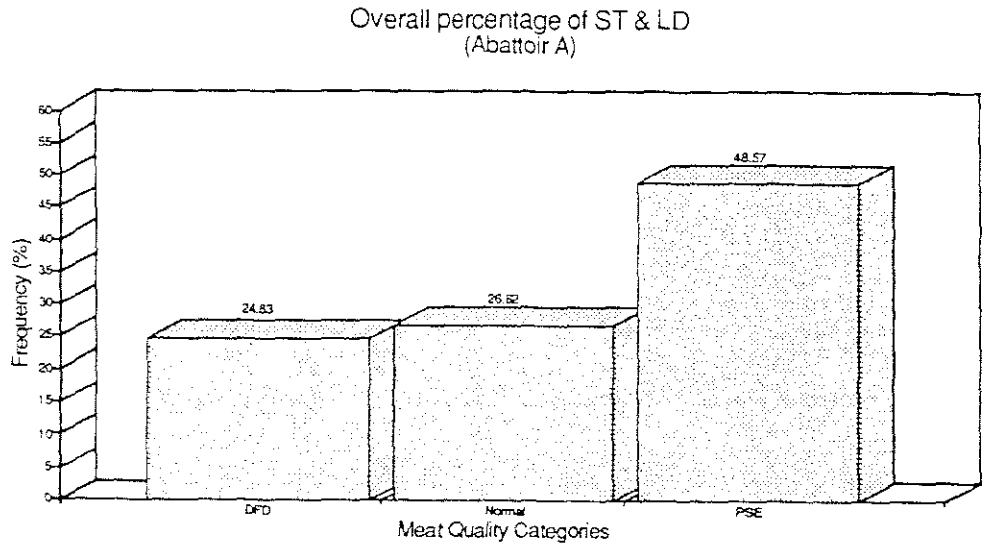


Figure 8a. Summary percentages of different meat quality category at abattoirs A and B for all parameters.



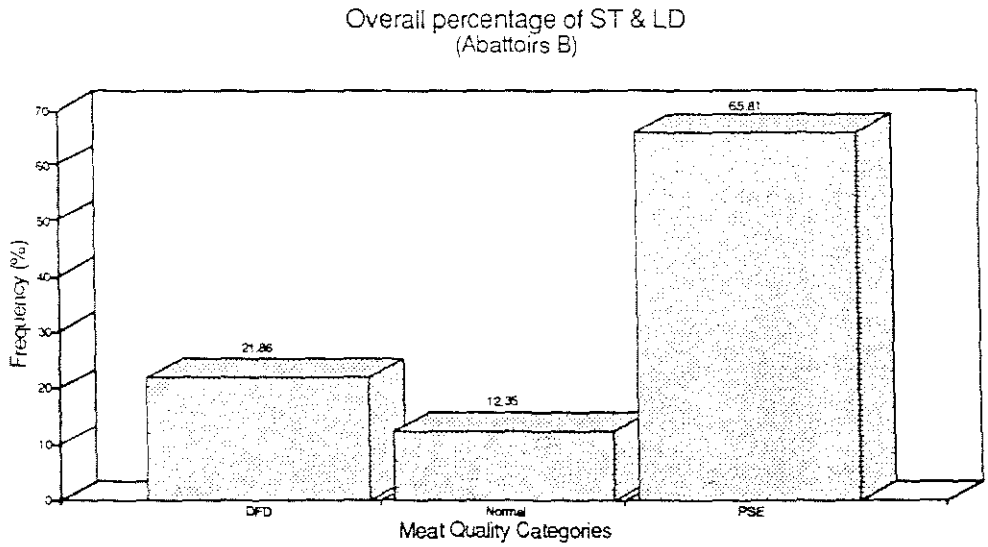
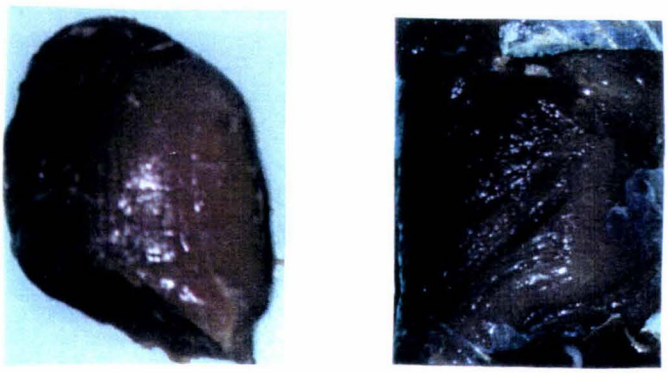


Figure 8b. Overall percentages of DFDo, normal and PSEo at abattoirs A and B for all parameters.

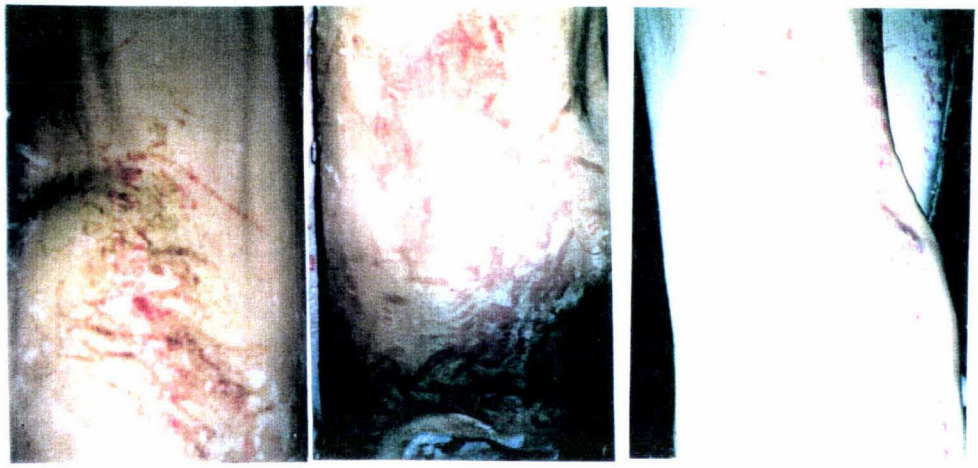
(a) (b)

Photo 1. Typical **PSE** pork found during the study in **ST (a)** and **LD (b)**.



(a) (b)

Photo 2. Typical **DFD** pork found during the study in **ST (a)** and **LD (b)**.



(a) (b)

Photo 3. Typical **Bruises (a)** and **scratches (b)** observed on a large number of carcasses during the study.

(a) (c)

(b) (d)

Photo 4. Possible causes of Bruising and Scratching.
(Note the blood on a number of pigs indicative of fighting)
(a) Overcrowding (c) Fighting
(b) Different sex (d) Mounting

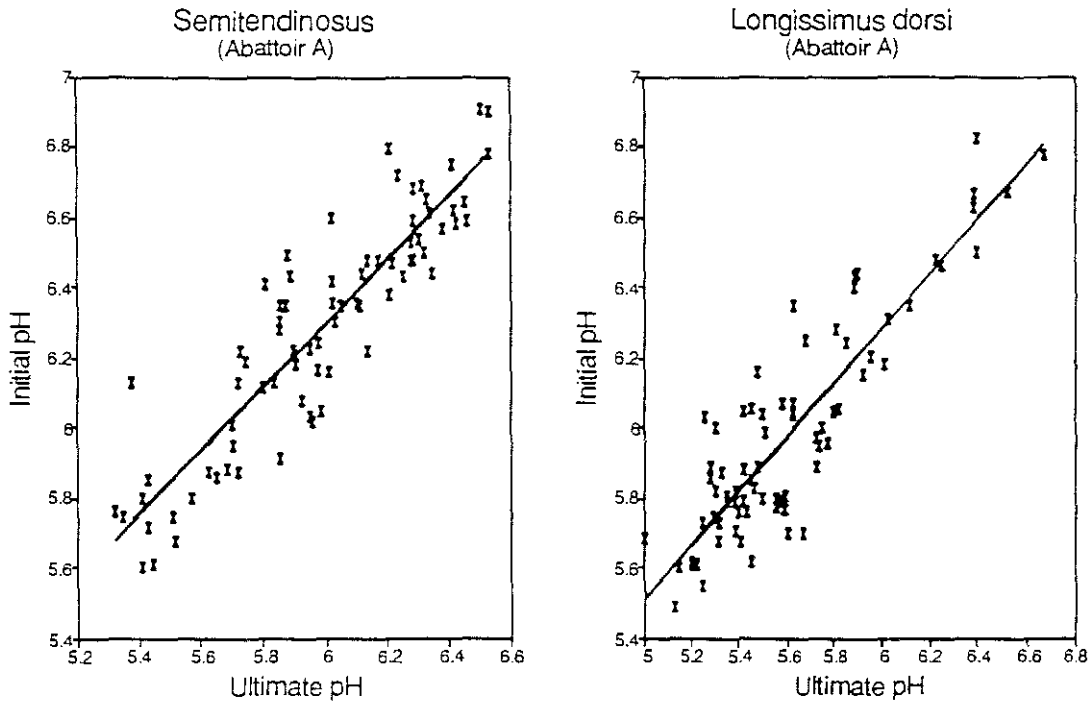


Figure 9. Relationship between pH_1 and pH_{24} of the ST and LD muscles at abattoir A.

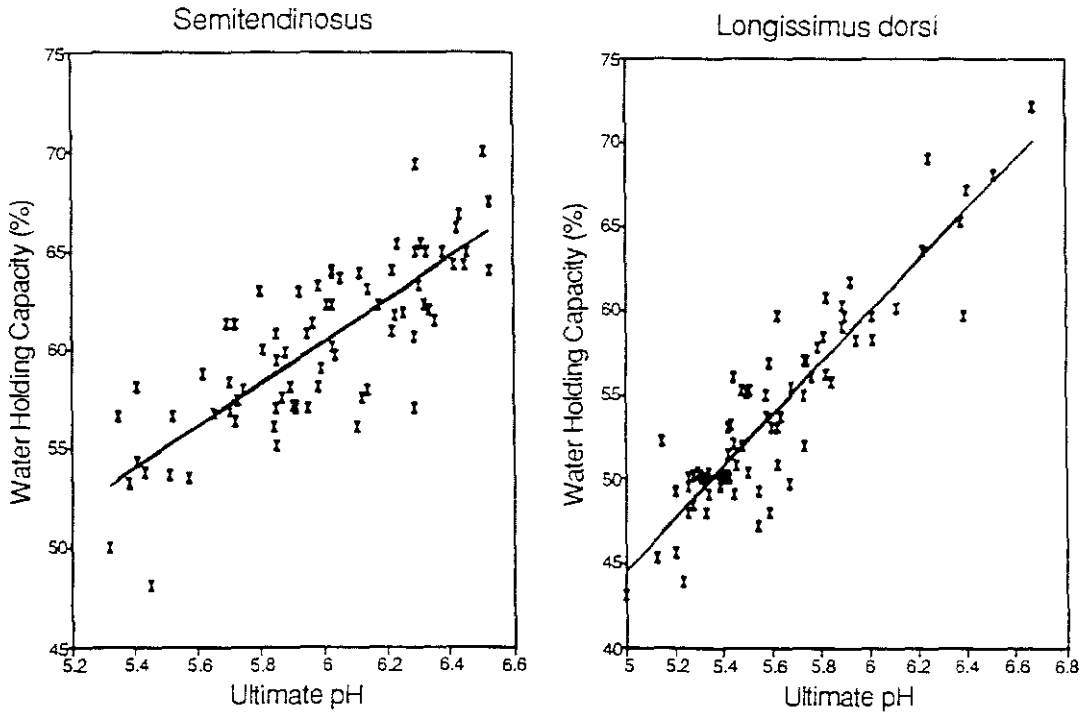


Figure 10. Relationship between WHC and pH_{24} of the ST and LD muscles at abattoir A.

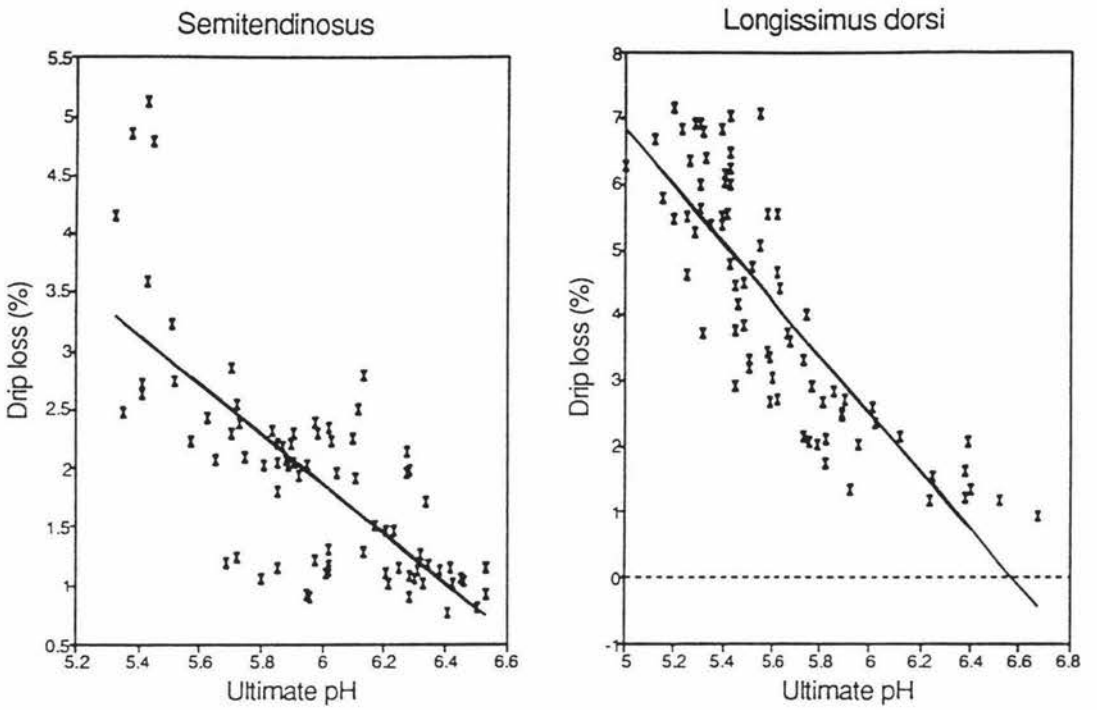


Figure 11. Relationship between drip loss and final pH of the ST and LD muscles at abattoir A.

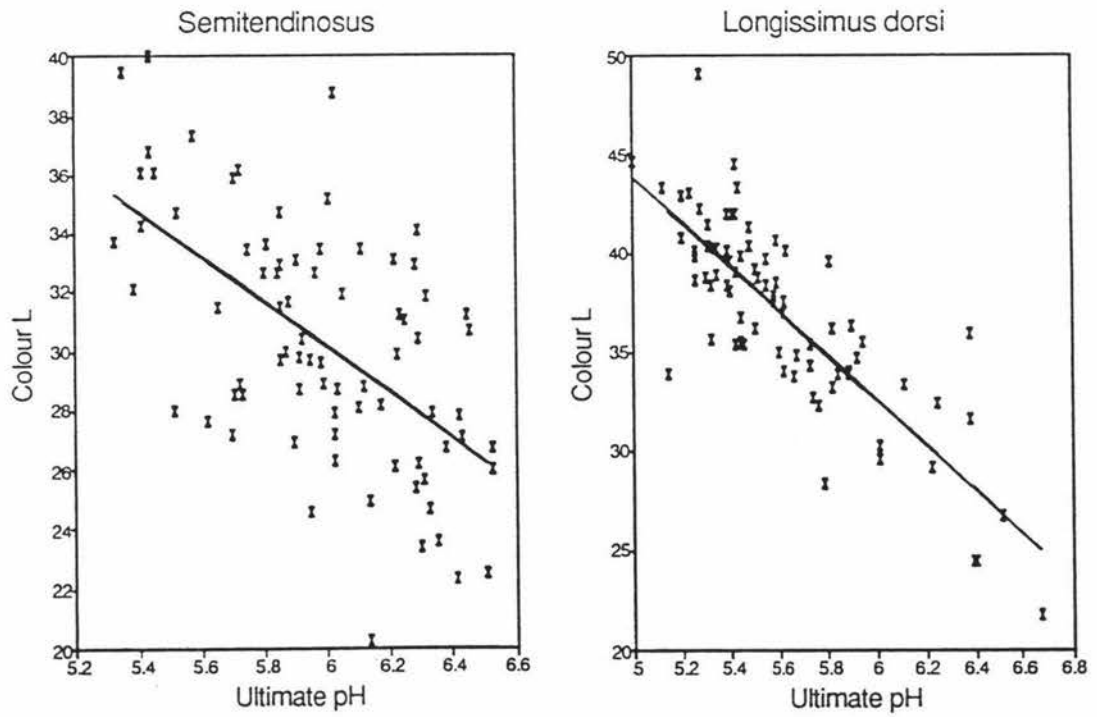


Figure 12. Relationship between colour L (brightness) and pH_{24} of the ST and LD muscles at abattoir A.

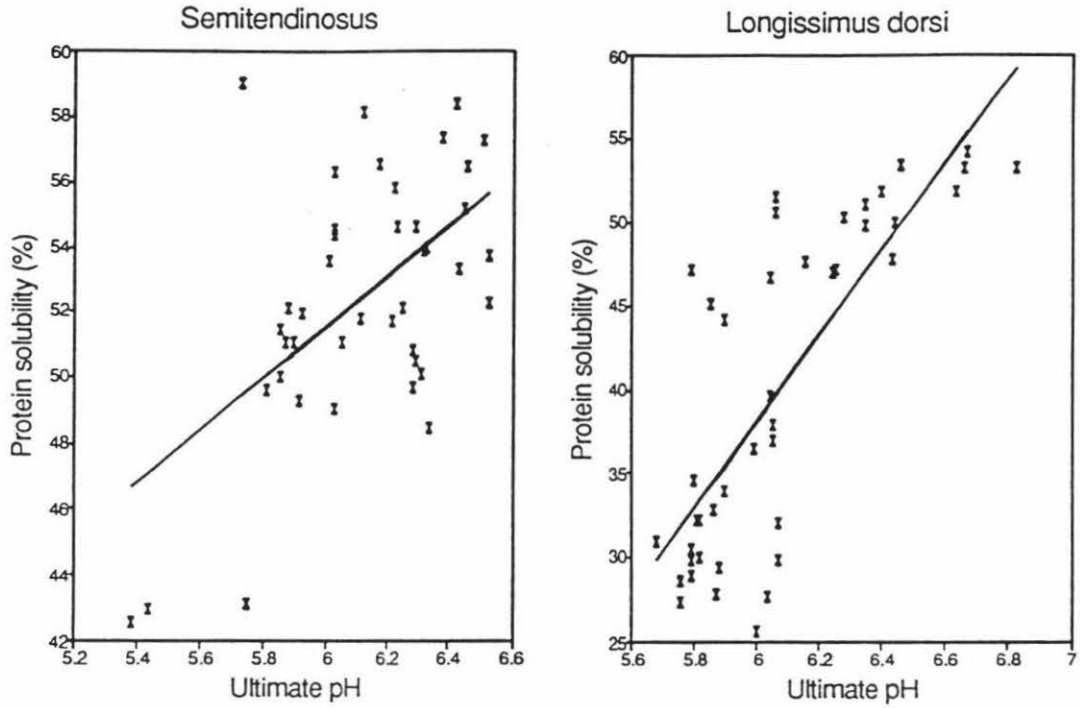


Figure 13. Relationship between protein solubility and pH_{24} of the ST and LD muscles at abattoir A.

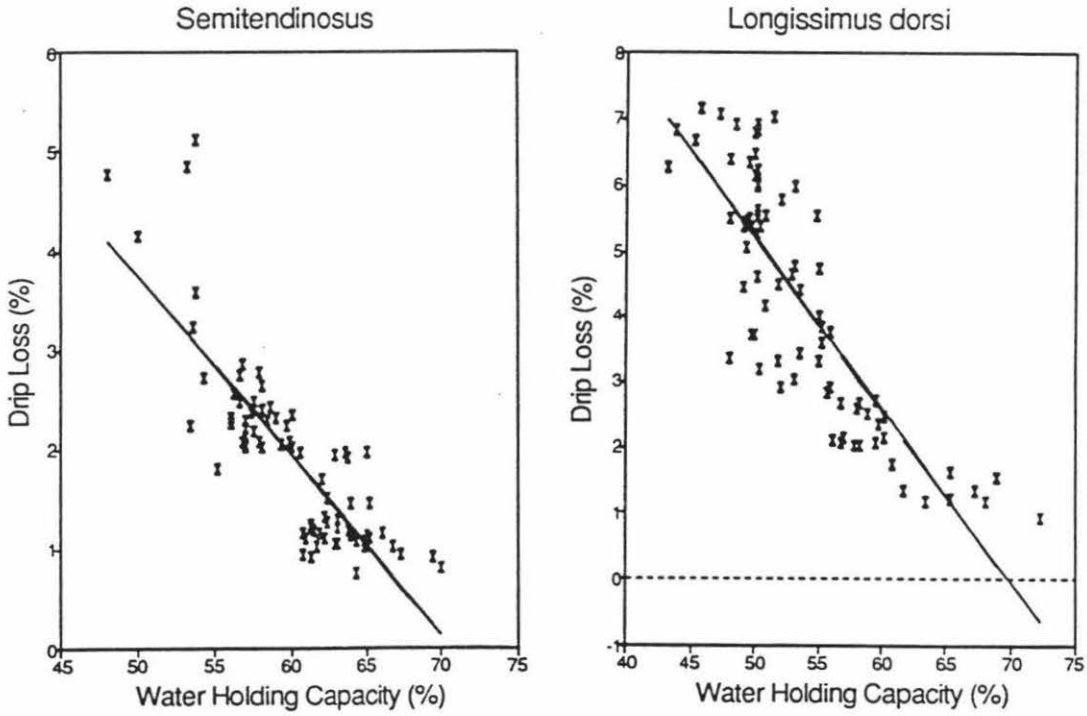


Figure 14. Relationship between drip loss and WHC of the ST and LD muscles at abattoir A.

