Nutritional characteristics of New Zealand export lamb and functional properties of selected beef forequarter muscles

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Abstract

Richmond Ltd. has recently undergone a change in strategy, away from the traditional commodity based meat industry, towards the modern food business. To do this, opportunities to add value to their current product range must be identified. This involves the conversion of traditionally low value commodity based products into products that demand a premium. An example of this is converting muscles that are currently used for grinding meat into a further processed convenience food (i.e. ready meals). Another method is to add further value to premium products by making them more appealing to consumers (i.e. nutritional information on labels). This work details investigations into the functional properties of selected beef forequarter muscles (low value commodity products) and the nutritional properties of selected export lamb products (premium products).

The functional properties of a number of beef forequarter muscles were measured to identify which had the best potential for further processing applications with respect to ready meals. The functional properties of tenderness, cook loss and shrinkage were measured for the Latissimus Dorsi, Pectorialis Profundus (Point End Brisket), Infraspinatus (Cross Cut Blade), Triceps Brachi Longhead (Main muscle in Bolar Shoulder Clod), Supraspinatus (Chuck Tender), Serratus Ventralis and Triceps Brachi Medialhead (Muscle in Bolar Shoulder Clod. From the tests conducted the Infraspinatus and the Triceps Brachi Longhead have been identified as having the best functional properties with respect to further processing for ready meal applications.

As well as conducting tests to identify the forequarter muscles with the best potential for further processing applications, investigations were carried out to identify cooking regimes that would optimise the functional properties. This work confirmed that there are three major chemical reactions, which determine the resultant functional properties of cooked meat. They are the denaturation and aggregation of the myofibrillar proteins and the denaturation and solubilisation of connective tissue (collagen). At around 50°C myosin (45% to 50% of the myofibrillar proteins) denatures, which results in a substantial increase in cook loss and reduction in water holding capacity. At around 60°C collagen (main connective tissue protein) denatures, which results in a substantial increase in tenderness and increase in cook loss. This is because as the collagen

denatures it loses it mechanical strength (increase in tenderness) and can no longer support its own structure, and causes it to contract. This contraction causes fluid within the meat and cook loss caused by the denaturation of myosin to be expelled from the meat by compressive forces (squeezed out). At around 70°C actomyosin (22% of the myofibrillar proteins) denatures. This results in a substantial increase in the cook loss and firming of the meat. The increase in cook loss or decrease in water holding capacity that occurs with myofibrillar protein denaturation is due to the fact that when these proteins denature and aggregate their ability to bind water is greatly reduced.

From the results of the cooking regime trials it is recommended that for functional property considerations that during the cooking of further processed meat products (i.e. ready meal applications) a meat temperature of 62°C should be aimed for, for the slowest heating region during cooking (usually the centre). This is because it has been identified that a cooking temperature of 65°C should not be exceeded otherwise detrimental effects can occur to the functional properties of the cooked meat.

For health concerns a 7D bacterial death reduction has to be achieved. This means that for a cooking temperature of 62°C the meat has to be held at this temperature for at least 5 minutes. Therefore the total cooking time would be the time needed to heat all the meat to 62°C plus 5 minutes to ensure a safe product. The heating or cooking system employed should also ensure that a minimal amount of the meat is heated above 65°C. This can be easily achieved by minimising the external cooking temperature, but long cooking times will result. An industrial cooking process will be a compromise between the cost associated with longer residence time and product functionality.

As mentioned earlier another way to add value is to supply nutritional information for selected cuts. Consequentially one of the objectives of this project was to provide some nutritional information for selected meat cuts. Though the primary objective of this part of the project was to develop a method for producing the needed information, so that Richmond N.Z. Ltd. can develop further information on an as needs basis.

The nutritional characteristics of a number of export lamb cuts from the saddle region has also been investigated and a method devised to allow further characterisation of

other cuts. The method involves breaking down a standard cut into its constituent components (e.g. Frenched rack consists of loin eye, fat cap, intercostals and fatty tissue). The constituent components are tested for their nutritional properties. The frenched rack nutritional properties are calculated from the nutritional properties of the constituents components and the yield data (percentage of each constituent component within a frenched rack) for frenched racks.