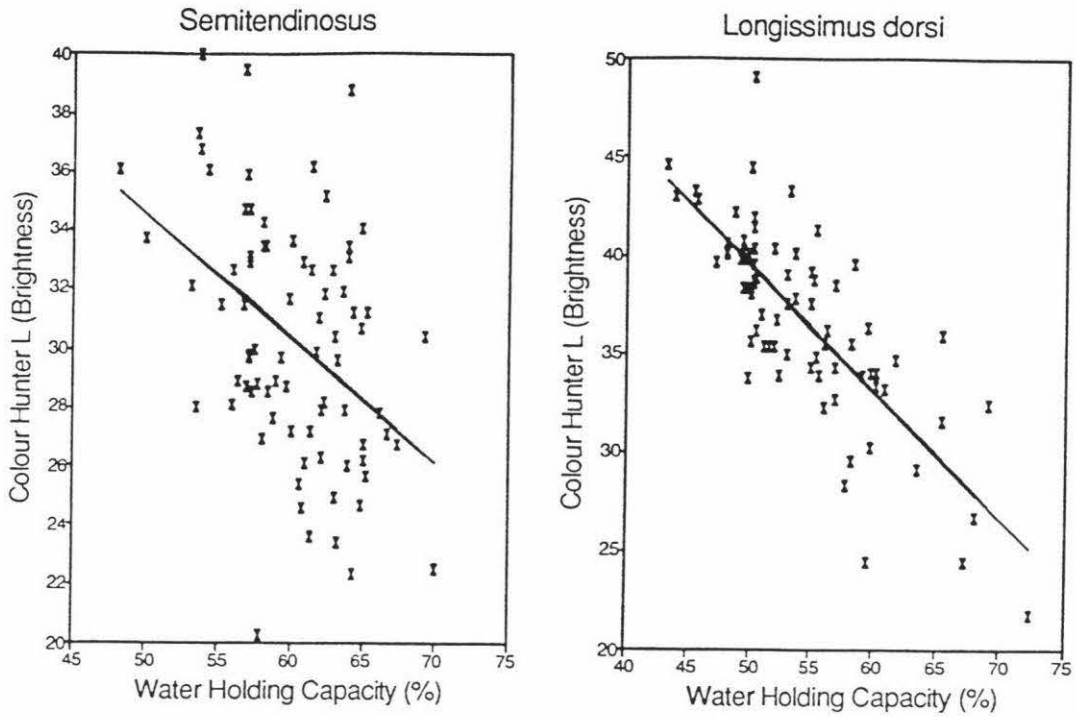


Figure 15. Relationship between colour L (brightness) and WHC of the ST and LD muscles at abattoir A.

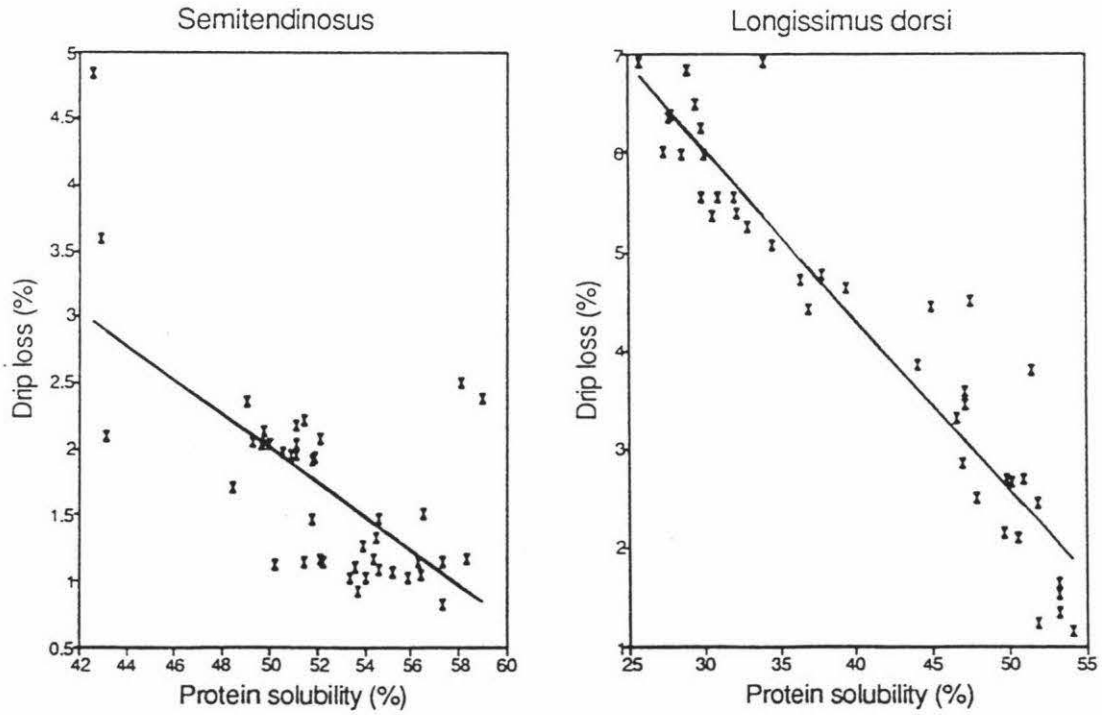


Figure 16. Relationship between drip loss and protein solubility of the ST and LD muscles at abattoir A.

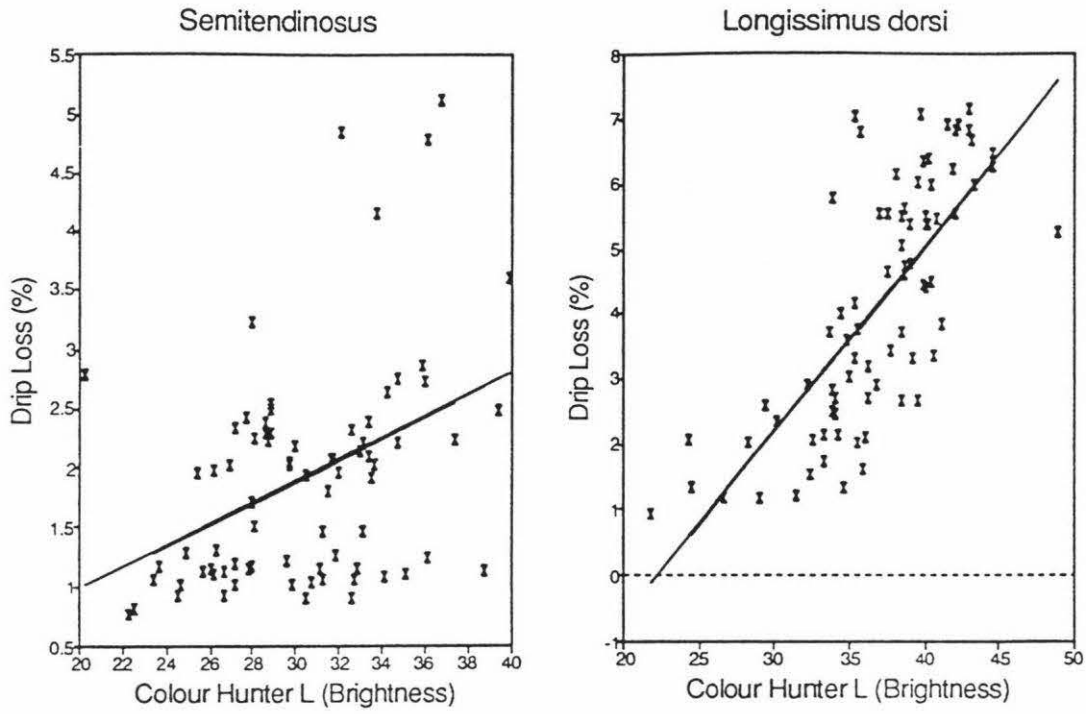


Figure 17. Relationship between drip loss and colour L (brightness) of the ST and LD muscles at abattoir A.

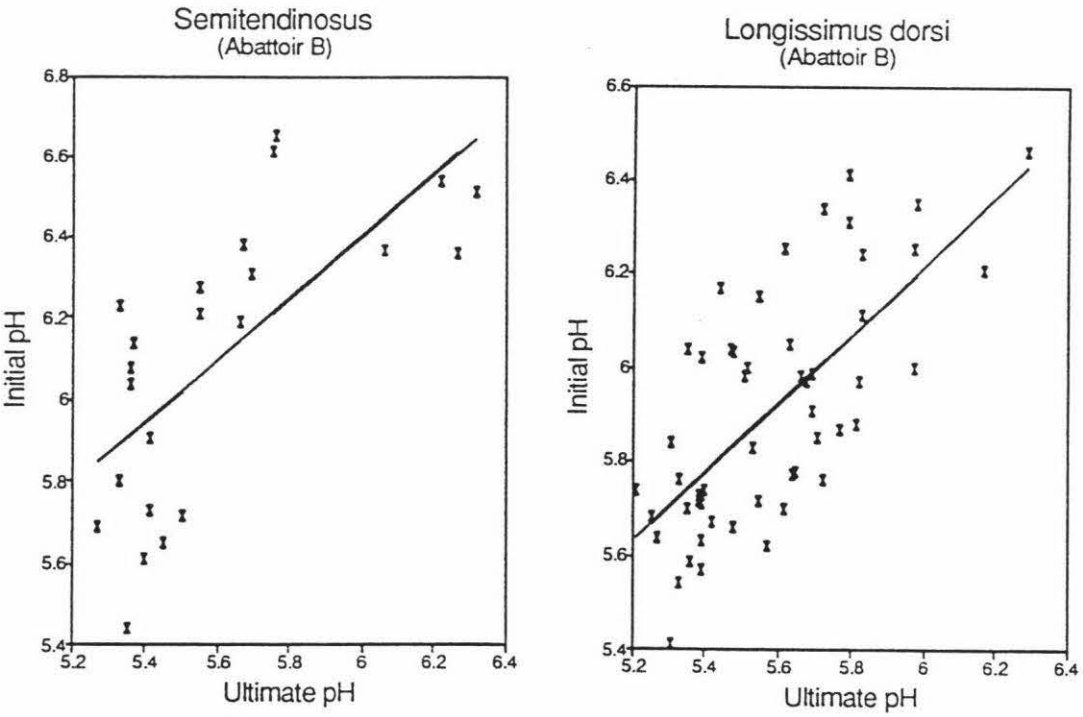


Figure 18. Relationship between pH_1 and pH_{24} of the ST and LD muscles at abattoir B.

Chapter V

DISCUSSION

The overall quality of pork from a meat plant can be judged in terms of the percentage of the carcasses identified as PSE or DFD. The overall results for this evaluation are presented in Table 2, and Figures 1a and 1b. Overall percentage of PSE_o and DFD_o of both muscle at two abattoirs were *57.2* % and *23.4* %, respectively. The mean values for PSE/MPSE were *48.57* % and *65.81* % for plants A and B respectively, and for DFD/MDFD were *24.83* % and *21.86* % for A and B respectively (shown in Figure 1c and 8b).

The results show that the different techniques used in this study to assess pork quality correlated well with each other. This concurs with a study done by Asghar and Yeates (1976) for Lamb. The high correlation between various functionality tests indicates that one or at most three (3) tests are necessary to classify carcasses into normal, MPSE, PSE, MDFD or DFD categories. Using multiple regression (shown in appendix B), the results were not useful because the various techniques used in this study to identify PSE and DFD were found to be highly interrelated with pH. Multiple regression could only provide meaningful information provided the independent variables used for the regression analysis were not significantly correlated with each another ($r = 0$).

The results were different for longissimus dorsi (LD) and semitendinosus (ST). The LD showed a higher percentage of PSE (*30.43%*) compared to the ST muscle,

whereas the ST has a higher percentage of DFD (*25.40%*) than LD. This may be caused by the difference in each muscle fibre. Muscle fibres type are divided into red and white fibre. Longissimus dorsi has higher number of white fibres (Ruusunen and Puolanne, 1988) while the Semitendinosus has a mixture (two-tonic) of red and white fibre types. PSE meat seems most likely to occur in muscle where there are more fast twitch glycolytic fibres, i.e., longissimus dorsi, than fast twitch oxidative fibres, i.e., semitendinosus, (Pearson and Young, 1989). The fast twitch oxidative muscle is more likely to become DFD because of its low glycogen levels at the time of slaughter (Beecher *et al.*, 1968). This may be a possible reason for the variability in results observed between the two muscles.

The overall incidence of PSE at two abattoirs was about *57 %*. This agrees with a preliminary study conducted by Massey University carried out in 1993. However, this cannot be regarded as conclusive evidence as the study was carried out at two abattoirs only and it is known that abattoir effects have a many influence on subsequent pork quality.

5.1 PRE-SLAUGHTER EFFECTS ON PORK QUALITY

The possible cause of factors contributory to the appearance of PSE and DFD meat, together with a better understanding of the problem, was investigated to determine the source of stressor. Information was gathered from the following: the pig producer, the transporter and the meat plant with the aim of determining the causes of both DFD and PSE at the respective meat plants.

Pigs that were slaughtered in abattoir A and B were either pellet or mash fed an amount based on liveweight once a day. They were transported in the double/single deck truck to the abattoir as a mixed group. The number in a load varied from 6 to 30 pigs with space allocations during transport varying from approximately 0.25 to 0.45 m^2 /pig. The transport journey was approximately 1 to 3 hours. On arrival the pigs were penned as one group in the lairage for an average of 22 hours in abattoir A and in abattoir B, the pigs were slaughtered after holding for 2 to 3.5 hours. They were stunned using an electrical stunner. The stunning time varied from 8 to 25 seconds depending on personnel performing the stunning (this occured on both plants). The pigs were not fed on the morning prior to slaughter, their last feed being 1 hour prior to transportation the previous day, a lapse of 27 to 28 hour from last feed to slaughter. The data collected considering pre-slaughter handling is shown in appendix A. Handling before, during and after slaughter may in part be responsible for the PSE and DFD problem. It is well known that pre-slaughter handling affects the incidence of PSE meat (Nielsen, 1981), also the influence of genotype and pre-slaughter handling could contribute to these results.

In this study, bruises and lacerations/scratches were found on the carcasses (shown in Table 4, Photo 3). Although no attempt was made to determine the age of bruises it is probable that the bruising and lacerations/scratches were caused during transportation and in the abattoir lairage area (overcrowding, mixing unfamiliar pigs and sexes). This can be seen in Photo 4. Bruising and associated skin damage (lacerations) are important sources of product loss. Losses occur due to the downgrading of bruised carcasses, loss of tissue trimmed from carcasses, condemnation of badly bruised carcasses as well as the

cost of labour associated with this extra processing. It is difficult to identify precisely how and when animals are bruised from farm to slaughter, but it could be expected that animals subjected to more handling will have more bruises.

Also in this study, females pigs seemed to be more prone to produce a PSE carcass, this is indicated by regressions of sex and pH_1. It was found that pH_1 has a significant ($p < 0.05$) correlation to sex (1 = entire male; 2 = female) with ($r = -0.3$). The regression analysis shows sex and slaughter time to be significant at $p < 0.001$ and $p < 0.05$, respectively. The statistical analyses among the 78 carcasses revealed no significant effects of weight and other pre-slaughter variables. Analysis of variance revealed a r^2 value of only 32 %. This indicates that initial pH was not greatly influenced by pre-slaughter treatment but that mixing the sexes as can influence the outcome of meat quality. Mixing can give rise to increased physical exertion because of the fighting and mounting activity. The physical exertion may deplete muscle glycogen stores and may lead to the production of DFD meat (Gallwey and Tarrant, 1979; Warris and Brown, 1985), and if the activity occurs immediately before slaughter, it may also increase the incidence of PSE meat (Wismer-Pedersen and Riemann, 1960). This suggests that there may be an advantage in handling the sexes differently after they leave the farm.

5.2 pH A TOOL TO ASSESS PORK QUALITY

pH is a measurement of the acidity or alkalinity of meat and it is used to evaluate both the PSE and DFD conditions. The pH measured at 45 minutes

after slaughter is used as an indication of the rate of acidification of the meat. A value below 6 is indicative of PSE pork. The ultimate pH measured after 24 hours post-mortem, is important in relation to stress-related pork quality defects. A value of greater than 6.2 is indicative of DFD pork. This is the value most meat research workers accept (Chizzolini *et al.*, 1993).

The initial pH value has often been used as one of the methods to assess meat quality. The results showed there to be a higher incidence of PSE in LD than in ST. As discussed above, the muscles with the higher initial pH values may be selectively active before slaughter. This could be the result from strenuous activity such as aggression or mounting.

When the initial pH was compared to the other parameters, the comparison showed a highly significant correlation coefficient ($p < 0.001$). This is shown in Table 11. Figures 9 and 17 shows the correlation of initial pH and final pH. This correlation suggests that initial pH can be a useful method in determining pork quality, although the results (see Table 5b and 6b) indicated that initial pH measurements understimated the true incidence of PSE compared with the categorisation based on the ultimate pH. This result indicated that initial pH is only effective in detecting carcasses which have rapid post-mortem glycolysis but does not identify carcasses that appear non-PSE at 45 minutes but which may subsequently develop PSE after 24 hours.

These observation showed that initial pH does not allow a precise estimate of the final outcome of meat characteristics. It confirms the claims of Smulders *et al.*(1983), Severini *et al.* (1984), Barton-Gade (1980 & 1987), Bendall and Swatland

(1988) that initial pH only provides a rough estimate of batches of carcasses rather than an estimate of the meat quality in single carcasses. This techniques was not too reliable in determining the meat quality because other factors may influence the result of the measurements like the convenience of the position of collection and the conditions prevailing in the abattoir (time and temperature).

As shown in Table 6, the percentages of PSE and normal meat increases whereas the DFD meat lessen if compared to the value in initial pH. This suggests that ultimate pH is a useful method in detecting the precise percentage of DFD and late PSE meat (Chadwick and Kempster, 1983).

The ultimate pH has marked influence on the physical properties of meat such as colour and texture. This can be seen in the high correlation with this parameter and the other parameters ($p < 0.001$) as shown in Table 11. This study confirms the observation made by Warriss (1982). The results indicate that the ultimate pH value of pigmeat can give a good indication of the quality of meat and is closely related to the (physical and psychological) stress to which the pig has been subjected. The stored energy (glycogen) is the important indicator in fatigued pigs. Since pH is a measure of acidity, the ultimate pH value indicates the level of stress of the pig before slaughter and thus the final quality of meat. This method is more accurate in quality assessment than the initial pH. However, this method is time consuming and complicated when compared with measurement of initial pH.

Measuring the initial pH gives an initial indication of the percentage of PSE meat whereas ultimate pH can give definite percentage of DFD meat and late

PSE. Therefore, combining both techniques will give a precise picture of meat quality.

In these results, it can also be observed that the incidence of DFD, normal and PSE pork were different for the two plants. The variation between these plants can probably be accounted for by the different pig suppliers (presence of PSS or halothane genes in the herd) and by differences in on-farm, transport, pre-slaughter and post-slaughter management practices.

5.3 WHC A TOOL TO ASSESS PORK QUALITY

Water holding capacity (WHC) is the ability of muscles to retain fluid. This is important in meat processing because WHC not only affects the pork quality but also influences the colour, taste, tenderness and yield of processed meat products (Hamm, 1960).

The correlation between ultimate pH (Figure 10) was assessed using Pearson correlation coefficient. The analysis showed that WHC had a high correlation with pH ($r = 0.81$ *ST*; $r = 0.92$ *LD*). The study confirms the work of Hamm (1960) in that as the ultimate pH value increases the WHC increases.

The relationship between WHC and percent drip loss nearly correlated perfectly ($r = -0.83$ ST; $r = -0.85$ LD). This is illustrated in Figure 14. This result indicates that WHC has a linear relationship with drip loss of meat. Hamm (1970)

suggested that changes in drip loss are the result of changes in WHC of myosin and actomyosin.

WHC was also negatively correlated to the colour hunter L value (r = *-0.43* ST; r = *-0.78* LD). However, the ST correlation was low and may be because of the two-toning colour characteristics of ST muscle (Beecher *et al.*, 1965). This is shown in Figure 15. In this result, the low WHC of meat corresponds well with higher visual reflectance value. As meat undergoes post-mortem changes muscle may initially take up water by osmosis due to glycogenolysis. In PSE meat, the influx of fluid is reversed so that the muscle fibres lose much of their fluid to the intercellular space which eventually result in a high reflectance value and a low WHC value.

The relationship to protein solubility was also assessed. It was found that correlation existed between WHC and protein solubility (r = *0.57 ST;* r = *0.82 LD*). This confirms the result of Bendall and Wismer-Pedersen (1962) that as protein denaturation increase so the WHC decreased. This positive relationship between WHC and protein solubility indicates that WHC is a sensitive indicator of variations in the change and structure of muscle protein (Hamm, 1970 & 1975). Myofibrillar protein being the main water holder of meat, any changes in this protein may affect the water holding capacity of meat (Penny, 1969).

As this functional test was highly correlated with some other simple measurement techniques it should be used to reinforce the reliability of other methods in determining meat quality.

5.4 DRIP LOSS A MEASURE OF PORK QUALITY

Drip loss is the loss of fluid during storage of meat. Drip loss has been used as a technique to evaluate the extent of PSE in meat. However, this technique did not prove to be satisfactory as other factors such as muscle (cold) shortening can increase drip loss (Honikel et al., 1986) which suggests that normal muscle might be incorrectly classified as MPSE or PSE.

The results of this study showed that the mean drip loss of PSE meat was higher in ST (*5.25*) than in LD (*4.29*). But on average, drip loss reading were about *2* % in ST and *4* % in LD in all samples and varied considerably from carcass to carcass (*0.76 - 5.12* for ST and *0.96 -7.17* for LD) regardless of whether the carcasses were PSE or DFD. This high variability in drip loss value may be caused by faulty chilling rates of the sample and / or by muscle (cold) shortening (Honikel et al., 1986).

Drip loss is greatly influenced by pH. In this study drip loss was highly correlated with pH_{24} (r = *-0.74* ST; r = *-0.84* LD) and pH_1 (r = *-0.65* ST; r = *-0.72* LD). Figure 11 shows the relationship of drip loss to final pH. It is known that pH fall is one factor that causes shrinkage of myofibrillar proteins (Offer and Knight, 1989). The pH fall reduces the negative charge on the thick and thin filaments and hence, reduces the repulsive forces between them causing the filament lattice to shrink to a new equilibrium where the reduced electrostatic pressure is balanced by the reduced restraint from transverse structural elements. On this basis we would expect that in DFD meat with a high final pH (> 6.2) the lattice would not shrink so much and that's why drip loss is

diminished in the DFD state. In the PSE state drip loss is increased. PSE muscle results when the pH of the meat is low (< 6.0) while the carcass is still warm (Wismer-Pedersen, 1959). This combination of pH and temperature causes the denaturation of several proteins. Although the denaturation of sarcoplasmic proteins may contribute to the increase in light scattering power, the main protein that is denatured is myosin (myofibrillar protein).

The study indicated a relationship of protein solubility and drip loss ($r = -0.65$ *ST*; $r = -0.95$ *LD*). This showed that high drip loss can also be attributed to protein denaturation (Honikel and Kim, 1985). However, Hamm (1982) suggested that increased drip loss is not necessarily the result of changes in meat protein solubility but is also caused by the contraction of muscle at low temperature (cold shortening) or at elevated temperatures (rigour shortening) during storage.

There has been some doubt about the importance of drip loss in the overall efficiency of meat production up to the point of consumption. It can be argued that reduced drip loss is of value to the meat industry but not to the consumer if the additional water retained in cutting and processing is subsequently lost during cooking. However, there is now some evidence that high drip loss is associated with higher cooking losses such that the consumer might benefit from the reduced PSE incidence (Malmfors and Nilsson, 1977).

Since drip losses are directly related to economic losses for the slaughter and processing industry, their importance in meat quality evaluation is obvious. However, drip loss can not be determined very quickly and this is clearly a

disadvantage.

5.5 COLOUR A TOOL FOR ASSESSING PORK QUALITY

Colour is one of the most important meat quality attributes because of the direct influence it has on the consumer. Consumers usually judge the quality, especially the freshness, of meat from its appearance, particularly colour.

A correct evaluation and understanding of colour measurements is rather difficult because no international standards exist (for PSE and DFD identification) for the instrument adopted in this study. Murray and Jones (1988) have published data on Longissimus dorsi colour obtained with a Minolta Chromameter II at 24 hours post-mortem and have related it to visual pork quality standards (similar to that shown in Table 1). In their work, PSE meat was associated with high L and B values. It can be noted that as meat moves towards the dark and dry character, all values decrease and it can be observed that the B value decreases most. One remarkable observation in this study was that meat, appearing to be PSE was not simply paler, more wet and soft than normal but more often, the meat also showed a yellow tint which when instrumentally measured, led to a shift in the balance between *a* and *b* value as a result of a relative increase of the latter. Nevertheless, in this study, its shows that all the attributes examined had good correlation with hunter LAB.

Categorisation of pork by colour into PSE, normal, and DFD showed a marked difference between muscle with *65.39* % of LD being categorised as PSE whereas

only *11.54* % of ST muscles were considered PSE. The marked difference of this result may be caused by the ST muscle. The ST has a red and white fibre content which will influence the result of colour brightness of meat (Beecher *et al.*, 1965).

Colour L correlated better with overall visual colour scores ($r = 0.62$ ST; $r = 0.84$ LD). The PSE pork samples showed high values for brightness (colour L) and yellowness (colour B) while the DFD pork samples showed low values for brightness and yellowness. The visual quality evaluation, based on the characteristics' of moisture (wetness), colour and texture, gave additional affirmative information. The mean of overall score (*1.76* ST and *2.97* LD), and colour L (*30.28* ST and *36.88* LD) and colour B (*6.62* ST and *6.92* LD) were almost on each category. This shows that the tristimulus hunter LAB and visual evaluation can be used hand in hand to increase the reliability.

The L (lightness) and B (yellowness) parameter of the hunter LAB was significantly ($p < 0.001$) correlated with the pH in both muscles (Table 11 and Figure 12). This confirms the observation of Barbut (1993) who suggested that the apparent pale colour in turkey meat is associated with lower pH. However, the colour values A (redness) did not correlate with the pH in LD but correlated ($p < 0.001$) in ST.

For WHC, it was found that hunter L and B were correlated ($r = -0.43$ in ST and $r = -0.78$ in LD). This results contradicts the suggestion of Kauffman et al. (1992) that much pork with low WHC can be classified as normal. It is widely known that colour lightness increases as the WHC decreases. Muscle with a low water holding capacity reflects more light and as a result the muscle is perceived to be

lighter in colour. For muscle with high WHC light is being trapped as a result the muscle is observed to be opaque in colour (MacDougall, 1982). The close relationship between WHC and colour L (brightness), when comparing normal with pale watery pork may, depend less on the direct influence of water holding capacity on colour brightness than on a change in the myoglobin under PSE condition.

These outcomes (in relation to pH and colour) are in good agreement with the study of Herring *et al.*(1971), where final pH and colour (ST and LD) were found to be significantly ($p < 0.001$) related to water holding capacity.

Drip loss was correlated ($p < 0.001$) with L and B parameter indicating that as drip loss increases the colour L and B values also increased (illustrated in Figure 16). Also, the protein solubility was correlated ($p < 0.05$) in L and B parameter. This is most probably due to less functional proteins in the PSE meat (i.e., possibly due to some denaturation during the fast pH decline and/or approaching the isoelectric point). As Bendall and Swatland suggested, fast pH decline will result in protein denaturation. This study supports this fact leading to lighter meat which showed low pH and higher drip loss.

Warris and Brown (1987) showed that the increased light scattering in PSE meat was mainly due to the denaturation of sarcoplasmic proteins, a result which is confirmed by the findings of Von Seth *et al.* (1991) who showed that water soluble proteins accounted for 66% of the variation of colour in pig longissimus dorsi. The causal relationship between pH and pork paleness confirms that protein denaturation contributes substantially to the increased paleness of severe

PSE pork. Other possible sources of light scattering have been ignored and even the molecular basis of the development of normal paleness in pork is poorly known. PSE pork is pale firstly because of changes in the structure of the myofibrillar protein and secondly the precipitation of soluble proteins on them, produced by a rapid fall in pH while the carcass is still warm which cause the myofibrillar proteins to scatter more light.

The effect of colour on economic value is difficult to quantify due to the subjective nature of consumer preference for this trait. Unlike drip loss which has a direct effect on carcass yield after cutting, processing and cooking. Although it is the ultimate degree of paleness that affects the economic value of pork, the manner in which paleness develops post-mortem is important in placing confidence limits on predictions made soon after slaughter. However, another problem when using colour of the fresh sample as a measure of quality is that it is affected by air, light, temperature and humidity, thereby reducing its reliability as an indicator of ultimate pork quality. In visual assessments problems can occur due to the complexicity in the human response (Bendall and Swatland, 1988). The visual assessment of pork quality is not acceptable to the pork industry because it lacks accuracy (humans vary on a daily basis and become fatigued, machines do not).

5.6 PROTEIN SOLUBILITY A TOOL FOR ASSESSING PORK QUALITY

Protein solubility is the ability of the protein to be dissolved in water or salt solutions. Proteins in the meat are greatly affected by changes in pH and

temperature (Offer and Knight, 1988). These factors may lead to alteration of protein structure (denaturation) characterized by loss or decrease of solubility.

The results of this study for protein solubility are shown in Table 9. In this study 42 samples were examined for protein solubility. Some samples were discarded because these were examined after 48 hours. Also, problems were encountered in storage temperatures of the samples. It was presumed that such samples had undergone severe denaturation and these results were also discarded.

The results showed that protein solubility correlates with the pH ($r = 0.49$ ST; $r = 0.78$ LD in pH_1; and ST $r = 0.57$ and LD $r = 0.77$ in pH_{24}). Figure 13 shows the correlation of protein solubility to final pH. These results are in accordance with the work of Bendall and Wismer-Pedersen (1962) who showed that protein solubility correlate well with pH. The pH of the meat has a significant effect on the protein solubility ($p < 0.001$). The significant effects of pH on the solubility of protein are in agreement with previous work showing that both sarcoplasmic and myofibrillar proteins are denatured in PSE meat (Sayre and Briskey, 1963). As the pH increased so the amount of soluble protein also increased. In PSE meat the amount of soluble protein was low. A possible cause for the decreased amount of soluble protein might be that some denaturation occurred (Penny, 1969), thus decreasing the solubility of protein. While in DFD meat (with high pH value) the protein solubility was usually high.

The development of PSE meat is usually associated with rapid anaerobic glycolysis and low initial pH. Such conditions cause denaturation of proteins, with ensuing changes in gross appearance of the muscle, and loss of colour,

water holding capacity and high drip loss. This study correlates with the colour (Hunter L and B), WHC and drip loss. This further confirms the results of Briskey (1964) that protein denaturation seriously affects the gross appearance of meat.

The correlation between soluble proteins and other parameters were high enough to motivate measurements. However, the protein solubility technique was not as effective in differentiating between MDFD and DFD pork but it could be used to differentiate, PSE, MPSE and normal pigmeat.

Chapter VI

CONCLUSION

PSE and DFD are common and continuing problems encountered in pig meat plants. Carcasses showing these characteristics can often not be identified until at least 24 hours' post-mortem. By that time, the pork may be en route to its final destination. A system that can predict the occurrence of PSE within an hour of slaughter would allow early separation and therefore more efficient handling of the different types of carcasses. The pH_1 is the only technique that classifies carcasses with a degree of accuracy on the slaughter floor. The problems in classifying PSE suggest the need for standardized techniques in measuring porcine meat quality. Further research to identify the specific factors responsible for the development of PSE must be done. The pH_{24}, WHC, drip loss, colour hunter LAB and protein solubilities are good techniques in identifying meat quality and they correlate well with pH. But to carry out these procedure is time consuming.

This study showed that the pork supply from two abattoirs located in Manawatu region (New Zealand) generated *41.98 to 72.41 % PSEo* and *10.65 to 36.05 % DFDo*. It is important to remember that this was an evaluation conducted over the three seasons (winter = early August to early September; spring = late September to late October; summer = mid December to mid January) and that no attempt was made to determine the reasons for the variations observed. It was known that several factors can effect pork quality, including genetics,

nutrition, time of year (temperature), handling on (farm, transportation and abattoir), method of slaughtering (stunning techniques), and chilling of the carcasses. If the survey were repeated, it is expected that different results might be achieved. However, these results give some idea of current pork quality. Thus, they can be used as an indicator of what the industry is currently producing in the Manawatu/Levin area of the country.

In relation to the incidence of PSE and DFD, the data from this study (N = 144) suggests similarities with those in Australia (Trout *et al.*, 1991). Generally, it is believed that the presence of the stress-sensitive gene is high in the New Zealand pig herd, thus the variation in the incidence of these meat quality problems probably reflects the differences in on-farm, transport, pre-slaughter and slaughter handling practices.

It is concluded from this preliminary study that there is a sizeable problem in pigmeat quality in the Manawatu region (New Zealand).

Chapter VII

RECOMMENDATION

What should the New Zealand pork industry do to guarantee that the pork it is producing is not only lean but also consistent in quality.

Here are some recommendations;

1. Guidelines should be established to insure acceptable production practices, management and welfare procedures should be instituted from farm through to the abattoir.

Common *mistakes* observed in abattoir handling were as follows;

a. overcrowding

b. excessive use of electric goads

c. mixing of different groups of pigs

d. mixing of different sexes

e. mishandling during unloading

f. longer than necessary stunning time (untrained stunner)

2. Procedures for *data capture* and *evaluation* of pork quality should be instituted. This should include the carcass weight, leanness and quality (pH, colour, and drip loss). This data should be recorded properly, stored in the computer and shared with farmers so that appropriate steps can be made to improve breeding stocks and to eliminate genetic problems that cause variation in meat quality.

3. More research must be done *with the cooperation* of farmers, abattoir owner and research organization (private, university, industry and government) into the pre-slaughter handling and post-slaughter processing of pigs. Research on determining the genotype (PSS gene) of pigs is highly recommended because it is believed that this gene, which causes pork quality (PSE) problems, is present in the New Zealand pig herd.

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APPENDIX A

Appendix a.1 Pre-slaughter (*Abattoir*) data at *abattoir A*.

Sample No.	Date slaughtered	Name of Farmer	Sex	Carcass weight	Bruises	Wounds
1	03-08-93	B	F	65.00	Right side lower shoulder/ Two	None
2	03-08-93	B	M	68.00	On the loin region (loin)/ One	None
3	03-08-93	B	M	67.50	On the loin region (Loin - deep seated)/ One	Scratches on the ears/ Many
4	03-08-93	B	M	65.50	On the loin, near forehead, right shoulder/ Many	Scratches on the abdominal, ear, & rump region/ Many
5	03-08-93	B	M	69.00	Rump region/ Three	Scratches on the rump & ears/ Many
6	03-08-93	B	M	70.00	On the lower left side shoulder, lower region of ears/ Many	Scratches on the abdominal region/ Many
7	10-08-93	B	M	65.50	On the left side of rump & loin region/ Many	Scratches on the abdominal region/ Many
8	10-08-93	B	F	63.00	Small hemorrhages on the loin region/ Few	None
9	10-08-93	B	M	68.00	On the right side of rump region/ Two	Scratches on the shoulder/ Few
10	10-08-93	B	M	68.50	On the rump & loin region/ Many	Scratches on the rump & shoulder/ Few
11	10-08-93	B	M	67.00	On the upper loin region/ One	None
12	10-08-93	B	M	66.00	On the loin region/ One	None
13	17-08-93	A	F	65.00	On the loin region/ One	None
14	17-08-93	A	F	64.50	On the right shoulder & rump region/ Two	None
15	17-08-93	A	F	67.00	None	Scratches on the rump region/ Few
16	17-08-93	A	F	65.50	On the lower left rump region/ One	None
17	17-08-93	A	M	68.00	On the rump & loin region/ Many	Scratches on the shoulder/ Many
18	17-08-93	A	M	67.50	On the lower loin region/ One	Scratches on the shoulder/ Few
19	24-08-93	C	M	74.60	On the loin of the head/ One	Scratches on the shoulder & rump region/ Many
20	24-08-93	C	F	76.20	On the rump & loin region/ Three	None

21	24-08-93	C	F	80.00	On the rump & loin region/ Four	None
22	24-08-93	C	M	77.60	On the left shoulder region/ One	Scratches on the shoulder & rump region/ Many
23	24-08-93	C	M	71.80	On the loin region/ Two	Scratches on the shoulder/ Few
24	24-08-93	C	F	61.60	On the left loin region/ One	Scratches on the rump region/ Few
25	31-08-93	A	M	73.60	On the lower front leg/ One (small)	Scratches on the shoulder/ Few
26	31-08-93	A	F	61.40	On the loin and rump region/ Many	Scratches on the loin region/ Many
27	31-08-93	A	F	76.00	None	Scratches on the lower shoulder/ Few
28	31-08-93	A	M	73.00	On the rump and shoulder region/ Many	Scratches all over the body/ Many (60%)
29	31-08-93	A	F	76.40	On the right loin region/ Two (small)	None
30	31-08-93	A	F	72.60	On the loin and rump region/ Few	None
31	07-09-93	C	F	69.80	None	None
32	07-09-93	C	F	73.60	Hemorrhages on the upper ST/ Many	None
33	07-09-93	C	F	78.80	Hemorrhages on the ST and LD/ Few	Scratches on the upper loin/ Few
34	07-09-93	C	F	68.80	On the loin and rump/ Few	None
35	07-09-93	C	F	70.40	None	Scratches on side of the abdomen/ Few
36	07-09-93	C	M	67.00	None	None
37	28-09-93	B	F	68.20	Hemorrhages on the loin/ Few	Scratches on the shoulder/ Few
38	28-09-93	B	M	62.20	On the shoulder and loin region/ Few	None
39	28-09-93	B	M	70.40	None	None
40	28-09-93	B	F	69.20	On the loin region/ Few	None
41	28-09-93	B	F	69.80	Loin with petechial hemorrhages/ Few	None
42	28-09-93	B	M	71.60	None	Scratches on the shoulder/ Few
43	05-10-93	C	F	80.00	On the left rump region/ Two	Scratches on the shoulder, loin & belly region/ Many

44	05-10-93	C	F	72.20	On the lower right rump region/ One	None
45	05-10-93	C	M	72.60	On the lower left rump region/ One	Scratches on the shoulder/ Few
46	05-10-93	C	M	72.50	On the rump region/ Five	Scratches on the shoulder/ Many
47	05-10-93	C	F	73.40	On the rump region/ Two	None
48	05-10-93	C	M	66.60	On the loin and rump region/ Three	None
49	12-10-93	A	M	76.40	None	Scratches on the belly/ Few
50	12-10-93	A	M	69.60	None	None
51	12-10-93	A	M	71.00	On the left rump region/ One	Scratches on the shoulder/ Many
52	12-10-93	A	M	78.60	None	Scratches on the shoulder/ Many
53	12-10-93	A	M	67.80	On the right rump region/ Two	Scratches on the shoulder/ Few
54	12-10-93	A	F	66.80	Hemorrhages on the LD/ Few	None
55	19-10-93	B	F	67.20	On the loin/ Few (small)	Scratches on the shoulder/ Few
56	19-10-93	B	F	70.00	On the lower loin/ Few	Scratches on the belly and upper left hindleg/ Many
57	19-10-93	B	F	71.80	On the lower loin/ Few	None
58	19-10-93	B	M	70.40	On the left rump/ One	None
59	19-10-93	B	M	62.40	Hemorrhages on ST/ Few	Scratches on the belly & head/ Few
60	19-10-93	B	M	66.80	None	Scratches on belly & head/ Few
61	26-10-93	C	M	76.00	On the right rump/ Four	Scratches on the shoulder/ Many
62	26-10-93	C	F	76.60	Hemorrhages in ST/ Few	Scratches on the shoulder/ Few
63	26-10-93	C	F	73.20	On the rump and loin/ Four	Scratches on the shoulder/ Few
64	26-10-93	C	M	69.80	None	Scratches on the shoulder/ Few
65	26-10-93	C	F	72.60	None	Scratches on the shoulder/ Few
66	26-10-93	C	F	71.80	None	Scratches on the shoulder/ Few
67	21-12-93	A	M	68.60	None	Scratches on the neck region/ Few

68	21-12-93	A	M	67.60	Hemorrhages on the loin/ Many	None
69	21-12-93	A	F	64.20	On the shoulder/ three	Scratches on the shoulder/ Few
70	21-12-93	A	M	61.40	On the upper loin/ Two	None
71	21-12-93	A	F	67.60	On the right rump/ Few	None
72	21-12-93	A	M	58.40	Hemorrhages on the loin/ Few	None
73	11-01-93	B	F	60.40	None	Scratches on the shoulder/ Few
74	11-01-93	B	F	57.00	On the rump & loin/ Many	None
75	11-01-93	B	F	65.60	On the loin/ Few	None
76	11-01-93	B	F	68.00	On the right shoulder/ One (big)	Scratches on the shoulder/ Many
77	11-01-93	B	M	66.60	None	Scratches on the shoulder/ Many
78	11-01-93	B	M	62.80	On the left upper rump/ Two	None

* = average stunning time was 10 seconds F = Female M = Male

Appendix a.2 Pre-slaughter (*Abattoir*) data at *abattoir B*[a].

Sample No.	Date slaughtered	Name of Farmer	Sex	Carcass weight	Bruises	Wounds
1	02-03-93	E	F	64.00	None	None
2	02-03-93	E	M	66.00	On the rump region/ Two	None
3	02-03-93	E	M	67.00	On the loin/ three	None
4	02-03-93	E	M	64.00	On the neck/ Many	Scratches on head & neck/ Many
5	02-03-93	E	F	67.00	On the abdominal/ Few	Scratches on abdominal/ Many
6	02-03-93	E	F	69.00	On the right shoulder/ One	Scratches on shoulder/ Many
7	02-03-93	E	M	62.00	On the left rump/ Two	None
8	02-03-93	E	F	60.00	On the loin/ One	None
9	02-03-93	E	F	57.00	On the shoulder/ Two	Scratches on the shoulder / Few
10	02-03-93	E	M	60.00	On the loin/ Three	Scratches on the abdomen/ Few
11	02-03-93	E	F	61.00	On the loin/ One	None

12	02-03-93	E	M	64.00	On the shoulder/ One	None
13	02-03-93	E	M	64.00	None	None
14	02-03-93	E	F	71.00	None	None
15	02-03-93	E	F	61.00	On the rump region/ One	Scratches on the rump region/ Few
16	02-03-93	E	M	60.00	None	None
17	02-03-93	E	F	62.00	On the rump region/ Two	Scratches on the rump/ Many
18	02-03-93	E	F	65.00	On the loin/ One	Scratches on the shoulder/ Few
19	02-03-93	E	M	68.00	On the forehead/ One	None
20	02-03-93	E	M	69.00	None	None
21	02-03-93	E	F	67.00	On the rump/ Two	None
22	02-03-93	E	F	68.00	On the shoulder/ One	Scratches on the shoulder/ Few
23	02-03-93	E	M	65.00	On the loin/ Two	Scratches on the shoulder/ Few
24	02-03-93	E	M	63.00	None	None
25	02-03-93	E	M	65.00	On the shoulder/ One	None
26	02-03-93	E	M	65.00	On the rump/ Two	Scratches on rump/ Few
27	02-03-93	E	F	69.00	One the loin/ One	None
28	02-03-93	E	F	89.00	None	None
29	02-03-93	E	F	64.00	On the rump/ One	None
30	02-03-93	E	M	58.00	On the shoulder/ One	None
31	21-09-93	A	F	40.60	None	None
32	21-09-93	A	F	43.40	None	None
33	21-09-93	A	M	38.20	On the loin/ Three	Scratches on the loin/ Many
34	21-09-93	A	F	68.00	On the left rump/ One	None
35	21-09-93	A	F	65.00	None	None
36	21-09-93	A	M	63.00	None	None
37	21-09-93	C	F	65.00	On the shoulder/ Two	Scratches on the shoulder/ Few
38	21-09-93	C	M	65.00	On the loin/ One	None
39	21-09-93	C	M	69.00	On the shoulder/ Two	None
40	21-09-93	C	F	89.00	On the rump/ One	Scratches on the shoulder/ Few
41	21-09-93	C	F	64.00	None	None

42	21-09-93	C	M	58.00	None	None
43	21-09-93	D	F	80.00	On the loin/ One	Scratches on the shoulder/ Few
44	21-09-93	D	F	72.20	On the rump/ Two	None
45	21-09-93	D	M	72.60	On the shoulder/ One	Scratches on the shoulder/ Few
46	21-09-93	D	M	72.50	On the rump/ Three	Scratches on the shoulder/ Few
47	21-09-93	D	F	73.40	On the loin/ Two	None
48	21-09-93	D	M	66.60	None	None
49	21-09-93	B	M	76.40	None	Scratches on the abdomen/ Few
50	21-09-93	B	M	69.60	On the loin/ One	None
51	21-09-93	B	M	71.00	On the rump/ Two	Scratches on the shoulder/ Few
52	21-09-93	B	M	78.60	None	Scratches on the shoulder/ Few
53	21-09-93	B	M	67.80	On the rump/ One	None
54	21-09-93	B	F	66.80	None	None
55	21-09-93	B	F	67.20	On the loin/ Two	None
56	21-09-93	B	F	70.00	On the loin/ One	None
57	21-09-93	B	F	71.80	On the lower loin/ Few	None
58	21-09-93	B	M	70.40	On the left rump/ One	None
59	21-09-93	B	M	62.40	None	Scratches on the shoulder/ Few
60	21-09-93	B	M	66.80	None	Scratches on the abdomen/ Few
61	21-09-93	C	M	76.00	On the rump/ One	Scratches on the shoulder/ Many
62	21-09-93	C	F	76.60	On the shoulder/ One	Scratches on the shoulder/ Few
63	21-09-93	C	F	73.20	On the loin/ Three	Scratches on the shoulder/ Few
64	21-09-93	C	M	69.80	None	None
65	21-09-93	C	F	72.60	None	Scratches on the shoulder/ Few
66	21-09-93	C	F	71.80	None	None

* = average stunning time was 10 seconds F = Female M = Male

Appendix a.3 Pre-slaughter (*Farms*) data at *abattoir A.*

Name of Farmer	Live weight (Kg)	Breed	Age Range (weeks)	Rearing Method	Kinds of Feeds	Last Feeding Time
A	85-95	L/LW/D	20-24	pens	mash	before loading
B	80-90	L/LW	20-26	pens	mash	6:00 am
C	80-90	L/LW/D	22-24	pens	meal	8:00 am

L = landrace; LW = large white; D = Duroc.