This method allowed the identification of the main sources of variation for nutritional characteristics. These differences were found to be caused by the lean to fat ratio, not nutritional differences in lean tissue from the same region of lamb (i.e. loin eye and tenderloin very similar nutritionally). The difference in lean to fat ration also accounts for the variation between grades (i.e. PX grade lamb cuts have a higher fat content than YX grade lamb cuts due to PX grade cuts having a higher percentage fat tissue in their cuts).

The cuts characterised were the shortloin section (whole section or chop), rack section (whole section or chop), 75mm racks frenched 25mm, boneless loin and tenderloin for both PX and YX grade lamb. The method will be applicable to other regions of lamb (i.e. hindquarter and forequarter) for which nutritional information already exists, but for which yielding data will have to be collected. The method would also be applicable to other species such as beef and venison, but both nutritional data for constituent components and yielding data would have to be collected.

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Chapter 1
Project Overview

1.1 Introduction

Richmond New Zealand Ltd. is a meat processing country based in the central North Island of New Zealand. Richmond Ltd. has recently undergone a change in strategy, away from the traditional commodity based meat industry, towards the modern food business. To do has meant that opportunities to add value to the current product range have to be identified. The key to this is knowledge of the raw materials (nutritional and functional). This 'extra' knowledge can be included as part of the product thereby adding value.

Products could be supplied to customers for further processing with information on how best to maximize yield or tenderness. Products could be tailored specifically to customer use. The information would also allow Richmond to identify optimal raw materials for further processing operations in house. The areas where information is specifically required is on the nutritional and functional properties of meat. This project is aimed at providing some of this information, but primarily in developing methods that can be used by Richmond N.Z. ltd. In the future to build a complete understanding of their products

The aim of the project was too add value to several different products currently produced by Richmond Ltd. This added value was to be accomplished in a number of ways. One was to collect nutritional information of selected meat cuts, so that the nutritional information could be displayed on the product via a label. The other approach was to measure the functional properties of selected meat cuts so that they could be assessed for their applicability to higher value products i.e. ready meals, restaurant meals. Along with the collection of the functional properties of selected meat cuts, how these functional properties were affected by cooking regime was investigated. This was done so that recommendations could be made on what cooking regime (time

and temperature) should be used to optimise the functional properties of cooked meat products.

1.2 Functional Properties

For Richmond to get the best return possible from its products, the functional properties of the products needs to be known. Knowledge of individual muscle functionality may allow identification of new uses for current low value products. It could also allow the identification of muscles most suited to specific applications, which could greatly assist in dealings with current and perspective industrial customers. Knowledge of individual muscle functionality could also assist Richmond Ltd. in developing further processed products in house. The beef forequarter was chosen as a model system for this work because it is currently a lower value product, usually combined as one whole cut. It contains a number of different muscles, which are known to have different functionality. The beef forequarter makes up a significant volume of the meat on a carcass, therefore it contains a large scope for different applications.

The functional properties of selected beef forequarter muscles were collected so that muscles could be identified which had the best potential for adding value. The functional properties measured were tenderness, cook loss and shrinkage as these are the most important when considering further processing applications. From the functional property ranking and processing considerations for the product under consideration i.e. ready meals, an overall ranking for potential to add value to the selected muscles could be constructed.

This ranking table could then be used to decide which muscles are most suitable for a particular application. This will allow the identification of muscles that may be currently under utilized and identify best uses for these in products to command a higher premium. The approach used in this work for the forequarter was developed with the intention that it could be repeated for other muscles and species to identify further added value opportunities and build a database of product functional properties. This worked is covered in detail in chapter 3 of the thesis.

Because the cooking regime used significantly effects meat functionality, some investigations were made into characterizing the effect of temperature and cooking regime on the resultant functional properties of the cooked meat. These changes in the functional properties with cooking regime are believed to be closely related to the various reactions occurring within meat during cooking. If the temperature at which these reactions occur is known, then recommendations for optimum cooking regimes to use can be made. Such information could be used to add value to industrial customers by assisting them to improve yields and giving their products better functionality.

Most industrial cooking regime are geared towards achieving a certain bacterial death reduction i.e. three decimal reduction or seven decimal reduction; 3D or 7D death, for pathogenic organisms such as *Listeria, Salmonella* many processors attempt to achieve this in the shortest possible time (high temperature for a short period of time). This allows a fast processing time, but employing cooking regimes that only worry about bacterial death will often be to the detriment of the quality of the resultant cooked product (e.g. decrease in tenderness and increase in cook loss). By combining knowledge of how functional properties are effected by cooking regime and micro organisms death kinetics, an optimum can be found which optimises the quality of the cooked product and achieves the desired bug death reduction. This worked is covered in detail in chapter 4 of the thesis.

1.3 Nutritional Properties of Export Lamb

There is a world wide trend in consumers becoming more educated about health and nutrition. This has had a flow on effect for food producers because as consumers become more aware of what they should be eating for a healthy diet, they want to know what is in the food they consume. This has meant that food producers who are able to provide nutritional information with their products are at an advantage over those who don't. This is because consumers regard the product as more informative hence appealing. A product labelled with nutritional information has had value added to it.

There are specific regulations outlining what information must be present on nutritional labels and this must be considered as part of this study.

The products most likely to benefit from nutritional information are premium products targeted directly towards final consumers, rather than low value products, which are further processes. Lamb saddle was chosen as a model system for this investigation as many premium products come from the saddle region. The approach used was developed with the intention that it could be repeated for other lamb cuts and other species i.e. beef. This was so Richmond Ltd. can build a database of product nutritional properties.

The objectives of the nutritional investigation were twofold. One was to collect nutritional information for export lamb products derived from the saddle region. The second was to identify the main causes of any variation for nutritional values for the products. This was so the best approach for any product nutritional analysis could be deduced i.e. were should most of the effort be concentrated to reduce time and cost of analysis. This work is covered in detail in chapter 5 of the thesis.

1.4 Structural aspects of meat

Before a discussion on the factors affecting the functional properties of meat can be started, a bit of background information is needed on the structure of muscle or meat (muscle post rigor). In mammals individual muscles are surrounded by a sheath of connective tissue known as the epimysium which extends into the tendons. From the epimysium, the perimysium, a network of finer connective tissue containing the larger blood vessels and nerves, penetrates throughout each muscle, separating groups of muscle fibres into muscle fibre bundles. Continuous with the perimysium is the finer network of the endomysium fibre. This connective tissue sheath surrounds each individual muscle fibre and contains the blood capillaries and nerve connections vital for muscle function in the live animal. This is best shown diagrammatically in Figure 1.1. In meat animals the muscle fibres vary in length from a few mm up to 30cm, depending on size and location of the muscle. In contrast the muscle fiber diameter are comparatively minute, varying between 10 and 100μm.

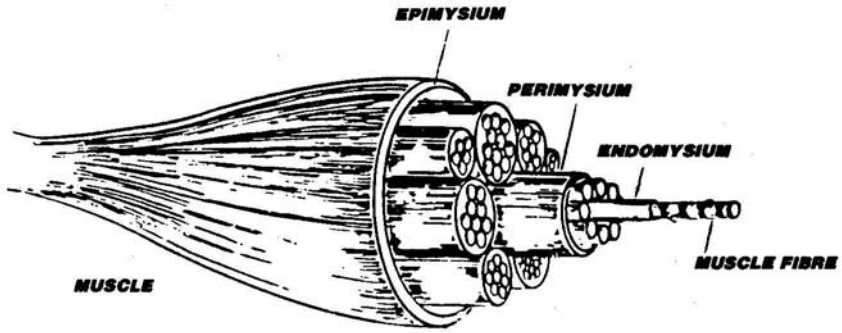

Figure 1.1: Diagram of muscle structure showing the arrangement of the connective tissue in relation to muscle fibres and muscle fibre bundles.

Underneath the endomysium, each muscle cell is surrounded by the sacrolemma, whose major function is to transmit the nerve impulses for muscle contraction. Occupying about 80% of the muscle cell volume is the contractile apparatus, made up of numerous myofibrils, which run the length of the cell. Each myofibril is about 1.0μm in diameter. The ordered alignment of the myofibrils within the muscle cell, gives muscle its characteristic striated appearance.