Appendix a.4 Pre-slaughter (*Farms*) data at *abattoir B.*

Name of Farmer	Live weight (Kg)	Breed	Age Range (weeks)	Rearing Method	Kinds of Feeds	Last Feeding Time
A	50-80	L/LW	20-26	pens	mash	bd
B	50-80	L/LW	20-26	pens	mash	bd
C	50-60	*	16-20	pens	mash	bd
D	50-60	*	16-20	pens	mash	bd
E	80-90	L/LW/D	20-26	pens	mash	6:00 am

L = landrace; LW = large white; D = Duroc; bd = before delivery.

Appendix a.5 Pre-slaughter (*Transportation*) data at *abattoir A.*

Date Transported	Name of Farmer	Trucking Company	Type of vehicle	Number of pig (Batch)	Distance (Km)	Weather Condition
02-08-93	A	Pedley	Truck/Single	20-30	20	Cloud amount 8 - moderate rain
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
09-08-93	A	Pedley	Truck/Single	20-30	20	Cloud amount 8
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
16-08-93	A	Pedley	Truck/Single	20-30	20	Blue sky - partly cloudy
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
23-08-93	A	Pedley	Truck/Single	20-30	20	Partly cloudy
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
30-08-93	A	Pedley	Truck/Single	20-30	20	Blue sky
	B	Pedley	Truck/Double	80-100	8	

	C	Pedley	Truck/Single	30-35	23	
06-09-93	A	Pedley	Truck/Single	20-30	20	Cloudy
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
27-09-93	A	Pedley	Truck/SIngle	20-30	20	Showers of rain - moderate rain
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
04-10-93	A	Pedley	Truck/Single	20-30	20	Cloudy - shower of rain - heavy rain
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
11-10-93	A	Pedley	Truck/Single	20-30	20	Cloud amount 8 - shower of rain - heavy rain
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
18-10-93	A	Pedley	Truck/Single	20-30	20	Cloud amount 8
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
25-10-93	A	Pedley	Truck/Single	20-30	20	Cloudy - Blue sky
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
20-12-93	A	Pedley	Truck/Single	20-30	20	Partly cloudy
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	
10-01-94	A	Pedley	Truck/Single	20-30	20	Cloud amount 5-7 - Cloud amount 1-4
	B	Pedley	Truck/Double	80-100	8	
	C	Pedley	Truck/Single	30-35	23	

Appendix a.6 Pre-slaughter (*Transportation*) data at *abattoir B*.

Date Transported	Name of Farmer	Trucking Company	Type of vehicle	Number of pig (Batch)	Distance (Km)	Weather Condition
02-03-93	E	*	Truck/Double	70-80		
21-09-93	A	Rider trans	Truck/Double	230		
	B	Rider trans	Truck/Double	160		
	C	Rider trans	Truck/Double	240		
	D	Rider trans	Truck/Double	230		

Appendix a.7 Pre-slaughter (*Loading and Unloading*) data at *abattoir A.*

NF	LOADING					UNLOADING					TT (min)
	TL (min)	RS ( )	NW	EU	DT (am)	AT (am)	TU (min)	RS ( )	NW	EU	
A	15	45	2	EG	09:00-10:00	09:00-10:15	15-20	15-20	2	EG	20
B	45-60	15	2	EG	10:00-11:00	10:15-11:15	15-20	15-20	2	EG	10
C	15-30	35-40	2	EG/S /H	10:00-10:30	10:15-10:45	15-20	15-20	2	EG	25

NF = name of farmer; TL = time of loading; RS = ramp slope; NW = number of worker; EU = equipment used; DT = departure time; AT = arrival time; TU = time of unloading; TT = transport time; EG = electric goad; S = sticks; H = hands.

Appendix a.8 Raw data on pH_1 and pH_{24} at *abattoir A.*

Sample No.	Date Killed	Semitendinosus				Longissimus Dorsi			
		Time Collected (AM)	pH_{45}	Time Collected* (AM)	pH	Time Collected (AM)	pH_{45}	Time Collected* (AM)	pH
1	3-8-93	10:48	5.91	10:56	5.85	10:47	5.89	10:58	5.73
2	3-8-93	10:52	5.87	11:00	5.72	10:50	5.77	11:02	5.59
3	3-8-93	10:54	6.05	11:03	5.99	10:53	5.96	11:04	5.77
4	3-8-93	10:59	5.72	11:06	5.43	10:56	5.71	11:07	5.39
5	3-8-93	11:00	6.23	11:10	5.95	10:58	6.31	11:09	6.02
6	3-8-93	11:02	6.38	11:12	6.21	11:03	6.18	11:13	6.01
7	10-8-93	10:35	5.75	11:00	5.51	10:36	5.83	11:01	5.46
8	10-8-93	10:38	5.80	11:02	5.41	10:39	5.78	11:03	5.55
9	10-8-93	10:40	6.22	11:05	5.90	10:43	5.97	11:07	5.73
10	10-8-93	10:45	6.54	11:10	6.30	10:46	6.50	11:11	6.39
11	10-8-93	10:48	6.36	11:12	6.10	10:52	5.95	11:15	5.74
12	10-8-93	10:55	6.13	11:16	5.84	10:56	6.00	11:17	5.75
13	17-8-93	11:04	6.21	11:35	5.91	11:05	5.79	11:36	5.42
14	17-8-93	11:06	5.80	11:37	5.57	11:07	5.81	11:38	5.59
15	17-8-93	11:08	6.30	11:39	6.03	11:09	5.70	11:40	5.60
16	17-8-93	11:10	5.87	11:41	5.62	11:10	5.73	11:41	5.32
17	17-8-93	11:12	6.48	11:44	6.14	11:13	5.70	11:45	5.67
18	17-8-93	11:15	6.44	11:47	6.35	11:16	6.48	11:48	6.23
19	24-8-93	10:50	6.22	10:52	6.14	10:51	6.05	10:56	5.79
20	24-8-93	10:52	5.95	10:53	5.70	10:53	5.68	10:54	5.32

21	24-8-93	10:55	5.86	10:54	5.65	10:56	5.76	10:55	5.40
22	24-8-93	10:58	6.02	10:56	5.96	10:59	5.80	10:57	5.50
23	24-8-93	11:01	6.03	10:58	5.95	11:03	5.75	11:00	5.30
24	24-8-93	11:03	5.61	11:01	5.45	11:04	5.61	11:02	5.23
25	31-8-93	11:00	6.24	11:05	5.98	11:01	6.21	11:06	5.95
26	31-8-93	11:03	5.76	11:08	5.32	11:04	5.69	11:09	5.00
27	31-8-93	11:06	6.13	11:11	5.72	11:07	5.73	11:12	5.25
28	31-8-93	10:09	6.75	11:14	6.41	11:11	6.78	11:16	6.67
29	31-8-93	10:13	6.12	11:18	5.80	11:14	5.62	11:19	5.45
30	31-8-93	10:16	6.17	11:21	5.98	10:40	6.06	10:45	5.82
31	7-9-93	10:40	6.01	10:45	5.70	10:41	5.62	10:46	5.20
32	7-9-93	10:43	5.60	10:47	5.41	10:44	5.55	10:48	5.25
33	7-9-93	10:45	5.88	10:49	5.69	10:47	5.60	10:50	5.15
34	7-9-93	10:49	5.75	10:52	5.35	10:51	5.49	10:53	5.12
35	7-9-93	10:52	5.68	10:54	5.52	10:53	5.61	10:55	5.20
36	7-9-93	10:55	6.48	10:56	6.29	10:56	6.15	10:57	5.92
37	28-9-93	10:05	6.48	10:10	6.17	9:57	5.68	10:11	5.41
38	28-9-93	10:06	6.22	10:12	5.73	9:58	6.04	10:13	5.62
39	28-9-93	10:07	6.43	10:14	5.89	9:59	6.05	10:15	5.42
40	28-9-93	10:08	6.35	10:16	5.87	10:01	5.87	10:17	5.33
41	28-9-93	10:10	6.19	10:18	5.75	10:02	6.06	10:19	5.82
42	28-9-93	10:11	6.62	10:20	6.42	10:03	6.46	10:20	6.25
43	5-10-93	9:00	5.85	9:10	5.43	9:01	5.81	9:11	5.35
44	5-10-93	9:02	6.42	9:12	6.02	9:04	6.28	9:13	5.81
45	5-10-93	9:05	6.30	9:14	5.85	9:06	5.86	9:15	5.28
46	5-10-93	9:08	6.64	9:16	6.45	9:10	6.35	9:17	6.11
47	5-10-93	9:11	6.28	9:18	5.85	9:11	6.05	9:18	5.63
48	5-10-93	9:14	6.49	9:20	5.88	9:12	5.89	9:19	5.28
49	12-10-93	9:50	6.36	10:00	6.02	9:15	5.89	10:01	5.48
50	12-10-93	9:52	6.69	10:02	6.31	9:54	6.66	10:03	6.38
51	12-10-93	9:55	6.44	10:04	6.12	9:50	5.79	10:05	5.39
52	12-10-93	10:00	6.65	10:06	6.33	10:01	6.43	10:07	5.89
53	12-10-93	10:04	6.57	10:08	6.38	10:06	6.67	10:09	6.52
54	12-10-93	10:08	6.42	10:10	6.02	10:09	5.82	10:12	5.39
55	19-10-93	9:51	6.18	10:11	5.91	9:52	5.76	10:12	5.40

56	19-10-93	9:53	6.59	10:13	6.46	9:55	5.79	10:14	5.58
57	19-10-93	9:56	6.60	10:15	6.02	9:58	5.79	10:16	5.35
58	19-10-93	10:00	6.48	10:17	6.28	10:02	6.07	10:18	5.62
59	19-10-93	10:03	6.50	10:19	6.32	10:04	6.63	10:20	6.38
60	19-10-93	10:05	6.61	10:21	6.34	10:06	6.24	10:22	5.85
61	26-10-93	10:15	6.90	10:00	6.53	10:16	6.82	10:02	6.40
62	26-10-93	10:17	6.72	10:03	6.23	10:18	6.44	10:04	5.90
63	26-10-93	10:19	6.91	10:05	6.51	10:20	6.25	10:06	5.68
64	26-10-93	10:21	6.68	10:07	6.29	10:22	6.04	10:08	5.50
65	26-10-93	10:23	6.79	10:10	6.21	10:24	5.99	10:11	5.51
66	26-10-93	10:25	6.41	10:12	5.81	10:26	5.76	10:14	5.43
67	21-12-93	1:00	6.59	12:55	6.29	1:01	6.35	12:56	5.62
68	21-12-93	1:02	6.53	12:57	6.28	1:03	5.79	12:58	5.42
69	21-12-93	1:04	6.47	12:59	6.22	1:06	5.85	1:00	5.45
70	21-12-93	1:07	6.35	1:01	6.05	1:08	6.16	1:03	5.48
71	21-12-93	1:09	6.35	1:04	6.11	1:11	5.88	1:06	5.42
72	21-12-93	1:13	6.16	1:07	6.01	1:14	5.80	1:08	5.55
73	11-01-94	9:10	6.08	9:00	5.92	9:42	6.00	9:02	5.31
74	11-01-94	9:05	6.58	9:03	6.43	9:06	6.40	9:04	5.89
75	11-01-94	9:08	6.13	9:06	5.38	9:09	6.03	9:07	5.26
76	11-01-94	9:10	6.35	9:08	5.85	9:12	5.82	9:10	5.31
77	11-01-94	9:15	6.78	9.12	6.53	9:16	6.07	9:13	5.58
78	11-01-94	9:18	6.43	9:14	6.25	9:20	6.06	9:15	5.45

Appendix a.9 Raw data on pH_1 and pH_{24} at *abattoir B*.

Sample No.	Date Killed	Semitendinosus				Longissimus Dorsi			
		Time Collected (AM)	pH_{45}	Time Collected* (AM)	pH	Time Collected (PM)	pH_{45}	Time Collected* (PM)	pH
1	02-03-93	*	*	*	*	3:10	5.98	3:00	5.66
2	02-03-93	*	*	*	*	3:11	5.99	3:02	5.69
3	02-03-93	*	*	*	*	3:13	6.34	3:03	5.72
4	02-03-93	*	*	*	*	3:15	6.25	3:04	5.97
5	02-03-93	*	*	*	*	3:16	5.88	3:06	5.81
6	02-03-93	*	*	*	*	3:18	5.71	3:08	5.39

7	02-03-93	*	*	*	*	3:20	5.70	3:09	5.35
8	02-03-93	*	*	*	*	3:21	5.70	3:10	5.62
9	02-03-93	*	*	*	*	3:22	5.87	3:11	5.77
10	02-03-93	*	*	*	*	3:23	5.77	3:12	5.64
11	02-03-93	*	*	*	*	3:25	5.78	3:13	5.65
12	02-03-93	*	*	*	*	3:27	5.83	3:14	5.53
13	02-03-93	*	*	*	*	3:29	5.66	3:15	5.48
14	02-03-93	*	*	*	*	3:31	6.00	3:16	5.97
15	02-03-93	*	*	*	*	3:32	5.76	3:18	5.72
16	02-03-93	*	*	*	*	3:34	5.97	3:19	5.82
17	02-03-93	*	*	*	*	3:36	5.62	3:20	5.57
18	02-03-93	*	*	*	*	3:38	5.72	3:21	5.55
19	02-03-93	*	*	*	*	3:39	5.73	3:22	5.39
20	02-03-93	*	*	*	*	3:41	6.21	3:24	6.17
21	02-03-93	*	*	*	*	3:43	5.97	3:25	5.68
22	02-03-93	*	*	*	*	3:44	5.91	3:26	5.69
23	02-03-93	*	*	*	*	3:46	5.57	3:27	5.39
24	02-03-93	*	*	*	*	3:48	6.00	3:28	5.52
25	02-03-93	*	*	*	*	3:49	5.59	3:29	5.36
26	02-03-93	*	*	*	*	3:51	5.67	3:30	5.42
27	02-03-93	*	*	*	*	3:53	5.63	3:31	5.39
28	02-03-93	*	*	*	*	3:55	5.85	3:32	5.71
29	02-03-93	*	*	*	*	3:57	6.05	3:33	5.63
30	02-03-93	*	*	*	*	3:59	6.11	3:35	5.83
31	21-09-93	1:40	6.29	*	*	1:41	6.22	*	*
32	21-09-93	1:43	6.06	*	*	1:42	5.69	*	*
33	21-09-93	1:45	6.42	*	*	1:46	5.74	*	*
34	21-09-93	1:47	6.39	*	*	1:48	5.89	*	*
35	21-09-93	1:49	6.38	*	*	1:50	6.29	*	*
36	21-09-93	1:51	6.38	1:45	5.67	1:52	6.03	1:46	5.48
37	21-09-93	1:53	6.36	*	*	1:54	6.29	*	*
38	21-09-93	1:55	6.23	1:48	5.33	1:56	5.74	1:50	5.21
39	21-09-93	1:57	5.69	1:51	5.27	1:58	5.64	1:52	5.27
40	21-09-93	1:59	6.31	1:54	5.69	2:01	5.72	1:56	5.38
41	21-09-93	2:03	6.38	*	*	2:04	6.29	*	*

42	21-09-93	2:06	6.21	1:58	5.55	2:07	6.04	1:59	5.47
43	21-09-93	2:08	6.04	2:00	5.36	2:10	6.02	2:01	5.39
44	21-09-93	2:12	6.65	2:03	5.76	2:13	6.41	2:04	5.79
45	21-09-93	2:14	6.08	2:05	5.36	2:16	5.68	2:06	5.25
46	21-09-93	2:18	6.19	2:08	5.66	2:19	6.15	2:09	5.55
47	21-09-93	2:20	6.28	2:10	5.55	2:21	6.17	2:11	5.44
48	21-09-93	2:23	5.73	*	*	2:24	5.96	*	*
49	21-09-93	2:25	6.14	2:13	5.37	2:26	6.04	2:14	5.35
50	21-09-93	2:28	5.91	2:15	5.41	2:29	5.98	2:16	5.51
51	21-09-93	2:30	6.37	2:18	6.06	2:31	6.35	2:19	5.98
52	21-09-93	2:32	6.51	2:21	6.32	2:33	6.46	2:22	6.29
53	21-09-93	2:34	6.54	2:23	6.22	2:35	6.24	2:24	5.83
54	21-09-93	2:37	6.36	2:26	6.27	2:38	6.25	2:27	5.62
55	21-09-93	2:39	6.61	2:28	5.75	2:40	6.31	2:29	5.79
56	21-09-93	2:41	5.44	2:31	5.35	2:42	5.41	2:32	5.31
57	21-09-93	2:44	5.72	2:33	5.50	2:45	5.76	2:35	5.33
58	21-09-93	2:46	5.65	2:36	5.45	2:47	5.54	2:38	5.33
59	21-09-93	2:49	5.73	2:39	5.41	2:50	5.74	2:40	5.40
60	21-09-93	2:51	5.80	2:42	5.33	2:52	5.84	2:43	5.31
61	21-09-93	2:54	5.61	2:44	5.40	2:55	5.73	2:45	6.38
62	21-09-93	2:57	6.31	*	*	2:58	6.13	*	*
63	21-09-93	2:59	6.40	*	*	3:00	6.05	*	*
64	21-09-93	3:02	6.01	*	*	3:03	5.98	*	*
65	21-09-93	3:05	6.00	*	*	3:07	5.89	*	*
66	21-09-93	3:08	5.92	*	*	3:09	5.91	*	*
Mean	*	*	5.79	*	5.61	*	5.84	*	5.58

Appendix a.10 Raw data on *water holding capacity* at *abattoir A.*

SN	DA	Semitendinosus				Longissimus Dorsi			
		Pre-wt (M)	Post-wt (M)	Pre-wt (FP)	Post-wt (FP)	Pre-wt (M)	Post-wt (M)	Pre-wt (FP)	Post-wt (FP)
1	04-08-93	0.3034	0.1698	0.5258	0.6644	0.3002	0.1701	0.5202	0.6545
2	04-08-93	0.3025	0.1740	0.5341	0.6632	0.3012	0.1522	0.5244	0.6804
3	04-08-93	0.3014	0.1803	0.5417	0.6648	0.3007	0.1699	0.5374	0.6693
4	04-08-93	0.3016	0.1651	0.5376	0.6762	0.3008	0.1536	0.5332	0.6844

5	04-08-93	0.3028	0.1739	0.5252	0.6542	0.3032	0.1832	0.5401	0.6610
6	04-08-93	0.3013	0.1824	0.5449	0.6622	0.3009	0.1774	0.5269	0.6524
7	11-08-93	0.3004	0.1701	0.5382	0.6774	0.3003	0.1601	0.5286	0.6758
8	11-08-93	0.3017	0.1704	0.5293	0.6665	0.3016	0.1424	0.5198	0.6791
9	11-08-93	0.3004	0.1726	0.5368	0.6656	0.3012	01720	05355	0.6646
10	11-08-93	0.3015	0.1898	0.5357	0.6463	0.3014	0.1796	0.5361	0.6574
11	11-08-93	0.3030	0.1711	0.5360	0.6679	0.3023	0.1701	0.5299	0.6649
12	11-08-93	0.3044	0.1731	0.5352	0.6671	0.3043	0.1762	0.5297	0.6590
13	18-08-93	0.3034	0.1745	0.5294	0.6586	0.3002	0.1550	0.5216	0.6754
14	18-08-93	0.3021	0.1632	0.5362	0.6758	0.3005	0.1713	0.5293	0.6588
15	18-08-93	0.3008	0.1804	0.5361	0.6569	0.3025	0.1621	0.5288	0.6695
16	18-08-93	0.3023	0.1780	0.5353	0.6593	0.3034	0.1543	0.5297	0.6796
17	18-08-93	0.3043	0.1941	0.5352	0.6460	0.3038	0.1541	0.5290	0.6799
18	18-08-93	0.3031	0.1870	0.5292	0.6450	0.3027	0.1933	0.5358	0.6453
19	25-08-93	0.3045	0.1791	0.5298	0.6561	0.3044	0.1798	0.5198	0.6464
20	25-08-93	0.3038	0.1746	0.5355	0.6649	0.3042	0.1551	0.5356	0.6854
21	25-08-93	0.3041	0.1740	0.5448	0.6751	0.3047	0.1540	0.5297	0.6797
22	25-08-93	0.3034	0.1901	0.5199	0.6349	0.3012	0.1554	0.5287	0.6775
23	25-08-93	0.3016	0.1849	0.5290	0.6467	0.3014	0.1523	0.5097	0.6598
24	25-08-93	0.3005	0.1503	0.5394	0.6950	0.3014	0.1332	0.5298	0.6982
25	01-09-93	0.3003	0.1748	0.5395	0.6651	0.3028	0.1775	0.5199	0.6451
26	01-09-93	0.3010	0.1551	0.5197	0.6696	0.3008	0.1345	0.5193	0.6896
27	01-09-93	0.3024	0.1852	0.5197	0.6358	0.3007	0.1563	0.5099	0.6595
28	01-09-93	0.3005	0.1931	0.5282	0.6353	0.3004	0.2162	0.5351	0.6184
29	01-09-93	0.3013	0.1903	0.5371	0.6485	0.3007	0.1602	0.5354	0.6792
30	01-09-93	0.3022	0.1907	0.5193	0.6298	0.3031	0.1832	0.5176	0.6373
31	08-09-93	0.3007	0.1762	0.5252	0.6501	0.3043	0.1577	0.5332	0.6852
32	08-09-93	0.3012	0.1751	0.5301	0.6561	0.3035	0.1479	0.5298	0.6855
33	08-09-93	0.3009	0.1867	0.5311	0.6471	0.3033	0.1601	0.5310	0.6743
34	08-09-93	0.3011	0.1715	0.5296	0.6597	0.3015	0.1405	0.5294	0.6932
35	08-09-93	0.3004	0.1705	0.5320	0.6621	0.3037	0.1428	0.5308	0.6937
36	08-09-93	0.3020	0.2094	0.5302	0.6219	0.3032	0.1875	0.5242	0.6392
37	29-09-93	0.3019	0.1882	0.5392	0.6523	0.3017	0.1620	0.5102	0.6599
38	29-09-93	0.3015	0.1738	0.5346	0.6626	0.3021	0.1610	0.5287	0.6696
39	29-09-93	0.3020	0.1772	0.5218	0.6476	0.3019	0.1701	0.5235	0.6643
40	29-09-93	0.3022	0.1767	0.5384	0.6659	0.3021	0.1608	0.5323	0.6786
41	29-09-93	0.3024	0.1762	0.5320	0.6582	0.3020	0.1726	0.5405	0.6719
42	29-09-93	0.3021	0.1985	0.5403	0.6419	0.3023	0.1994	0.5412	0.6341
43	06-10-93	0.3015	0.1636	0.5409	0.6797	0.3016	0.1602	0.5405	0.6866