Under phase contrast microscopy, the contractile apparatus of the muscle fibre appears banded or striated in longitudinal section. This is due to the manner in which the structural components of each myofibril are held in lateral and longitudinal register. In relaxed muscle, the dark bands represent areas of dense protein structure, which are anisotropic under polarized light and as such have been termed the A-bands. The I-bands derive their name from the isotropic refractiveness of the lighter bands in which the constituent proteins are less dense. In the central region of each A-band is the less dense H-zone which itself is bisected by the dark M-line. The highly refractive Z-line is also clearly visible as a sharp dark band within the middle of each I-band. This is shown diagrammatically is Figure 1.2.

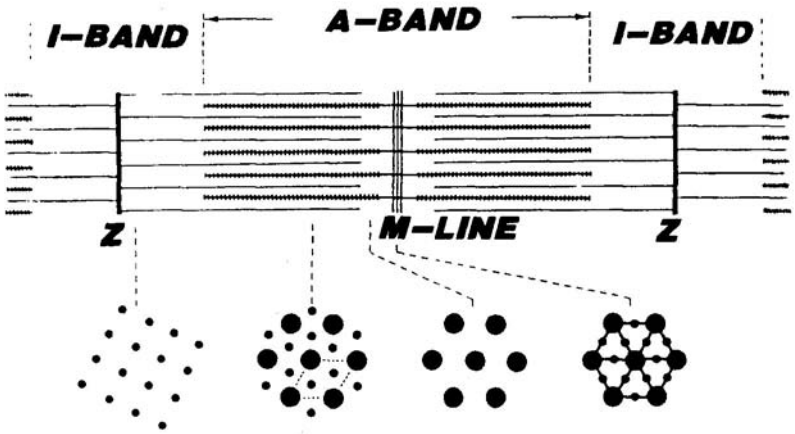

Figure 1.2: Diagram of the ultrastructural organisation of the muscle sarcomere bounded on each side of a Z-line. Underneath the sarcomere, from left to right, are cross-sectional representations of the organization of (I) the thin filaments near the Z-line, (II) the overlap regions of the thick and thin filaments, (III) the thick filaments, and (IV) the M-line in the centre of the sarcomere.

This banded appearance is due to the extent of overlap of two sets of filaments. Thin filaments (comprised of actin), 8nm in diameter and 1.0μm in length, extend from either side of the Z-line and make up the I-band. Thick filaments (comprised of myosin), 10-12nm in diameter and 1.6mm in length define the extent of each A-band. These thick filaments lie in the centre of the individual contractile units of the myofibril. The contractile units themselves are known as sarcomeres, each sarcomere lying between two Z-lines such that the I-bands are shared by adjacent sarcomeres.

The thick filaments are formed by the spontaneous association of the filamentous protein myosin. The myosin molecule is characterized by having to globular head sections attached to a long tail. On each side of the central clear zone of the A-band, all the myosin molecules are symmetrically orientated with their heads pointing away from the centre of the filament. This bipolar structural arrangement is responsible for the smooth central zone (150-200nm) of the thick filaments, which consists of the tail segments of overlapping myosin molecules pointing in opposite directions. The ordered packing arrangement also accounts for the manner in which three or four pairs of myosin heads protrude from around the circumference of the thick filaments at 14.3nm intervals tracing a helical pathway with a repeat distance of 42.9nm per helical twist.

There are several other proteins associated with the thick filaments but myosin is by far the most prevalent.

The thin filaments are formed from the spherical monomers of actin condense to form the double-helical actin strand. The two actin strands, which make up each thin filament twist across each other every 36.5nm. The other major proteins of the thin filaments are the proteins tropomyosin and troponin but actin is the most prevalent in the thin filaments. During muscle contraction the width of the I-bands decreases as the thin filaments are drawn into the spaces between the thick filaments in the centre of each sarcomere. Throughout contraction, the A-bands maintain their constant length. Sarcomere length thus depends on the extent of overlap between the thick and thin filaments, which themselves remain at constant length. The amount of overlap or how far the thick and thin filaments slide over one another governs the sarcomere length (contraction state of muscle), which is in turned governed by the release or uptake of various chemicals within muscles.

Post rigor the muscle loses the ability to release and uptake these chemicals and the thick and thin filaments become permanently bound together (unless chemically treated), the muscle has turned to meat and the sarcomere length is set. Unless the meat is chemically or mechanically treated, or aged, the main factor affecting the resultant functionality of the meat is the cooking regime used.