44	06-10-93	0.3019	0.1935	0.5407	0.6489	0.3014	0.1760	0.5470	0.6719
45	06-10-93	0.3018	0.1708	0.5444	0.6734	0.3015	0.1671	0.5411	0.6843
46	06-10-93	0.3021	0.1951	0.5459	0.6531	0.3017	0.1811	0.5202	0.6398
47	06-10-93	0.3019	0.1808	0.5417	0.6636	0.3012	0.1701	0.5403	0.6794
48	06-10-93	0.3013	0.1810	0.5332	0.6536	0.3016	0.1603	0.5326	0.6789
49	13-10-93	0.3004	0.1803	0.5301	0.6498	0.3018	0.1714	0.5304	0.6645
50	13-10-93	0.3014	0.1922	0.5327	0.6369	0.3010	0.1943	0.5382	0.6423
51	13-10-93	0.3005	0.1796	0.5435	0.6709	0.3007	0.1632	0.5324	0.6748
52	13-10-93	0.3021	0.1888	0.5311	0.6364	0.3015	0.1834	0.5295	0.6525
53	13-10-93	0.3022	0.1927	0.5366	0.6416	0.3041	0.2047	0.5446	0.6405
54	13-10-93	0.3003	0.1944	0.5431	0.6516	0.3040	0.1609	0.5335	0.6767
55	20-10-93	0.3044	0.1761	0.5378	0.6666	0.3035	0.1604	0.5387	0.6862
56	20-10-93	0.3052	0.1977	0.5333	0.6387	0.3071	0.1695	0.5337	0.6728
57	20-10-93	0.3034	0.1896	0.5474	0.6609	0.3016	0.1625	0.5444	0.6872
58	20-10-93	0.3072	0.1767	0.5387	0.6677	0.3026	0.1618	0.5508	0.6985
59	20-10-93	0.3079	0.1888	0.5539	0.6670	0.3078	0.1952	0.5518	0.6559
60	20-10-93	0.3080	0.1873	0.5402	0.6542	0.3043	0.1763	0.5713	0.6931
61	27-10-93	0.3006	0.2018	0.5596	0.6573	0.3036	0.2046	0.5379	0.6363
62	27-10-93	0.3031	0.1952	0.5582	0.6622	0.3053	0.1867	0.5443	0.6656
63	27-10-93	0.3086	0.2172	0.5375	0.6273	0.3015	0.1778	0.5400	0.6693
64	27-10-93	0.3034	0.1935	0.5417	0.6469	0.3028	0.1800	0.5401	0.6695
65	27-10-93	0.3096	0.2079	0.5499	0.6581	0.3032	0.1780	0.5224	0.6528
66	27-10-93	0.3021	0.1822	0.5493	0.6693	0.3085	0.1679	0.5405	0.6811
67	22-12-93	0.3033	0.1984	0.5682	0.6732	0.3050	0.1825	0.5293	0.6504
68	22-12-93	0.3038	0.1822	0.5406	0.6589	0.3017	0.1550	0.5302	0.6796
69	22-12-93	0.3037	0.1885	0.5519	0.6667	0.3044	0.1571	0.5326	0.6855
70	22-12-93	0.3008	0.1860	0.5432	0.6526	0.3025	0.1785	0.5309	0.6550
71	22-12-93	0.3025	0.1934	0.5518	0.6602	0.3057	0.1691	0.5372	0.6799
72	22-12-93	0.3022	0.1883	0.5298	0.6432	0.3017	0.1509	0.5352	0.6874
73	12-01-94	0.3013	0.1884	0.5326	0.6438	0.3044	0.1739	0.5372	0.6868
74	12-01-94	0.3031	0.1999	0.5315	0.6312	0.3029	0.1804	0.5353	0.6546
75	12-01-94	0.3038	0.1766	0.5375	0.6778	0.3017	0.1763	0.5333	0.6845
76	12-01-94	0.3047	0.1800	0.5459	0.6636	0.3038	0.1616	0.5364	0.6856
77	12-01-94	0.3023	0.1878	0.5464	0.6543	0.3020	0.1824	0.5397	0.6751
78	12-01-94	0.3037	0.1849	0.5490	0.6633	0.3020	0.1702	0.5360	0.6681

SN = sample number; DA = date analyzed; M = meat; FP = filter paper.

Appendix a.11 Raw data on *drip loss* at *abattoir A.*

Sample No.	Date Analyzed	Semitendinosus		Longissimus Dorsi	
		Pre-wt of the muscle	Post-wt of the muscle	Pre-wt of the muscle	Post-wt of the muscle
1	05-08-93	97.1302	95.3704	99.6121	96.2817
2	05-08-93	98.7200	96.2000	99.8511	96.5007
3	05-08-93	99.8042	97.5043	99.8821	96.9819
4	05-08-93	99.3508	94.2604	99.9632	94.4834
5	05-08-93	98.0051	96.0244	97.6308	95.3409
6	05-08-93	97.8701	96.7803	99.5312	96.9311
7	12-08-93	99.6519	96.4219	99.8902	95.7204
8	12-08-93	99.3907	96.6903	99.6611	92.6009
9	12-08-93	99.2314	97.0413	99.8209	97.6610
10	12-08-93	99.2914	98.2415	99.8819	97.8019
11	12-08-93	99.7416	97.4915	99.9222	95.9118
12	12-08-93	99.5400	97.2401	99.0000	96.9403
13	19-08-93	99.6608	97.3803	99.3111	92.3412
14	19-08-93	99.2004	96.9801	99.8615	97.1814
15	19-08-93	99.2827	97.0726	99.0623	96.0421
16	19-08-93	99.4207	97.0106	99.4413	92.6911
17	19-08-93	99.2928	98.0126	99.3602	95.6700
18	19-08-93	99.9527	98.7726	99.9114	98.7109
19	26-08-93	99.6632	96.8931	99.8010	97.7808
20	26-08-93	99.5408	96.6906	99.8102	96.1100
21	26-08-93	99.2522	97.2020	99.2121	93.1320
22	26-08-93	99.5015	98.5812	99.7131	96.5127
23	26-08-93	99.3303	98.4104	99.3401	93.7600
24	26-08-93	99.6616	94.9209	99.6030	92.8229
25	02-09-93	99.7411	97.3618	99.4309	97.4207
26	02-09-93	99.3220	95.2021	99.2000	92.9801
27	02-09-93	99.4406	98.2103	99.8417	95.2515
28	02-09-93	99.3606	98.6005	99.2801	98.3300
29	02-09-93	99.1813	98.1414	99.3132	96.4029
30	02-09-93	99.0711	97.8710	99.4210	97.7008
31	09-09-93	99.0503	96.7805	99.3412	93.9209
32	09-09-93	99.3305	96.7111	99.1024	93.6321

33	09-09-93	99.3502	98.1610	99.4132	93.6831
34	09-09-93	99.0423	96.5822	99.6403	92.9801
35	09-09-93	99.5813	96.8415	99.6521	92.5120
36	09-09-93	99.2529	98.3424	99.1838	97.8529
37	30-09-93	99.6712	98.1624	99.1661	93.6578
38	30-09-93	99.3653	97.0048	99.3243	94.7138
39	30-09-93	99.9003	97.8712	99.2334	94.5025
40	30-09-93	99.5706	97.4017	99.0873	92.7565
41	30-09-93	99.4857	97.4026	99.1367	97.0506
42	30-09-93	99.8723	98.7141	99.0511	97.5203
43	07-10-93	99.1507	95.5891	99.0592	93.7290
44	07-10-93	99.7025	98.5703	99.4452	96.7950
45	07-10-93	99.7401	97.5395	99.8422	94.6133
46	07-10-93	99.3547	98.2943	99.5463	97.3961
47	07-10-93	99.7252	97.6906	99.6538	95.2520
48	07-10-93	99.0538	97.0026	99.2118	92.3327
49	14-10-93	99.8140	97.4650	99.6499	95.8180
50	14-10-93	99.4562	98.3454	99.5673	97.9389
51	14-10-93	99.7318	97.2445	99.4334	92.6331
52	14-10-93	99.0069	97.9909	99.8768	97.3823
53	14-10-93	99.0293	97.9052	99.3407	98.1810
54	14-10-93	99.5838	98.4102	99.6523	94.2854
55	21-10-93	99.5069	97.4647	99.7650	93.7599
56	21-10-93	99.7440	98.7033	99.8240	96.3905
57	21-10-93	99.4950	98.1806	99.8470	94.4912
58	21-10-93	99.2002	97.0788	99.7164	94.1933
59	21-10-93	99.6340	98.3767	99.5775	98.3424
60	21-10-93	99.6566	97.9571	99.5905	96.7376
61	28-10-93	99.0450	98.1232	99.3620	98.0081
62	28-10-93	99.6660	98.1972	99.4640	96.7800
63	28-10-93	99.0770	98.2601	99.5320	95.9673
64	28-10-93	99.6820	98.6054	99.6230	96.3206
65	28-10-93	99.7272	98.2754	99.2530	94.5599
66	28-10-93	99.5260	97.5078	99.6430	93.6799
67	23-12-93	99.9052	97.9368	99.5942	96.9023

68	23-12-93	99.9141	97.9544	99.6440	93.4173
69	23-12-93	99.1510	98.1317	99.8810	95.4219
70	23-12-93	99.7196	97.7680	99.4999	95.0132
71	23-12-93	99.6300	97.7257	99.3131	92.8731
72	23-12-93	99.4172	98.3153	99.8702	94.8189
73	13-01-94	99.3481	97.4352	99.0601	92.2035
74	13-01-94	99.3114	98.2946	99.1569	96.7302
75	13-01-94	99.8935	95.0548	99.1702	92.8658
76	13-01-94	99.3212	98.1837	99.4702	93.5226
77	13-01-94	99.2868	98.1415	99.4318	93.9168
78	13-01-94	99.0142	97.8682	99.2281	95.4667

Appendix a.12 Raw data on *visual evaluation score* at *abattoir A.*

SN	DA	Semitendinosus				Longissimus Dorsi			
		C	T	W	OS	C	T	W	OS
1	04-08-93	3	2	2	2	3	3	3	3
2	04-08-93	3	2	2	2	4	3	4	4
3	04-08-93	2	2	2	2	2	2	2	2
4	04-08-93	4	3	4	4	4	4	4	4
5	04-08-93	2	1	2	2	2	2	2	2
6	04-08-93	1	1	1	1	2	1	2	2
7	11-08-93	3	2	3	3	3	2	3	3
8	11-08-93	3	3	3	3	4	4	4	4
9	11-08-93	3	2	2	2	3	2	2	2
10	11-08-93	0	0	1	0	1	0	0	0
11	11-08-93	2	2	2	2	3	3	4	3
12	11-08-93	2	2	2	2	2	2	2	2
13	18-08-93	2	2	2	2	4	3	3	3
14	18-08-93	3	3	3	3	3	3	4	3
15	18-08-93	2	2	2	2	3	3	3	3
16	18-08-93	2	3	3	3	4	3	4	4
17	18-08-93	1	2	1	1	3	3	2	3
18	18-08-93	0	0	0	0	2	1	1	1
19	25-08-93	0	1	1	1	2	2	2	2

20	25-08-93	3	2	3	3	4	4	3	4
21	25-08-93	2	3	3	3	4	3	4	3
22	25-08-93	2	1	2	2	3	3	3	3
23	25-08-93	1	2	1	1	4	3	4	4
24	25-08-93	3	3	4	3	4	4	4	4
25	01-09-93	3	2	2	2	3	2	2	2
26	01-09-93	3	3	3	3	4	4	4	4
27	01-09-93	3	2	3	3	4	3	4	4
28	01-09-93	1	1	1	1	0	0	0	0
29	01-09-93	2	2	3	2	3	3	3	3
30	01-09-93	2	1	1	1	2	2	1	2
31	08-09-93	2	3	2	2	4	3	4	4
32	08-09-93	3	3	3	3	4	4	3	4
33	08-09-93	2	3	2	2	3	4	4	4
34	08-09-93	4	3	3	3	4	4	4	4
35	08-09-93	3	3	3	3	4	4	4	4
36	08-09-93	2	1	1	1	3	2	2	2
37	29-09-93	2	2	3	2	4	4	3	4
38	29-09-93	2	2	1	2	3	3	2	3
39	29-09-93	2	2	1	2	3	3	2	3
40	29-09-93	2	2	1	2	4	4	3	4
41	29-09-93	3	2	2	2	2	2	3	2
42	29-09-93	2	1	1	1	1	1	1	1
43	06-10-93	4	3	3	3	4	3	4	4
44	06-10-93	3	2	2	2	3	3	2	3
45	06-10-93	2	3	2	2	4	4	4	4
46	06-10-93	2	1	1	1	2	2	2	2
47	06-10-93	2	3	2	2	3	2	3	3
48	06-10-93	3	3	3	3	4	4	4	4
49	13-10-93	2	2	2	2	4	3	3	3
50	13-10-93	1	2	2	2	2	1	1	1
51	13-10-93	2	2	2	2	4	4	4	4
52	13-10-93	1	1	1	1	3	2	2	2
53	13-10-93	2	1	1	1	1	1	1	1
54	13-10-93	2	1	1	1	4	3	4	4

55	20-10-93	2	2	2	2	3	3	3	3
56	20-10-93	2	1	1	1	3	3	3	3
57	20-10-93	1	1	2	1	4	3	4	4
58	20-10-93	2	2	2	2	3	2	3	3
59	20-10-93	2	1	1	1	1	1	1	1
60	20-10-93	1	2	1	1	2	2	2	2
61	27-10-93	1	0	0	0	1	1	0	1
62	27-10-93	2	1	1	1	3	2	2	2
63	27-10-93	0	0	0	0	2	3	3	3
64	27-10-93	2	1	1	1	4	3	3	3
65	27-10-93	2	1	1	1	4	4	3	4
66	27-10-93	3	2	2	2	4	4	4	4
67	22-12-93	1	1	0	1	2	3	2	2
68	22-12-93	1	2	1	1	4	4	3	4
69	22-12-93	2	1	1	1	4	4	4	4
70	22-12-93	2	1	1	1	4	3	3	3
71	22-12-93	2	1	1	1	4	3	4	4
72	22-12-93	2	1	1	1	4	3	4	4
73	12-01-94	1	2	2	2	4	3	4	4
74	12-01-94	1	1	1	1	2	2	1	2
75	12-01-94	2	3	3	3	4	4	4	4
76	12-01-94	2	1	2	2	4	4	4	4
77	12-01-94	0	1	1	1	3	4	4	4
78	12-01-94	2	1	1	1	2	3	3	3

SN = sample number; DA = date analyzed; C = colour; T = texture; W = wetness; OS = overall scores.

Appendix a.13a Raw data on ***hunter L A B colour*** of *ST* at *abattoir A*.

SN	DA	Semitendinosus								
		L			A			B		
		III D65	III A	III C	III D65	III A	III C	III D65	III A	III C
1	04-08-93	30.79	32.89	30.84	12.52	22.25	11.97	8.42	4.99	9.19
2	04-08-93	28.12	30.30	28.19	13.33	22.52	12.83	7.95	4.91	8.66
3	04-08-93	28.19	30.19	28.25	12.43	21.95	11.93	7.04	4.15	7.77
4	04-08-93	36.03	38.12	36.11	10.69	13.69	10.24	6.37	10.78	7.06

5	04-08-93	28.46	31.09	29.51	10.48	19.46	10.05	5.13	2.85	5.78
6	04-08-93	25.41	28.52	24.48	13.39	23.65	12.87	7.22	4.19	7.96
7	11-08-93	27.39	29.15	27.45	11.05	20.35	10.61	6.01	3.42	6.68
8	11-08-93	35.41	37.34	35.46	10.60	19.65	10.03	8.91	5.22	9.66
9	11-08-93	32.59	34.25	32.64	9.18	18.87	8.67	7.64	4.14	8.42
10	11-08-93	22.03	25.18	23.11	14.14	23.89	13.69	6.45	3.92	7.12
11	11-08-93	27.43	29.25	27.49	10.87	19.46	10.40	6.92	4.09	7.59
12	11-08-93	31.95	33.91	32.00	11.63	21.44	11.09	7.88	4.54	8.65
13	18-08-93	28.04	29.92	28.09	11.39	20.16	10.92	7.05	4.22	7.73
14	18-08-93	36.97	38.06	37.03	12.45	15.49	11.95	8.22	4.97	8.92
15	18-08-93	27.97	30.00	28.03	12.97	23.00	12.49	6.77	3.96	7.48
16	18-08-93	26.95	28.93	27.01	12.25	21.80	11.78	7.06	4.15	7.76
17	18-08-93	24.24	26.25	24.31	13.21	22.59	12.77	6.08	3.64	6.72
18	18-08-93	22.96	24.91	23.03	13.12	22.37	12.73	5.47	3.31	6.08
19	25-08-93	19.38	22.03	19.48	19.37	28.72	18.99	5.59	3.86	6.15
20	25-08-93	35.36	36.92	35.40	8.34	17.96	7.78	7.72	4.06	8.52
21	25-08-93	30.86	32.83	30.92	11.77	21.71	11.24	7.81	4.49	8.58
22	25-08-93	31.99	33.96	32.05	11.95	22.20	11.42	7.44	4.23	8.23
23	25-08-93	23.88	25.84	23.95	13.01	22.49	12.61	5.70	3.39	6.33
24	25-08-93	35.43	37.39	35.48	11.25	21.14	10.69	8.39	4.82	9.18
25	01-09-93	32.70	34.83	32.76	12.47	22.65	11.89	8.88	5.18	9.69
26	01-09-93	32.95	35.33	33.02	13.87	23.90	13.26	9.70	5.90	10.52
27	01-09-93	35.57	37.36	35.61	9.76	19.34	9.19	8.53	4.78	9.32
28	01-09-93	21.50	23.86	21.59	16.62	26.35	16.22	5.62	3.62	6.21
29	01-09-93	32.08	33.88	32.13	10.40	20.30	9.87	7.63	4.23	8.41
30	01-09-93	29.03	30.77	29.08	10.55	20.11	10.06	6.78	3.76	7.49
31	08-09-93	27.89	29.87	27.96	12.21	20.97	11.77	7.00	4.30	7.65
32	08-09-93	33.57	35.49	33.62	10.45	19.81	9.87	8.94	5.15	9.75
33	08-09-93	26.47	28.54	26.54	13.21	22.67	12.76	6.63	4.01	7.31
34	08-09-93	38.84	40.65	38.89	9.20	18.50	8.61	9.45	5.37	10.26
35	08-09-93	34.08	36.02	34.14	10.97	20.48	10.42	8.39	4.87	9.17
36	08-09-93	29.75	31.77	29.80	12.44	22.51	11.92	7.51	4.33	8.27
37	29-09-93	27.43	29.49	27.49	13.06	22.55	12.58	7.00	4.22	7.69
38	29-09-93	27.94	29.85	27.99	11.93	21.47	11.46	6.82	3.97	7.51
39	29-09-93	26.26	28.22	26.31	12.47	21.66	11.99	6.80	4.04	7.47

40	29-09-93	29.32	31.27	29.39	11.64	21.05	11.12	7.56	4.41	8.30
41	29-09-93	32.78	34.65	32.84	10.63	20.74	10.08	8.12	4.53	8.93
42	29-09-93	27.09	29.13	27.15	13.05	22.79	12.57	6.75	4.01	7.45
43	06-10-93	39.35	41.16	39.39	9.59	19.65	9.00	8.98	4.96	9.82
44	06-10-93	38.23	39.76	38.27	8.23	17.36	7.69	7.51	4.03	8.27
45	06-10-93	33.99	36.13	34.05	12.33	22.69	11.74	9.08	5.29	9.92
46	06-10-93	30.51	32.50	30.51	12.17	22.38	11.64	7.50	4.27	8.27
47	06-10-93	28.92	31.19	29.00	14.26	24.75	13.72	7.77	4.62	8.54
48	06-10-93	31.15	32.78	31.19	7.92	17.46	7.30	9.25	4.99	10.10
49	13-10-93	26.51	28.40	26.58	11.77	21.00	11.33	6.49	3.82	7.16
50	13-10-93	24.96	27.11	25.03	14.18	24.20	13.74	6.50	3.91	7.17
51	13-10-93	28.19	30.05	28.24	11.52	21.04	11.07	6.59	3.81	7.28
52	13-10-93	24.40	25.24	24.44	10.57	20.82	10.01	8.09	4.46	8.90
53	13-10-93	26.09	27.96	26.15	11.94	21.53	11.48	6.21	3.55	6.89
54	13-10-93	27.24	29.26	27.30	12.52	22.09	12.04	7.15	4.23	7.86
55	20-10-93	29.06	31.04	29.12	12.13	21.71	11.63	7.29	4.28	8.01
56	20-10-93	30.04	31.93	30.10	11.32	21.15	10.79	7.38	4.16	8.14
57	20-10-93	25.55	27.67	25.61	13.39	22.31	12.92	7.32	4.54	7.98
58	20-10-93	32.30	34.10	32.36	10.45	19.85	9.95	7.42	4.22	8.15
59	20-10-93	31.27	33.08	31.33	10.81	20.29	10.33	7.04	4.02	7.75
60	20-10-93	27.18	29.29	27.25	13.85	23.82	13.36	6.47	3.85	7.18
61	27-10-93	26.00	28.08	26.07	13.37	22.82	12.90	6.78	4.10	7.45
62	27-10-93	30.52	32.52	30.58	12.00	21.47	11.48	7.77	4.58	8.51
63	27-10-93	21.67	24.08	21.76	16.73	26.37	16.32	6.19	3.99	6.79
64	27-10-93	33.26	35.19	33.92	11.04	20.94	10.46	8.35	4.73	9.17
65	27-10-93	32.43	34.42	32.48	11.55	21.35	10.97	8.39	4.82	9.18
66	27-10-93	32.96	34.93	33.02	11.43	21.24	10.91	8.07	4.68	8.83
67	22-12-93	25.50	27.53	25.57	12.98	22.22	12.54	6.60	4.02	7.25
68	22-12-93	24.61	26.89	24.69	15.32	25.22	14.89	6.39	3.96	7.06
69	22-12-93	29.17	31.15	29.23	12.27	22.19	11.77	7.12	4.10	7.86
70	22-12-93	31.39	33.11	31.43	9.42	19.01	8.86	8.15	4.49	8.94
71	22-12-93	32.87	34.59	32.91	9.37	19.30	8.80	8.24	4.48	9.05
72	22-12-93	34.54	36.36	34.59	10.31	20.47	9.73	8.05	4.39	8.88
73	12-01-94	29.69	31.76	29.76	12.36	21.86	11.83	7.97	4.73	8.72
74	12-01-94	26.48	28.39	26.54	12.19	21.65	11.73	6.31	3.67	7.00

75	12-01-94	31.43	33.52	31.49	12.33	21.94	11.77	8.28	4.90	9.06
76	12-01-94	32.26	34.17	32.31	11.36	21.31	10.82	7.74	4.38	8.51
77	12-01-94	25.27	27.46	25.34	14.70	24.91	14.25	6.36	3.80	7.02
78	12-01-94	30.49	32.23	30.54	10.57	20.14	10.07	6.77	3.74	7.50

SN = sample number; DA = date analyzed; ST = semitendinosus.

Appendix a.13b Raw data on *hunter L A B colour* of *LD* at *abattoir A.*

SN	DA	Longissimus Dorsi								
		L			A			B		
		III D65	III A	III C	III D65	III A	III C	III D65	III A	III C
1	04-08-93	34.66	36.55	34.70	11.38	21.13	10.84	7.59	4.33	8.34
2	04-08-93	40.02	41.83	40.05	9.56	19.13	8.97	9.31	5.26	10.09
3	04-08-93	31.61	33.45	31.65	9.51	19.05	8.91	9.62	5.47	10.42
4	04-08-93	37.80	39.55	37.84	9.83	19.51	9.28	8.07	4.47	8.84
5	04-08-93	29.61	31.51	29.66	11.89	21.31	11.41	6.91	4.03	7.61
6	04-08-93	28.82	30.86	28.87	13.02	22.30	12.53	6.96	4.22	7.65
7	11-08-93	34.83	36.34	34.85	8.54	17.38	8.06	7.02	3.82	7.71
8	11-08-93	39.09	40.76	39.12	9.17	18.24	8.63	8.09	4.52	8.82
9	11-08-93	33.79	35.17	33.82	7.86	16.38	7.40	6.20	3.29	6.88
10	11-08-93	24.27	25.71	23.30	8.80	17.25	8.39	5.56	3.01	6.18
11	11-08-93	33.77	35.38	33.80	9.49	18.55	9.00	6.77	3.72	7.46
12	11-08-93	32.00	33.70	32.04	9.90	19.20	9.41	7.16	4.00	7.89
13	18-08-93	34.67	36.48	34.70	10.01	19.35	9.46	8.56	4.88	9.33
14	18-08-93	37.84	35.59	37.88	10.48	16.71	9.98	7.00	3.97	7.71
15	18-08-93	34.40	36.14	34.43	9.55	18.99	9.00	8.37	4.68	9.15
16	18-08-93	35.04	36.73	35.07	9.31	18.85	8.76	8.07	4.44	8.85
17	18-08-93	33.08	34.79	33.12	9.60	18.97	9.05	7.81	4.33	8.58
18	18-08-93	28.59	30.10	28.64	9.08	17.74	8.63	5.89	3.20	6.56
19	25-08-93	27.77	29.49	27.81	11.16	20.22	10.71	5.66	3.21	6.32
20	25-08-93	37.75	39.50	37.78	9.73	19.51	9.16	8.33	4.60	9.12
21	25-08-93	37.40	39.20	37.44	9.79	19.39	9.22	8.71	4.89	9.49
22	25-08-93	35.70	37.07	35.73	7.73	16.48	7.25	6.37	3.31	7.07
23	25-08-93	38.10	39.77	38.14	8.68	17.81	8.12	8.61	4.78	9.39

24	25-08-93	42.44	44.03	42.47	8.59	18.24	8.03	7.92	4.24	8.71
25	01-09-93	34.99	36.47	35.02	8.16	16.85	7.66	7.02	3.79	7.73
26	01-09-93	43.93	45.90	43.96	10.09	19.97	9.44	10.51	6.02	11.35
27	01-09-93	37.98	39.93	38.02	10.76	20.50	10.17	9.30	5.36	10.10
28	01-09-93	20.96	23.21	21.03	16.23	25.38	15.82	5.06	3.28	5.63
29	01-09-93	36.20	37.78	36.23	7.97	17.29	7.40	8.63	4.65	9.44
30	01-09-93	32.58	34.38	32.63	10.30	19.74	9.74	7.97	4.49	8.73
31	08-09-93	40.26	41.74	40.28	7.83	16.42	7.33	7.64	4.19	8.34
32	08-09-93	39.55	41.16	39.57	8.45	17.93	7.89	8.49	4.62	9.26
33	08-09-93	33.11	35.36	33.16	13.72	23.36	13.12	8.84	5.37	9.61
34	08-09-93	42.60	44.36	42.63	9.12	18.67	8.53	9.31	5.22	10.11
35	08-09-93	42.34	44.00	42.37	8.45	17.89	7.89	8.97	4.95	9.75
36	08-09-93	34.08	35.64	34.12	8.35	17.51	7.80	7.79	4.20	8.56
37	29-09-93	41.36	43.28	41.39	10.25	19.59	9.66	9.58	5.57	10.35
38	29-09-93	36.87	38.74	36.91	10.24	19.79	9.67	8.83	5.04	9.61
39	29-09-93	38.43	40.20	38.47	9.64	19.08	9.06	8.64	4.83	9.41
40	29-09-93	39.60	41.45	39.64	9.64	18.73	9.06	9.42	5.43	10.18
41	29-09-93	35.66	36.91	35.69	5.76	14.78	5.20	7.88	3.92	8.69
42	29-09-93	31.81	33.47	31.85	9.71	19.02	9.18	7.13	3.89	7.88
43	06-10-93	39.59	41.27	39.63	9.33	18.87	8.80	7.84	4.33	8.59
44	06-10-93	38.97	40.36	38.99	7.66	16.40	7.15	6.92	3.64	7.64
45	06-10-93	48.47	50.31	48.50	9.12	18.51	8.50	10.24	5.87	11.05
46	06-10-93	32.72	34.30	32.76	9.13	18.36	8.63	6.90	3.73	7.63
47	06-10-93	39.57	41.09	39.60	8.26	17.32	7.72	7.51	4.03	8.25
48	06-10-93	41.67	43.27	41.70	8.35	17.36	7.80	8.26	4.55	9.01
49	13-10-93	40.66	42.28	40.68	8.36	17.48	7.80	8.74	4.85	9.51
50	13-10-93	35.44	36.86	35.47	7.73	16.64	7.23	6.96	3.66	7.69
51	13-10-93	41.40	43.08	41.43	8.55	17.83	7.97	9.00	5.00	9.79
52	13-10-93	33.07	35.46	33.09	6.70	15.71	6.13	8.21	4.28	9.00
53	13-10-93	26.18	27.73	26.23	9.56	18.10	9.13	5.70	3.15	6.33
54	13-10-93	39.51	41.19	39.54	8.78	18.04	8.21	8.83	4.92	9.60
55	20-10-93	38.86	40.62	38.90	9.34	19.18	8.76	8.87	4.89	9.68
56	20-10-93	37.20	38.89	37.23	9.08	18.49	8.52	8.42	4.65	9.19
57	20-10-93	38.28	40.03	38.31	9.46	18.89	8.87	8.60	4.78	9.39
58	20-10-93	36.43	38.11	36.47	8.84	18.35	8.25	8.57	4.67	9.39

59	20-10-93	30.96	32.64	31.00	9.89	19.31	9.37	6.92	3.78	7.67
60	20-10-93	33.28	34.91	33.32	9.54	18.59	9.03	6.81	3.74	7.53
61	27-10-93	23.84	25.58	23.89	11.69	20.31	11.27	5.15	3.00	5.75
62	27-10-93	35.68	37.37	35.72	9.79	19.00	9.28	7.33	4.09	8.05
63	27-10-93	34.16	35.94	34.21	10.66	20.46	10.10	7.21	3.97	8.00
64	27-10-93	38.64	40.12	38.67	8.00	16.89	7.48	7.31	3.92	8.03
65	27-10-93	38.13	39.74	38.17	8.68	17.84	8.14	7.94	4.36	8.69
66	27-10-93	42.72	44.32	42.76	8.17	17.20	7.59	8.51	4.65	9.29
67	22-12-93	33.56	35.07	33.59	7.67	16.75	7.10	8.22	4.39	9.01
68	22-12-93	41.43	42.86	41.45	7.49	16.44	6.95	7.46	3.93	8.22
69	22-12-93	39.27	40.93	39.30	9.02	18.46	8.47	8.06	4.42	8.84
70	22-12-93	39.85	41.35	39.87	7.74	17.12	7.17	8.09	4.26	8.88
71	22-12-93	44.09	45.46	44.12	6.66	15.79	6.09	7.96	4.09	8.75
72	22-12-93	37.90	39.35	37.93	7.87	17.03	7.34	7.07	3.67	7.83
73	12-01-94	40.90	42.55	40.94	8.87	18.29	8.30	8.12	4.43	8.91
74	12-01-94	33.47	35.02	33.51	8.92	17.97	8.41	6.7	3.6	7.42
75	12-01-94	39.28	40.92	39.32	9.15	18.32	8.62	7.49	4.13	8.24
76	12-01-94	39.79	41.62	39.83	10.33	19.89	9.76	8.18	4.62	8.96
77	12-01-94	36.95	38.59	36.99	9.31	18.8	8.76	7.39	3.99	8.16
78	12-01-94	34.89	36.61	34.93	10.08	19.43	9.55	7.26	4.04	8.01

SN = sample number; DA = date analyzed; LD = longissimus dorsi.

Appendix a.13c. Mean of raw data on *hunter L A B colour* at *abattoir A.*

Sample No.	Date Analyzed	Semitendinosus			Longissimus Dorsi		
		L	A	B	L	A	B
1	04-08-93	31.51	15.58	7.53	35.30	14.45	6.75
2	04-08-93	28.87	16.23	7.17	40.63	12.55	8.22
3	04-08-93	28.88	15.44	6.32	32.24	12.49	8.50
4	04-08-93	36.75	11.54	8.07	38.40	12.87	7.13
5	04-08-93	29.69	13.33	4.59	30.26	14.87	6.18
6	04-08-93	26.14	16.64	6.46	29.52	15.95	6.28
7	11-08-93	28.00	14.00	5.37	35.34	14.33	6.18
8	11-08-93	36.07	13.43	7.93	39.66	12.01	7.14

9	11-08-93	33.16	12.24	6.73	34.26	10.55	5.46
10	11-08-93	23.44	17.24	5.83	24.43	11.48	4.92
11	11-08-93	28.06	17.34	2.30	34.32	12.35	5.98
12	11-08-93	32.62	14.72	7.02	32.58	12.84	6.35
13	18-08-93	28.68	14.16	6.33	35.28	12.94	7.59
14	18-08-93	37.35	13.30	7.37	38.44	12.39	6.23
15	18-08-93	28.67	16.15	6.07	34.99	12.51	7.40
16	18-08-93	27.63	15.28	6.32	35.61	12.31	7.12
17	18-08-93	24.93	16.19	5.48	33.66	12.54	6.91
18	18-08-93	23.63	16.07	4.95	29.11	11.82	5.22
19	25-08-93	20.30	22.36	5.20	28.36	14.03	5.06
20	25-08-93	35.89	11.36	6.77	38.34	12.80	7.35
21	25-08-93	31.54	14.91	6.96	38.01	12.80	7.70
22	25-08-93	32.67	15.19	6.63	36.17	10.49	5.58
23	25-08-93	24.56	16.04	5.14	38.67	11.54	7.59
24	25-08-93	36.10	14.36	7.46	42.98	11.62	6.96
25	01-09-93	33.43	15.67	7.92	35.49	10.89	6.18
26	01-09-93	33.77	17.01	8.71	44.60	13.17	9.29
27	01-09-93	36.18	12.76	7.54	38.64	13.81	8.25
28	01-09-93	22.32	19.73	5.15	21.73	19.14	4.66
29	01-09-93	32.70	13.52	6.76	36.74	10.89	7.57
30	01-09-93	29.63	13.57	6.01	33.20	13.26	7.06
31	08-09-93	28.57	14.98	6.32	40.76	10.53	6.72
32	08-09-93	34.23	13.38	7.95	40.09	11.42	7.46
33	08-09-93	27.18	16.21	5.98	33.88	16.73	7.94
34	08-09-93	39.46	12.10	8.36	43.20	12.11	8.21
35	08-09-93	34.75	13.96	7.48	42.90	11.41	7.89
36	08-09-93	30.44	15.62	6.70	34.61	11.22	6.85
37	29-09-93	28.14	16.06	6.30	42.01	13.17	8.50
38	29-09-93	28.59	14.95	6.10	37.51	13.23	7.83
39	29-09-93	26.93	15.37	6.10	39.03	12.59	7.63
40	29-09-93	29.99	14.60	6.76	40.23	12.48	8.34
41	29-09-93	33.42	13.82	7.19	36.09	8.58	6.83
42	29-09-93	27.79	16.14	6.07	32.38	12.64	6.30
43	06-10-93	39.97	12.75	7.92	40.16	12.33	6.92

44	06-10-93	38.75	11.09	6.60	39.44	10.40	6.07
45	06-10-93	34.72	15.59	8.10	49.09	12.04	9.05
46	06-10-93	31.17	15.40	6.68	33.26	12.04	6.09
47	06-10-93	29.70	17.58	6.98	40.09	11.10	6.60
48	06-10-93	31.71	10.89	8.11	42.21	11.17	7.27
49	13-10-93	27.16	14.70	5.82	41.21	11.21	7.70
50	13-10-93	25.70	17.37	5.86	35.92	10.53	6.10
51	13-10-93	28.83	14.54	5.89	41.97	11.45	7.93
52	13-10-93	24.69	13.80	7.15	33.87	9.51	7.16
53	13-10-93	26.73	14.98	5.55	26.71	12.26	5.06
54	13-10-93	27.93	15.55	6.41	40.08	11.68	7.78
55	20-10-93	29.74	15.16	6.53	39.46	12.43	7.81
56	20-10-93	30.69	14.42	6.56	37.77	12.03	7.42
57	20-10-93	26.28	16.21	6.61	38.87	12.41	7.59
58	20-10-93	32.92	13.42	6.60	37.00	11.81	7.54
59	20-10-93	31.89	13.81	6.27	31.53	12.86	6.12
60	20-10-93	27.91	17.01	5.83	33.84	12.39	6.03
61	27-10-93	26.72	16.36	6.11	24.44	14.42	4.63
62	27-10-93	31.21	14.98	6.95	36.26	12.69	6.49
63	27-10-93	22.50	19.81	5.66	34.77	13.74	6.39
64	27-10-93	34.12	14.15	7.42	39.14	10.79	6.42
65	27-10-93	33.11	14.62	7.46	38.68	11.55	7.00
66	27-10-93	33.64	14.53	7.19	43.27	10.99	7.48
67	22-12-93	26.20	15.91	5.96	34.07	10.51	7.21
68	22-12-93	25.40	18.48	5.80	41.91	10.29	6.54
69	22-12-93	29.85	15.41	6.36	39.83	11.98	7.11
70	22-12-93	31.98	12.43	7.19	40.36	10.68	7.08
71	22-12-93	33.46	12.49	7.26	44.56	9.51	6.93
72	22-12-93	35.16	13.50	7.11	38.39	10.75	6.19
73	12-01-94	30.40	15.35	7.14	41.46	11.82	7.15
74	12-01-94	27.14	15.19	5.66	34.00	11.77	5.91
75	12-01-94	32.15	15.36	7.41	39.84	12.03	6.62
76	12-01-94	32.91	14.50	6.88	40.41	13.33	7.25
77	12-01-94	26.02	17.95	5.73	37.51	12.29	6.51
78	12-01-94	31.09	13.59	6.00	35.48	13.02	6.44

Appendix a.14a Raw data on ***protein solubility*** of *ST* at *abattoir A*.

SN	DA	Total Protein		Protein Solubility							
				0.5 *M* KCl				0.1 *M* KCl			
		SW (g)	TP (%)	SW (g)	SP wt (g)	P wt (g)	TP (%)	SW (g)	SP wt (g)	P wt (g)	TP (%)
1	05-08-93	0.5008	20.62	*	*	*	*	*	*	*	*
2	05-08-93	0.5017	20.36	*	*	*	*	*	*	*	*
3	05-08-93	0.5022	20.35	*	*	*	*	*	*	*	*
4	05-08-93	0.5003	19.03	*	*	*	*	*	*	*	*
5	05-08-93	0.5024	20.50	*	*	*	*	*	*	*	*
6	05-08-93	0.5133	22.33	*	*	*	*	*	*	*	*
7	12-08-93	0.5015	19.61	*	*	*	*	*	*	*	*
8	12-08-93	0.5008	18.94	*	*	*	*	*	*	*	*
9	12-08-93	0.5017	20.84	*	*	*	*	*	*	*	*
10	12-08-93	0.5307	23.42	*	*	*	*	*	*	*	*
11	12-08-93	0.5023	21.40	*	*	*	*	*	*	*	*
12	12-08-93	0.5101	21.25	*	*	*	*	*	*	*	*
13	19-08-93	0.5012	20.18	*	*	*	*	*	*	*	*
14	19-08-93	0.5002	17.72	*	*	*	*	*	*	*	*
15	19-08-93	0.5005	20.10	*	*	*	*	*	*	*	*
16	19-08-93	0.5023	19.03	*	*	*	*	*	*	*	*
17	19-08-93	0.5102	21.81	*	*	*	*	*	*	*	*
18	19-08-93	0.5124	23.72	*	*	*	*	*	*	*	*
19	26-08-93	0.5051	22.16	*	*	*	*	*	*	*	*
20	26-08-93	0.5039	20.41	*	*	*	*	*	*	*	*
21	26-08-93	0.5036	19.17	*	*	*	*	*	*	*	*
22	26-08-93	0.5019	20.54	*	*	*	*	*	*	*	*
23	26-08-93	0.5034	20.00	*	*	*	*	*	*	*	*
24	26-08-93	0.5007	19.03	*	*	*	*	*	*	*	*
25	02-09-93	0.5009	20.34	*	*	*	*	*	*	*	*
26	02-09-93	0.5003	16.30	*	*	*	*	*	*	*	*
27	02-09-93	0.5010	19.17	*	*	*	*	*	*	*	*
28	02-09-93	0.5009	19.60	*	*	*	*	*	*	*	*
29	02-09-93	0.5008	19.54	*	*	*	*	*	*	*	*
30	02-09-93	0.5101	22.32	*	*	*	*	*	*	*	*

31	09-09-93	0.5011	20.61	*	*	*	*	*	*	*	*
32	09-09-93	0.5014	20.34	*	*	*	*	*	*	*	*
33	09-09-93	0.5078	21.38	*	*	*	*	*	*	*	*
34	09-09-93	0.5012	19.03	*	*	*	*	*	*	*	*
35	09-09-93	0.5009	19.70	*	*	*	*	*	*	*	*
36	09-09-93	0.5061	21.98	*	*	*	*	*	*	*	*
37	30-09-93	0.5024	19.67	10.01	10.44	09.52	10.69	10.01	09.43	10.51	5.94
38	30-09-93	0.5148	21.39	10.01	10.11	09.88	10.13	10.01	09.31	10.65	5.38
39	30-09-93	0.5417	22.09	10.02	10.53	09.45	10.50	10.01	09.81	10.15	5.88
40	30-09-93	0.5020	21.87	10.01	10.11	09.85	9.38	10.01	08.11	11.85	4.94
41	30-09-93	0.5037	22.32	10.01	09.14	10.81	9.88	10.01	09.01	10.94	4.69
42	30-09-93	0.5110	23.08	10.01	10.02	09.93	11.13	10.02	11.52	08.43	4.00
43	07-10-93	0.5013	20.73	10.01	10.02	09.95	9.06	10.01	09.02	10.94	5.13
44	07-10-93	0.5413	20.71	10.01	09.80	10.16	10.88	10.01	09.84	10.12	4.94
45	07-10-93	0.5046	19.44	10.01	09.43	10.55	9.81	10.01	08.47	11.50	5.00
46	07-10-93	0.5050	19.94	10.01	08.95	11.02	10.75	10.01	09.19	10.78	4.48
47	07-10-93	0.5044	19.66	10.01	09.22	10.77	9.06	10.01	10.14	09.82	3.38
48	07-10-93	0.5019	19.96	10.01	08.69	11.30	9.75	10.01	08.18	11.78	4.00
49	14-10-93	0.5040	20.83	10.02	09.50	10.46	10.00	10.01	09.55	10.40	4.63
50	14-10-93	0.5027	19.56	10.01	11.92	08.05	9.44	10.00	10.86	09.10	5.88
51	14-10-93	0.5038	19.72	10.01	10.70	09.26	8.31	10.02	09.10	10.85	3.44
52	14-10-93	0.5040	19.91	10.00	10.86	09.10	8.69	10.00	11.80	08.15	3.44
53	14-10-93	0.5072	19.73	10.02	10.04	09.89	9.56	10.01	10.83	09.14	3.62
54	14-10-93	0.5040	20.12	10.02	11.47	08.50	9.38	10.01	09.30	10.65	5.69
55	21-10-93	0.5085	17.02	10.02	10.49	09.47	8.19	10.01	09.46	10.49	4.56
56	21-10-93	0.5080	17.21	10.01	09.37	10.59	9.31	10.01	10.64	09.31	3.38
57	21-10-93	0.5006	16.70	10.02	11.59	08.38	8.25	10.03	10.67	09.33	4.63
58	21-10-93	0.5077	20.87	10.03	10.58	09.39	10.06	10.04	10.40	09.55	5.25
59	21-10-93	0.5074	21.08	10.02	10.50	09.46	8.56	10.02	10.35	09.60	3.31
60	21-10-93	0.5055	18.11	10.03	10.61	09.34	8.50	10.03	10.25	09.70	4.50
61	28-10-93	0.5065	19.63	10.02	08.81	11.12	9.75	10.02	10.13	09.81	3.25
62	28-10-93	0.5077	20.38	10.04	09.68	10.29	9.31	10.03	11.20	08.75	3.13
63	28-10-93	0.5056	20.01	10.05	09.72	10.25	9.75	10.01	10.37	09.59	3.62
64	28-10-93	0.5096	19.33	10.02	09.64	10.31	9.63	10.04	10.06	09.90	3.94
65	28-10-93	0.5052	20.17	10.02	10.41	09.52	8.63	10.01	11.62	08.34	3.25

66	28-10-93	0.5080	16.46	10.03	10.97	09.01	9.56	10.04	12.54	07.40	5.38
67	23-12-93	0.5019	19.27	10.01	10.65	09.28	8.94	10.01	11.25	08.70	4.13
68	23-12-93	0.5027	19.31	10.01	10.99	09.00	9.00	10.02	11.08	08.88	4.50
69	23-12-93	0.5021	19.77	10.01	10.73	09.24	9.06	10.01	11.56	08.40	3.62
70	23-12-93	0.5043	19.98	10.02	10.14	09.81	9.25	10.02	10.72	09.24	4.00
71	23-12-93	0.5051	19.96	10.01	09.92	10.05	9.75	10.00	10.76	09.19	4.19
72	23-12-93	0.5061	19.71	10.02	10.03	09.96	9.06	10.01	10.83	09.13	3.50
73	13-01-94	0.5103	18.30	10.03	09.09	10.86	9.50	10.01	10.77	09.18	3.50
74	13-01-94	0.5071	17.21	10.02	08.88	11.07	10.44	10.02	09.78	10.18	4.69
75	13-01-94	0.5052	17.90	10.02	09.42	10.55	8.94	10.02	11.30	08.65	4.13
76	13-01-94	0.5042	19.39	10.02	10.39	09.58	9.75	10.00	10.56	09.39	4.88
77	13-10-94	0.5045	19.17	10.02	09.39	10.56	9.69	10.01	09.38	10.57	4.31
78	13-01-94	0.5071	19.48	10.00	09.74	10.22	10.25	10.02	10.19	09.77	4.81

ST = semitendinosus; SN = sample number; DA = date analyzed; SW = sample weight; TP = total protein; SP = supernatant; P = precipitate; wt = weight.

Appendix a.14b Raw data on *protein solubility* of *LD* at *abattoir A.*

S N	DA	Total Protein		Protein Solubility							
				0.5 *M* KCl				0.1 *M* KCl			
		SW (g)	TP (%)	SW (g)	SP wt (g)	P wt (g)	TP (%)	SW (g)	SP wt (g)	P wt (g)	TP (%)
1	05-08-93	0.5019	19.61	*	*	*	*	*	*	*	*
2	05-08-93	0.5028	19.12	*	*	*	*	*	*	*	*
3	05-08-93	0.5102	20.93	*	*	*	*	*	*	*	*
4	05-08-93	0.5091	18.72	*	*	*	*	*	*	*	*
5	05-08-93	0.5018	20.66	*	*	*	*	*	*	*	*
6	05-08-93	0.5191	21.96	*	*	*	*	*	*	*	*
7	12-08-93	0.5023	19.49	*	*	*	*	*	*	*	*
8	12-08-93	0.5007	18.70	*	*	*	*	*	*	*	*
9	12-08-93	0.5046	21.05	*	*	*	*	*	*	*	*
10	12-08-93	0.5204	24.05	*	*	*	*	*	*	*	*
11	12-08-93	0.5038	19.46	*	*	*	*	*	*	*	*
12	12-08-93	0.5040	21.03	*	*	*	*	*	*	*	*
13	19-08-93	0.5009	19.37	*	*	*	*	*	*	*	*

14	19-08-93	0.5025	18.32	*	*	*	*	*	*	*	*
15	19-08-93	0.5014	19.03	*	*	*	*	*	*	*	*
16	19-08-93	0.5025	18.42	*	*	*	*	*	*	*	*
17	19-08-93	0.5022	19.15	*	*	*	*	*	*	*	*
18	19-08-93	0.5034	23.12	*	*	*	*	*	*	*	*
19	26-08-93	0.5039	19.80	*	*	*	*	*	*	*	*
20	26-08-93	0.5042	19.64	*	*	*	*	*	*	*	*
21	26-08-93	0.5017	18.75	*	*	*	*	*	*	*	*
22	26-08-93	0.5029	18.83	*	*	*	*	*	*	*	*
23	26-08-93	0.5012	18.99	*	*	*	*	*	*	*	*
24	26-08-93	0.5001	17.93	*	*	*	*	*	*	*	*
25	02-09-93	0.5011	18.30	*	*	*	*	*	*	*	*
26	02-09-93	0.5002	14.94	*	*	*	*	*	*	*	*
27	02-09-93	0.5001	14.15	*	*	*	*	*	*	*	*
28	02-09-93	0.5121	24.36	*	*	*	*	*	*	*	*
29	02-09-93	0.5016	18.28	*	*	*	*	*	*	*	*
30	02-09-93	0.5017	21.94	*	*	*	*	*	*	*	*
31	09-09-93	0.5002	17.48	*	*	*	*	*	*	*	*
32	09-09-93	0.5002	17.18	*	*	*	*	*	*	*	*
33	09-09-93	0.5008	18.97	*	*	*	*	*	*	*	*
34	09-09-93	0.5001	16.36	*	*	*	*	*	*	*	*
35	09-09-93	0.5012	16.69	*	*	*	*	*	*	*	*
36	09-09-93	0.5132	23.27	*	*	*	*	*	*	*	*
37	29-09-93	0.5009	22.53	10.01	09.02	10.93	7.75	10.01	10.44	09.50	3.31
38	29-09-93	0.5241	22.69	10.01	09.93	10.02	8.25	10.01	10.13	09.80	3.69
39	29-09-93	0.5222	22.20	10.01	10.40	09.54	8.13	10.01	11.01	08.90	3.81
40	29-09-93	0.5431	21.28	10.01	10.00	09.97	7.44	10.01	11.12	08.80	3.94
41	29-09-93	0.5021	21.17	10.02	10.48	09.48	10.13	10.02	11.23	08.70	4.69
42	29-09-93	0.5416	24.75	10.01	10.02	09.92	10.13	10.02	11.54	08.41	3.38
43	07-10-93	0.5041	19.11	10.01	10.18	09.78	8.63	10.01	12.43	07.52	4.69
44	07-10-93	0.5019	20.78	10.01	10.58	09.38	9.31	10.01	10.63	09.32	4.38
45	07-10-93	0.5014	20.14	10.01	11.30	08.65	8.19	10.01	11.42	08.51	5.19
46	07-10-93	0.5033	19.83	10.01	09.15	10.80	10.63	10.01	09.47	10.49	5.06
47	07-10-93	0.5022	20.70	10.01	09.55	10.40	8.81	10.01	09.73	10.22	4.69
48	07-10-93	0.5022	20.18	10.01	11.05	08.90	7.31	10.01	12.02	07.93	3.88

49	14-10-93	0.5075	19.47	10.01	10.84	09.10	8.56	10.02	11.96	08.00	4.19
50	14-10-93	0.5076	19.49	10.01	08.53	11.40	10.44	10.02	10.70	09.00	3.44
51	14-10-93	0.5034	20.40	10.02	09.63	10.30	6.69	10.02	12.09	07.88	2.88
52	14-10-93	0.5024	20.39	10.02	11.63	08.31	8.63	10.02	10.06	09.89	5.13
53	14-10-93	0.5034	21.30	10.01	10.46	09.49	9.88	10.02	09.25	10.70	5.00
54	14-10-93	0.5024	20.95	10.01	09.95	10.00	7.50	10.02	11.79	08.15	3.44
55	21-10-93	0.5138	20.99	10.03	11.74	08.21	7.69	10.02	11.72	08.20	5.13
56	21-10-93	0.5055	19.00	10.03	11.59	08.37	8.81	10.04	12.37	07.59	4.69
57	21-10-93	0.5109	18.93	10.01	11.59	08.35	7.44	10.01	12.38	07.57	4.75
58	21-10-93	0.5097	18.85	10.02	11.27	08.70	7.00	10.03	12.45	07.50	4.19
59	21-10-93	0.5049	18.84	10.01	11.96	08.00	9.13	10.02	11.60	08.31	5.25
60	21-10-93	0.5066	19.89	10.02	11.19	08.74	8.56	10.03	12.30	07.65	4.00
61	28-10-93	0.5040	20.82	10.01	08.62	11.32	10.50	10.01	10.82	09.10	3.31
62	28-10-93	0.5013	19.08	10.01	10.48	09.46	8.63	10.00	11.91	08.02	3.56
63	28-10-93	0.5079	20.47	10.02	10.82	09.14	8.50	10.02	12.12	07.80	3.62
64	28-10-93	0.5101	18.58	10.03	11.45	08.50	9.13	10.02	12.63	07.30	4.94
65	28-10-93	0.5127	20.72	10.04	10.88	09.08	8.00	10.01	12.43	07.52	3.94
66	28-10-93	0.5084	17.38	10.02	11.51	08.45	6.38	10.01	12.68	07.25	4.06
67	23-12-93	0.5032	19.51	10.02	09.50	10.45	9.31	10.01	10.09	09.92	3.81
68	23-12-93	0.5049	20.19	10.02	09.91	10.05	7.44	10.02	11.81	08.13	3.69
69	23-12-93	0.5011	19.70	10.01	09.79	10.15	8.25	10.01	11.85	08.12	3.06
70	23-12-93	0.5074	19.87	10.02	10.75	09.20	8.19	10.02	11.65	08.30	3.50
71	23-12-93	0.5032	20.34	10.01	09.52	10.40	7.38	10.01	11.09	08.85	3.62
72	23-12-93	0.5035	20.88	10.02	09.98	10.00	7.31	10.02	11.82	08.14	3.13
73	13-01-94	0.5038	19.71	10.01	10.86	09.09	6.25	10.01	12.25	07.70	3.50
74	13-10-94	0.5038	16.80	10.00	08.93	11.01	10.00	10.02	10.36	09.59	4.31
75	13-01-94	0.5026	17.85	10.02	11.17	08.78	7.31	10.02	12.29	07.65	4.94
76	13-01-94	0.5055	19.30	10.02	11.20	08.75	7.88	10.01	11.91	08.03	5.06
77	13-01-94	0.5049	17.68	10.03	09.82	10.15	8.00	10.00	11.41	08.54	4.63
78	13-01-94	0.5042	17.10	10.01	10.86	09.10	9.25	10.00	11.90	08.05	4.81

LD = longissimus dorsi; SN = sample number; DA = date analyzed; SW = sample weight; TP = total protein; SP = supernatant; P = precipitate; wt = weight.

Appendix a.15 Mean of raw data on pH_1, pH_{24}, *WHC* and ***drip loss*** at *abattoir A.*

Sample No.	pH_1		pH		WHC (%)		Drip Loss (%)	
	ST	LD	ST	LD	ST	LD	ST	LD
1	5.91	5.89	5.85	5.73	55.13	51.90	1.81	3.34
2	5.87	5.77	5.72	5.59	56.30	48.00	2.55	3.36
3	6.05	5.96	5.99	5.77	58.97	56.03	2.30	2.90
4	5.72	5.71	5.43	5.39	53.80	49.60	5.12	5.48
5	6.23	6.31	5.95	6.02	57.00	59.70	2.02	2.35
6	6.38	6.18	6.21	6.01	60.90	58.17	1.11	2.61
7	5.75	5.83	5.51	5.46	53.60	50.93	3.24	4.17
8	5.80	5.78	5.41	5.55	54.27	47.23	2.72	7.08
9	6.22	5.97	5.90	5.73	57.07	56.97	2.21	2.16
10	6.54	6.50	6.30	6.39	63.13	59.57	1.06	2.08
11	6.36	5.95	6.10	5.74	56.03	55.00	2.26	4.01
12	6.13	6.00	5.84	5.75	56.03	56.90	2.31	2.08
13	6.21	5.79	5.91	5.42	56.93	51.40	2.29	7.02
14	5.80	5.81	5.57	5.59	53.47	56.83	2.24	2.68
15	6.30	5.70	6.03	5.60	59.73	53.10	2.23	3.05
16	5.87	5.73	5.62	5.32	58.67	50.03	2.42	6.79
17	6.48	5.70	6.14	5.67	63.07	49.70	1.29	3.71
18	6.44	6.48	6.35	6.23	61.40	63.50	1.18	1.20
19	6.22	6.05	6.14	5.79	57.90	57.80	2.78	2.02
20	5.95	5.68	5.70	5.32	56.87	50.07	2.86	3.71
21	5.86	5.76	5.65	5.40	56.80	50.00	2.07	6.13
22	6.02	5.80	5.96	5.50	61.33	50.40	0.92	3.21
23	6.03	5.75	5.95	5.30	60.77	50.30	0.93	5.62
24	5.61	5.61	5.45	5.23	48.13	43.87	4.78	6.81
25	6.24	6.21	5.98	5.95	58.13	58.27	2.39	2.02
26	5.76	5.69	5.32	5.00	50.03	43.23	4.15	6.27
27	6.13	5.73	5.72	5.25	61.30	50.13	1.24	4.60
28	6.75	6.78	6.41	6.67	64.30	72.23	0.76	0.96
29	6.12	5.62	5.80	5.45	62.87	52.07	1.05	2.93
30	6.17	6.06	5.98	5.82	63.17	60.77	1.21	1.73
31	6.01	5.62	5.70	5.20	58.37	49.33	2.29	5.46
32	5.60	5.55	5.41	5.25	58.00	48.10	2.64	5.52

33	5.88	5.60	5.69	5.15	61.33	52.23	1.20	5.76
34	5.75	5.49	5.35	5.12	56.63	45.40	2.48	6.68
35	5.68	5.61	5.52	5.20	56.63	45.70	2.75	7.17
36	6.48	6.15	6.29	5.92	69.43	61.67	0.92	1.34
37	6.48	5.68	6.17	5.41	62.30	50.10	1.51	5.55
38	6.22	6.04	5.73	5.62	57.33	53.03	2.38	4.64
39	6.43	6.05	5.89	5.42	58.07	53.07	2.03	4.77
40	6.35	5.87	5.87	5.33	57.50	48.03	2.18	6.39
41	6.19	6.06	5.75	5.82	57.93	56.20	2.09	2.10
42	6.62	6.46	6.42	6.25	66.13	69.03	1.16	1.55
43	5.85	5.81	5.43	5.35	53.73	49.20	3.59	5.38
44	6.42	6.28	6.02	5.81	63.93	58.37	1.14	2.66
45	6.30	5.86	5.85	5.28	57.00	50.20	2.21	5.24
46	6.64	6.35	6.45	6.11	64.27	60.13	1.07	2.16
47	6.28	6.05	5.85	5.63	59.37	53.63	2.04	4.42
48	6.49	5.89	5.88	5.28	59.87	48.57	2.07	6.93
49	6.36	5.89	6.02	5.48	60.10	55.30	2.35	3.85
50	6.69	6.66	6.31	6.38	65.27	65.30	1.12	1.64
51	6.44	5.79	6.12	5.39	57.53	50.13	2.49	6.84
52	6.65	6.43	6.33	5.89	64.90	59.00	1.03	2.50
53	6.57	6.67	6.38	6.52	65.00	68.03	1.14	1.17
54	6.42	5.82	6.02	5.39	63.83	49.73	1.18	5.39
55	6.18	5.76	5.91	5.40	57.07	50.17	2.05	6.02
56	6.59	5.79	6.46	5.58	64.87	53.63	1.04	3.44
57	6.60	5.79	6.02	5.35	62.17	50.40	1.32	5.36
58	6.48	6.07	6.28	5.62	57.00	50.77	2.14	5.54
59	6.50	6.63	6.32	6.38	62.30	65.30	1.26	1.24
60	6.61	6.24	6.34	5.85	62.00	55.67	1.71	2.86
61	6.90	6.82	6.53	6.40	67.43	67.20	0.93	1.36
62	6.72	6.44	6.23	5.90	65.33	59.57	1.47	2.70
63	6.91	6.25	6.51	5.68	70.07	55.37	0.82	3.58
64	6.68	6.04	6.29	5.50	64.93	55.07	1.08	3.31
65	6.79	5.99	6.21	5.51	63.93	55.20	1.46	4.73
66	6.41	5.76	5.81	5.43	60.00	53.13	2.03	5.98
67	6.59	6.35	6.29	5.62	65.00	59.63	1.97	2.70

68	6.53	5.79	6.28	5.42	60.57	50.20	1.96	6.25
69	6.47	5.85	6.22	5.45	61.73	49.03	1.03	4.46
70	6.35	6.16	6.05	5.48	63.53	51.97	1.96	4.51
71	6.35	5.88	6.11	5.42	63.87	50.03	1.91	6.48
72	6.16	5.80	6.01	5.55	62.20	49.27	1.11	5.06
73	6.08	6.00	5.92	5.31	62.93	50.13	1.93	6.92
74	6.58	6.40	6.43	5.89	66.77	60.23	1.02	2.45
75	6.13	6.03	5.38	5.26	53.23	49.60	4.84	6.36
76	6.35	5.82	5.85	5.31	60.77	50.27	1.15	5.98
77	6.78	6.07	6.53	5.58	64.03	54.87	1.15	5.55
78	6.43	6.06	6.25	5.45	61.90	55.97	1.16	3.79
Mean	6.28	5.99	5.98	5.62	60.19	54.05	1.91	4.15

Appendix a.16 Mean of raw data on ***colour*** and ***protein solubility*** at *abattoir A*.

S N	Visual Colour		Colour Hunter (*L*)		Colour Hunter (*A*)		Colour Hunter (*B*)		Protein Solubility	
	ST	LD	ST	LD	ST	LD	ST	LD	ST	LD
1	2	3	31.51	35.30	15.58	14.45	7.53	6.75	*	*
2	2	4	28.87	40.63	16.23	12.55	7.17	8.22	*	*
3	2	2	28.88	32.24	15.44	12.49	6.32	8.50	*	*
4	4	4	36.75	38.40	11.54	12.87	8.07	7.13	*	*
5	2	2	29.69	30.26	13.33	14.87	4.59	6.18	*	*
6	1	2	26.14	29.52	16.64	15.95	6.46	6.28	*	*
7	3	3	28.00	35.34	14.00	11.33	5.37	6.18	*	*
8	3	4	36.07	39.66	13.43	12.01	7.93	7.14	*	*
9	2	2	33.16	34.26	12.24	10.55	6.73	5.46	*	*
10	0	0	23.44	24.43	17.24	11.48	5.83	4.92	*	*
11	2	3	28.06	34.32	13.58	12.35	6.20	5.98	*	*
12	2	2	32.62	32.58	14.72	12.84	7.02	6.35	*	*
13	2	3	28.68	35.28	14.16	12.94	6.33	7.59	*	*
14	3	3	37.35	38.44	13.30	12.39	7.37	6.23	*	*
15	2	3	28.67	34.99	16.15	12.51	6.07	7.40	*	*
16	3	4	27.63	35.61	15.28	12.31	6.32	7.12	*	*
17	1	3	24.93	33.66	16.19	12.54	5.48	6.91	*	*

18	0	1	23.63	29.11	16.07	11.82	4.95	5.22	*	*
19	1	2	20.30	28.36	22.36	14.03	5.20	5.06	*	*
20	3	4	35.89	38.34	11.36	12.80	6.77	7.35	*	*
21	3	3	31.54	38.01	14.91	12.80	6.96	7.70	*	*
22	2	3	32.67	36.17	15.19	10.49	6.63	5.58	*	*
23	1	4	24.56	38.67	16.04	11.54	5.14	7.59	*	*
24	3	4	36.10	42.98	14.36	11.62	7.46	6.96	*	*
25	2	2	33.43	35.49	15.67	10.89	7.92	6.18	*	*
26	3	4	33.77	44.60	17.01	13.17	8.71	9.29	*	*
27	3	4	36.18	38.64	12.76	13.81	7.54	8.25	*	*
28	1	0	22.32	21.73	19.73	19.14	5.15	4.66	*	*
29	2	3	32.70	36.74	13.52	10.89	6.76	7.57	*	*
30	1	2	29.63	33.20	13.57	13.26	6.01	7.06	*	*
31	2	4	28.57	40.76	14.98	10.53	6.32	6.72	*	*
32	3	4	34.23	40.09	13.38	11.42	7.95	7.46	*	*
33	2	4	27.18	33.88	16.21	16.73	5.98	7.94	*	*
34	3	4	39.46	43.20	12.10	12.11	8.36	8.21	*	*
35	3	4	34.75	42.90	13.96	11.41	7.48	7.89	*	*
36	1	2	30.44	34.61	15.62	11.22	6.70	6.85	*	*
37	2	4	28.14	42.01	16.06	13.17	6.30	8.50	56.54	31.00
38	2	3	28.59	37.51	14.95	13.23	6.10	7.83	59.05	39.59
39	2	3	26.93	39.03	15.37	12.59	6.10	7.63	51.09	37.97
40	2	4	29.99	40.23	14.60	12.48	6.76	8.34	51.06	27.85
41	2	2	33.42	36.09	13.82	8.58	7.19	6.83	43.17	50.50
42	1	1	27.79	32.38	16.14	12.64	6.07	6.30	58.39	53.36
43	3	4	39.97	40.16	12.75	12.33	7.92	6.92	42.94	32.19
44	2	3	38.75	39.44	11.09	10.40	6.60	6.07	56.30	50.26
45	2	4	34.72	49.09	15.59	12.04	8.10	9.05	51.41	32.93
46	1	2	31.17	33.26	15.40	12.04	6.68	6.09	55.19	49.75
47	2	3	29.70	40.09	17.58	11.10	6.98	6.60	49.95	36.99
48	3	4	31.71	42.21	10.89	11.17	8.11	7.27	52.10	33.91
49	2	3	27.16	41.21	14.70	11.21	5.82	7.70	49.06	44.13
50	2	1	25.70	35.92	17.37	10.53	5.86	6.10	50.13	53.25
51	2	4	28.83	41.97	14.54	11.45	5.89	7.93	58.15	29.01
52	1	2	24.69	33.87	13.80	9.51	7.15	7.16	54.00	47.84

53	1	1	26.73	26.71	14.98	12.26	5.55	5.06	57.33	54.14
54	1	4	27.93	40.08	15.55	11.68	6.41	7.78	54.39	32.22
55	2	3	29.74	39.46	15.16	12.43	6.53	7.81	49.24	27.38
56	1	3	30.69	37.77	14.42	12.03	6.56	7.42	56.42	47.24
57	1	4	26.28	38.87	16.21	12.41	6.61	7.59	54.50	30.56
58	2	3	32.92	37.00	13.42	11.81	6.60	7.54	49.68	29.88
59	1	1	31.89	31.53	13.81	12.86	6.27	6.12	53.88	51.85
60	1	2	27.91	33.84	17.01	12.39	5.83	6.03	48.49	47.01
61	0	1	26.72	24.44	16.36	14.42	6.11	4.63	53.66	53.24
62	1	2	31.21	36.26	14.98	12.69	6.95	6.49	54.60	49.93
63	0	3	22.50	34.77	19.81	13.74	5.66	6.39	57.27	47.14
64	1	3	34.12	39.14	14.15	10.79	7.42	6.42	54.62	46.69
65	1	4	33.11	38.68	14.62	11.55	7.46	7.00	51.73	36.51
66	2	4	33.64	43.27	14.53	10.99	7.19	7.48	49.59	28.69
67	1	2	26.20	34.07	15.91	10.51	5.96	7.21	50.48	51.01
68	1	4	25.40	41.91	18.48	10.29	5.80	6.54	50.83	29.85
69	1	4	29.85	39.83	15.41	11.98	6.36	7.11	55.84	45.06
70	1	3	31.98	40.36	12.43	10.68	7.19	7.08	51.04	47.62
71	1	4	33.46	44.56	12.49	9.51	7.26	6.93	51.80	29.41
72	1	4	35.16	38.39	13.50	10.75	7.11	6.19	53.59	34.52
73	2	4	30.40	41.46	15.35	11.82	7.14	7.15	51.91	25.67
74	1	2	27.14	34.00	15.19	11.77	5.66	5.91	53.34	51.77
75	3	4	32.15	39.84	15.35	12.03	7.41	6.62	42.54	27.62
76	2	4	32.91	40.41	14.50	13.33	6.88	7.25	51.43	30.11
77	1	4	26.02	37.51	17.95	12.29	5.73	6.51	52.26	32.00
78	1	3	31.09	35.48	13.59	13.02	6.00	6.44	52.13	51.47
M	1.76	2.97	30.28	36.88	14.97	12.19	6.62	6.91	52.41	40.22

SN = sample number; M = mean.

APPENDIX B

Appendix b.1 Mean, standard error (se), standard deviation (sd), and range values for the pork quality parameters of *ST* and *LD*.

		N	Mean	SE	SD	Range
pH_1[a]	ST	78	6.28	0.04	0.32	5.60 - 6.91
	LD	78	5.99	0.03	0.31	5.49 - 6.82
pH_{24}[a]	ST	78	5.98	0.04	0.32	5.32 - 6.53
	LD	78	5.62	0.04	0.36	5.00 - 6.67
pH_1[b]	ST	36	5.79	0.24	1.44	5.44 - 6.42
	LD	66	5.84	0.11	0.61	5.41 - 6.46
pH_{24}[b]	ST	23	5.61	0.07	0.31	5.27 - 6.32
	LD	53	5.58	0.05	0.23	5.21 - 6.29
WHC	ST	78	60.19	0.48	4.28	48.13 - 70.07
	LD	78	54.05	0.67	5.92	43.23 - 72.23
DL	ST	78	1.91	0.10	0.92	0.76 - 5.12
	LD	78	4.15	0.21	1.84	0.96 - 7.17
L	ST	78	30.28	0.47	4.16	20.30 - 39.97
	LD	78	36.88	0.55	4.88	21.73 - 49.09
A	ST	78	14.97	0.22	1.96	10.89 - 22.36
	LD	78	12.19	0.18	1.56	8.58 - 19.14
B	ST	78	6.62	0.10	0.86	4.59 - 8.71
	LD	78	6.91	0.11	0.97	4.63 - 9.29
Chroma	ST	78	16.45	0.19	1.66	12.91 - 22.96
	LD	78	14.09	0.16	1.44	10.97 - 19.70
Hue	ST	78	2.24	0.09	0.82	1.08 - 7.49
	LD	78	1.62	0.05	0.46	0.98 - 4.03
OVS	ST	78	1.76	0.10	0.87	0 - 4.0
	LD	78	2.97	0.12	1.08	0 - 4.0
PS	ST	78	52.41	0.43	3.84	42.54 - 59.05
	LD	78	40.22	1.10	9.70	25.67 - 54.14

[a] = abattoir A; [b] = abattoir B; N = number of observation; WHC = water holding capacity; DL = drip loss; L = colour lightness; A = colour redness; B = colour yellowness; OVS = overall visual score; PS = protein solubility.

Appendix b.2 ANOVA result of *ST* on pre-slaughter effects with pH_1 as dependent variable.

Variables	Parameter Estimate	Standard Error	T values	Level of Significance
Intercep	5.4580	3.5622	1.532	0.1302
Weight	0.0099	0.0085	1.175	0.2441
Sex	-0.2576	0.0702	-3.671	0.0005
Farmer's name	0.1208	0.1754	0.689	0.4934
Loading time	-0.0225	0.0100	-2.262	0.0269
Travel time	0.2176	0.1360	1.600	0.1142
Distance of travel	-0.2124	0.1532	-1.386	0.1702
Time of last feeding	-0.0051	0.0044	-1.149	0.2547
Resting time	0.3965	0.1823	2.175	0.0332
Slaughter time	-0.0052	0.0019	-2.780	0.0070
Weather condition	-0.0239	0.0176	-1.358	0.1790

F value = 3.121 R-square = 31.78% C.V. = 4.55621

Appendix b.3 ANOVA result of *LD* on pre-slaughter effects with pH_1 as independent variable.

Variable	Parameter Estimate	Standard Error	T values	Level of Significance
Intercep	6.9678	3.4384	2.026	0.0467
Weight	0.0032	0.0082	0.392	0.6963
Sex	-0.3114	0.0677	-4.599	0.0001
Farmer's name	-0.0406	0.1693	-0.240	0.8112
Loading time	-0.0073	0.0096	-0.760	0.4500
Travel time	0.0395	0.1313	0.301	0.7647
Distance of travel	-0.0533	0.1479	-0.360	0.7198
Time of last feeding	-0.00008	0.0043	-0.019	0.9847
Resting time	0.0674	0.1760	0.383	0.7029
Slaughter time	-0.0018	0.0018	-0.987	0.3271
Weather condition	-0.0129	0.0170	-0.758	0.4509

F vlaue = 2.903 R-square = 30.23% C.V. = 4.61074

Appendix b.4 ANOVA result of *ST* with pH_1 as independent variable.

Variables	Parameter Estimate	Standard Error	T values	Level of Significance
Intercep	-0.0655	0.8516	-0.077	0.9389
pH_{24}	0.8827	0.1135	7.778	0.0001
WHC	0.0151	0.0080	1.884	0.0637
Drip loss	0.0417	0.0327	1.274	0.2069
Colour L	-0.0080	0.0085	-0.937	0.3518
Colour A	-0.0056	0.0127	-0.439	0.6620
Colour B	0.0601	0.0319	1.884	0.0637
Visual Score	0.0022	0.0404	0.055	0.9566

F value = 50.867 R-square = 83.57 % C.V. = 2.1875

Appendix b.5 ANOVA result of *LD* with pH_1 as independent variable.

Variables	Parameter Estimate	Standard Error	T values	Level of Significance
Intercep	1.8280	0.7967	2.294	0.0248
pH_{24}	0.4132	0.1256	3.289	0.0016
WHC	0.0295	0.0065	4.524	0.0001
Drip loss	0.0453	0.0159	2.849	0.0057
Colour L	0.0136	0.0074	1.838	0.0702
Colour A	-0.0015	0.0120	-0.129	0.8980
Colour B	-0.0313	0.0241	-1.301	0.1975
Visual Score	-0.0708	0.0414	-1.709	0.0919

F value = 60.799 R-square = 85.88 % C.V. = 2.0296

Appendix b.6 ANOVA result of *ST* with pH_{24} as independent variable.

Variables	Parameter Estimate	Standard Error	T values	Level of Significance
Intercep	4.9125	0.8642	5.685	0.0001
WHC	0.0262	0.0084	3.139	0.0025
Drip loss	-0.0033	0.0352	-0.094	0.9253
Colour L	0.0046	0.0098	0.473	0.6381
Colour A	-0.1063	0.2805	-0.379	0.7059
Colour B	-0.1036	0.2001	-0.518	0.6062
Overall visual score	-0.1194	0.0717	-1.665	0.1006
Chroma	0.1241	0.3342	0.371	0.7116
Hue	-0.0101	0.1611	-0.063	0.9502
Wetness	-0.0187	0.0487	-0.384	0.7019
Visual colour	-0.0275	0.0419	-0.656	0.5143
Texture	-0.0494	0.0416	-1.187	0.2395

F value = 29.234 R-square = 82.97 % C.V. = 2.3979

Appendix b.7 ANOVA result of *LD* with pH_{24} as independent variable.

Variables	Parameter Estimate	Standard Error	T values	Level of Significance
Intercep	4.8830	0.5208	9.375	0.0001
WHC	0.0221	0.0055	4.022	0.0002
Drip loss	-0.0052	0.0148	-0.348	0.7289
Colour L	-0.0000	0.0070	-0.003	0.9973
Colour A	0.0598	0.0389	1.538	0.1288
Colour B	0.0932	0.0949	0.982	0.3297
Overall visual score	-0.0315	0.0546	-0.577	0.5657
Chroma	-0.1240	0.0649	-1.910	0.0605
Hue	0.2623	0.2156	1.217	0.2280
Wetness	-0.0304	0.0291	-1.047	0.2987
Visual colour	-0.0168	0.0357	-0.470	0.6396
Texture	-0.0925	0.0333	-2.777	0.0071

F value = 65.983 R-square = 91.66 % C.V. = 1.9700

Appendix b.8 Pearson correlation coefficient analysis of *ST*.

Variables	pH_i	pH	WHC	DL	CL	CA	CB	Chroma	Hue	Wetness	VCS	Texture	OVS
pH	+0.90 (0.0001)	-	-	-	-	-	-	-	-	-	-	-	-
WHC	+0.78 (0.0001)	+0.81 (0.0001)	-	-	-	-	-	-	-	-	-	-	-
DL	-0.65 (0.0001)	-0.74 (0.0001)	-0.83 (0.0001)	-	-	-	-	-	-	-	-	-	-
CL	-0.51 (0.0001)	-0.59 (0.0001)	-0.43 (0.0001)	+0.41 (0.0002)	-	-	-	-	-	-	-	-	-
CA	+0.35 (0.0018)	+0.41 (0.0002)	+0.25 (0.0249)	-0.22 (0.0500)	-0.74 (0.0001)	-	-	-	-	-	-	-	-
CB	-0.44 (0.0001)	-0.58 (0.0001)	-0.40 (0.0003)	+0.45 (0.0001)	+0.78 (0.0001)	-0.47 (0.0001)	-	-	-	-	-	-	-
Chroma	*	+0.32 (0.004)	+0.17 (0.1407)	-0.13 (0.2527)	-0.65 (0.0001)	+0.97 (0.0001)	-0.30 (0.0069)	-	-	-	-	-	-
Hue	*	+0.41 (0.0002)	+0.16 (0.1614)	-0.21 (0.0615)	-0.65 (0.0001)	+0.53 (0.0001)	-0.62 (0.0001)	+0.57 (0.0001)	-	-	-	-	-
Wetness	*	-0.82 (0.0001)	-0.72 (0.0001)	+0.68 (0.0001)	+0.60 (0.0001)	-0.44 (0.0001)	+0.55 (0.0001)	-0.35 (0.0018)	-0.36 (0.0013)	-	-	-	-
VCS	*	-0.71 (0.0001)	-0.58 (0.0001)	+0.54 (0.0001)	+0.83 (0.0001)	-0.70 (0.0001)	+0.68 (0.0001)	-0.61 (0.0001)	-0.55 (0.0001)	+0.70 (0.0001)	-	-	-
Texture	*	-0.81 (0.0001)	-0.72 (0.0001)	+0.67 (0.0001)	+0.49 (0.0001)	-0.30 (0.008)	+0.52 (0.0001)	-0.20 (0.0738)	-0.29 (0.0094)	+0.81 (0.0001)	+0.63 (0.0001)	-	-
OVS	-0.78 (0.0001)	-0.87 (0.0001)	-0.77 (0.0001)	+0.73 (0.0001)	+0.62 (0.0001)	-0.48 (0.0001)	+0.56 (0.0001)	-0.39 (0.0005)	-0.38 (0.0007)	+0.93 (0.0001)	+0.77 (0.0001)	+0.87 (0.0001)	-
PS	+0.49 (0.0009)	+0.57 (0.0001)	+0.57 (0.0001)	-0.65 (0.0001)	-0.32 (0.0360)	+0.10 (0.5180)	-0.39 (0.0105)	+0.04 (0.8250)	+0.25 (0.1067)	-0.43 (0.0046)	-0.27 (0.0831)	-0.53 (0.0003)	-0.50 (0.0007)

WHC = water holding capacity; DL = drip loss; CL = tristimulus colour L; CA = tristimulus colour A; CB = tristimulus colour B;
VCS = visual colour score; OVS = overall visual score; PS = protein solubility.

Appendix b.9 Pearson correlation coefficient analysis of *LD*.

Variables	pH_1	pH_{24}	WHC	DL	CL	CA	CB	Chroma	Hue	Wetness	VCS	Texture	VS
pH_{24}	+0.89 (0.0001)	-	-	-	-	-	-	-	-	-	-	-	-
WHC	+0.89 (0.0001)	+0.92 (0.0001)	-	-	-	-	-	-	-	-	-	-	-
DL	-0.72 (0.0001)	-0.84 (0.0001)	-0.85 (0.0001)	-	-	-	-	-	-	-	-	-	-
CL	-0.69 (0.0001)	-0.82 (0.0001)	-0.78 (0.0001)	+0.75 (0.0001)	-	-	-	-	-	-	-	-	-
CA	+0.14 (0.2098)	+0.21 (0.0706)	+0.23 (0.0416)	-0.13 (0.2618)	-0.45 (0.0001)	-	-	-	-	-	-	-	-
CB	-0.67 (0.0001)	-0.73 (0.0001)	-0.68 (0.0001)	+0.63 (0.0001)	+0.72 (0.0001)	-0.08 (0.4987)	-	-	-	-	-	-	-
Chroma	*	-0.03 (0.8123)	+0.01 (0.9264)	+0.07 (0.5696)	-0.22 (0.0502)	+0.93 (0.0001)	+0.22 (0.0584)	-	-	-	-	-	-
Hue	*	+0.65 (0.0001)	+0.63 (0.0001)	-0.52 (0.0001)	-0.79 (0.0001)	+0.70 (0.0001)	-0.74 (0.0001)	+0.49 (0.0001)	-	-	-	-	-
Wetness	*	-0.87 (0.0001)	-0.85 (0.0001)	+0.81 (0.0001)	+0.79 (0.0001)	-0.21 (0.0707)	+0.61 (0.0001)	+0.02 (0.8885)	-0.58 (0.0001)	-	-	-	-
VCS	*	-0.87 (0.0001)	-0.86 (0.0001)	+0.81 (0.0001)	+0.86 (0.0001)	-0.35 (0.0017)	+0.66 (0.0001)	-0.15 (0.2010)	-0.70 (0.0001)	+0.85 (0.0001)	-	-	-
Texture	*	-0.88 (0.0001)	-0.81 (0.0001)	+0.79 (0.0001)	+0.81 (0.0001)	-0.20 (0.0810)	+0.67 (0.0001)	-0.01 (0.9020)	-0.62 (0.0001)	+0.82 (0.0001)	+0.83 (0.0001)	-	-
VS	-0.84 (0.0001)	-0.92 (0.0001)	-0.89 (0.0001)	+0.86 (0.0001)	+0.84 (0.0001)	-0.18 (0.1055)	+0.67 (0.0001)	+0.02 (0.8726)	-0.61 (0.0001)	+0.92 (0.0001)	+0.91 (0.0001)	+0.92 (0.0001)	-
PS	+0.78 (0.0001)	+0.77 (0.0001)	+0.82 (0.0001)	-0.95 (0.0001)	-0.72 (0.0001)	-0.01 (0.9702)	-0.62 (0.0001)	-0.23 (0.1373)	+0.46 (0.0024)	-0.77 (0.0001)	-0.76 (0.0001)	-0.69 (0.0001)	-0.84 (0.0001)

WHC = water holding capacity; DL = drip loss; CL = tristimulus colour L; CA = tristimulus colour A; CB = tristimulus colour B;
VCS = visual colour score; OVS = overall visual score; PS = protein solubility.

APPENDIX C

form 1

QUESTIONNAIRE

EVALUATION OF PORK QUALITY IN NEW ZEALAND
(ABATTOIR)

Meat plant:

Name : _____

Address: _____

Pigs background:

Name of owner : _____
Age range : _____
Live weight range : _____

Means of transportation of pigs:

Trucking company : _____
Drivers name : _____
Vehicle used : ☐ Truck ☐ Trailer ☐ Other _____
☐ Single deck ☐ Double deck
Number of pigs (per batch) : _____

Unloading procedure:

Time of loading : _____
Ramp slope (°) : _____
Number of worker : _____
Equipment used : ☐ Electric goad ☐ Stick ☐ Flapper
☐ Others _____

Trucking distance:

Time of arrival : _____
Distance from farm to abattoir (miles or kilometer) : _____

Weather condition:

Temperature (°C) : _____
Humidity (%) : _____
Condition : ☐ sunny ☐ rainy ☐ cloudy

Lairage:

Pen by : ☐ Batch ☐ Sex ☐ Mixed
Given water after : ☐ arrival ☐ 1 - 2 hours ☐ 3 - 6 hours ☐ one day ☐ none
Given feeds after : ☐ arrival ☐ 1 - 2 hours ☐ 3 - 6 hours ☐ one day ☐ none
Overhead sprinkler : ☐ with ☐ without
Given bath with pressurized water : ☐ low ☐ medium ☐ high

Slaughter:

Date : _____
Time : _____
Stunning procedure : ☐ electric ☐ percussion ☐ CO_2
Average stunning time : _____
Bleeding ;
Average time from stunning to bleeding : _____
Average time from bleeding to scalding : _____
Scalding procedure : ☐ hot water vat ☐ Steam
Average time of scalding : _____

QUESTIONNAIRE

EVALUATION OF PORK QUALITY IN NEW ZEALAND
(FARM)

Pig owner :

Name of farmer : _____
Address : _____

Pigs background:

Breed : _____
Age range : _____
Live weight range : _____
Rearing method : ☐ open ☐ pens
Sex ratio (M/F) : _____
(if transported/delivered in mixed sex)

Means of transportation of pigs:

Trucking company : _____
Drivers name : _____
Vehicle used : ☐ Truck ☐ Trailer ☐ Other _____
☐ Single deck ☐ Double deck
Number of pigs (per batch) : _____

In-farm:

Type of feeds given : ☐ pelleted ☐ mash ☐ Other _____
Time of last feeding : Solid Liquid (water)
Date _____ Date _____
Time _____ Time _____

Loading procedure:

Time of loading : _____
Ramp slope (°) : _____
Number of worker : _____
Equipment used : ☐ Electric goad ☐ Stick ☐ Flapper
☐ Others _____

Trucking distance:

Time of departure : _____
Time of arrival in abattoir : _____
Distance (miles or kilometre) : _____

Weather condition:

Temperature (°C) : _____
Humidity (%) : _____
Condition : ☐ sunny ☐ rainy ☐ cloudy

form 3

QUESTIONNAIRE

EVALUATION OF PORK QUALITY IN NEW ZEALAND
(TRUCKING COMPANY)

Trucking company:

Name : _____

Address: _____

Customer (pigs owner):

Name of owner : _____
Address : _____

Capacity of vehicle:

Maximum : _____
Minimum : _____

Size of the vehicle:

Length (metre) : _____
Width (metre) : _____
Height (metre) : _____

Description : ☐ covered ☐ uncovered

Date :_____ Time:_____ Sample #:____

Weight:_____ Sex:___ Breed:_____ Age:_____

Visible defects:
☐ Bruise Locations:_____

Sizes:_____ Number: ☐ Light ☐ Heavy
Probable cause: ☐ Transportation ☐ Handler ☐ Farm ☐ Abattoir

☐ Wounds Locations:_____
Sizes:_____ Number: ☐ Light ☐ Heavy
Probable cause: ☐ Transportation ☐ Handler ☐ Farm ☐ Abattoir

SEMITENDINOSUS / LONGISSIMUS

pH_1: _____ Date & Time collected:_____

pH_u: _____ Date & Time collected:_____

VISUAL AND COLOUR TEXTURE SCORES:

Wetness: ☐ 0 :dry ☐ 1 :slightly dry ☐ 2 :normal ☐ 3 :slightly wet ☐ 4 :wet

Colour: ☐ 0 :dark ☐ 1 :slightly dark ☐ 2 :normal ☐ 3 :slightly pale ☐ 4 :pale

Texture: ☐ 0 :firm ☐ 1 :slightly firm ☐ 2 :normal ☐ 3 :slightly loose ☐ 4 :soft

Combined overall visual scores for meat quality:

☐ 0 : DFD ☐ 1 : Mild DFD ☐ 2 : Normal ☐ 3 : Mild PSE ☐ 4 : PSE

HUNTER L A B VALUES (COLORQUEST) (200 g - 40/10 mm):

Illums	Ill D65	III A	Ill C	Average	Std Dev
L	____	____	____	____	____
A	____	____	____	____	____
B	____	____	____	____	____

WATER HOLDING CAPACITY (0.3 grams muscle):

Pre - weight of meat:_____
Pre-weight of filter paper:_____
Post-weight of filter paper:_____
Post-weight of meat:_____

Percentage of WHC of muscle (Diff. of FP wt., less M wt. X 100):_____

TOTAL PROTEIN (0.50 grams minced muscle):

Weight of the sample = _____
Total Nitrogen = _____

Total protein = Total Nitrogen (%) x 6.25 = _____

PROTEIN SOLUBILITY (10 grams minced muscle):

0.1 *M* KCl	Sample wt. (Wt - g)	S-tant (wt-g)	Solid (wt -g)	Protein
	_____	_____	_____	____

0.5 *M* KCl	Sample wt. (Wt - g)	S-tant (wt-g)	Solid (wt -g)	Protein
	_____	_____	_____	____

Protein Solubility = _____

Formula: $\frac{\text{Supernatant wt. of 0.6 } M \times \text{protein (\%) of 0.6 } M - \text{Supernatant wt. of 0.2 } M \times \text{Protein (\%) of 0.2 } M}{\text{Sample wt} \times \text{Total protein}}$

DRIP LOSS (100 g - 2.5 cm thick muscle):

Weight of the muscle: _____
Weight of reweigh muscle: _____

Percentage of drip loss (diff. of original wt X 100):_____

Note: Time of recording.

pH_1 - 45 minutes after slaughter; pH_u - after 24 hours; Colour - after 24 hours
WHC - after 24 hours; Protein solubility - within 48 hours; Drip loss - after 48 hours