Chapter 2
Literature Review

2.1 Introduction

Before value can be added to meat products it is essential to have an understanding of meat composition and chemistry and how these affect meat functionality. As well as how cooking regime effects the meat functionality. Methodologies for the measurement of functionality are also required. This chapter overviews the literature on these topics.

2.2 Collagen

2.2.1 Collagen structure

Collagen appears as bundles of non-branching fibrils. The basic structural unit of a collagen fibre is the needle-like tropocollagen (TC) molecule. The TC molecule is a group of three polypeptide α-chains. The basic molecular α-chains are individually twisted into a left-handed helix, and three such helixes are wrapped around each other to form a right-handed superhelix. The three chains are held together by hydrogen bonds between the oxygen atoms and nitrogen atoms of peptide linkages in adjacent chains. The rigidity of collagen arises from the fact that the triple helix structure allows maximal formation of hydrogen bonds, (Yannas 1972), (Laakkonen 1973) and (Sims and Bailey 1981).

Proline and hydroxyproline make up about a quarter of the links in the collagen molecule. They prevent easy rotation of the regions in which they are located. The higher the proline and hydroxyproline content the greater the resistance of the molecule to heat and chemical denaturation (Laakkonen 1973).

As collagen matures in an animal the amount of intermolecular bonding between α-chains of tropocollagen increases. Mature collagen fibrils are seen as assemblies of tropocollagen molecules joined together by a variety of intermolecular covalent cross-linkages to from a vast asymmetrical polymer network (Yannas 1972).

2.2.2 Crosslinking and solubility

A certain proportion of the covalent intermolecular cross-links in collagen are in a heat labile form. The proportion varies with age of tissue, anatomical tissue location and species. The heat labile bonds are called aldamine bonds, however these aldamine bonds are stabilised with age to keto bonds, which are not heat labile. Stabilisation of the aldamine bonds to keto bonds accounts for the observed decrease in solubility and increase in shrinkage temperature with age (Yannas 1972), (Laakkonen 1973), (Harris and Shorthose 1988) and (Sims and Bailey 1981).

It is well known that the extent of polymerisation of collagen within muscle tissue increases with age of an animal. Reducible crosslinks (both heat labile aldamine and heat stable keto-amine) are formed in head-to-tail longitudinal crosslinks. This confers considerable tensile strength to the collagen fibres. The increase in heat stable collagen crosslinks with age is shown up in differential scanning calorimetry (DSC) scans of animals of differing ages. The effect is to increase the initial temperature at which denaturation begins (To) and a decrease in the total enthalpy of denaturation (Bernal and Stanley 1987). This can be explained by the fact that crosslinking stabilises the collagen, thereby increasing To, and less bonds are broken during denaturation causing a decrease in enthalpy. Along with this increase in collagen strength, there is also a decrease in the amount of soluble collagen. This means the amount of collagen denatured to gelatin for a given cooking regime is reduced, resulting in tougher meat (Powell *et al.* 2000) and (Beltran *et al*. 1991).

Upon the application of heat to collagenous tissue, a certain amount of the collagen is dissolved from the fibre and goes into solution. The amount released decreases with increasing cross-linkages and increasing maturity of crosslinks. Tissue from young animals often releases most soluble material within about 10 minutes, but the process is very slow in old animals. The total amount of labile collagen also decreases with age (e.g. 1 year old bull meat cooked at 71°C for one hour had 21.7% labile collagen, compared to 2.0% for aged cows), (Laakkonen 1973).

Enzymatic treatment with collagenase has been shown to markedly reduce both the total enthalpy and initial denaturation temperature, although the effect lessens with age (e.g.

77% reduction for calves, 25% for steers and no change for cull cows) (Beltran *et al.* 1991). This implies that as the amount of collagen crosslinks increases (or as crosslinks mature), the less susceptible the collagen is to enzymatic attack.

2.2.3 Connective Tissue in Muscle

The role of connective tissue in meat tenderness has often been studied, this is because the structural integrity and strength of collagen affects the texture of cooked meat. During the cooking process, collagen can undergo a number of physical and chemical changes. Upon heating the collagen is denatured and shrinks. Some of the collagen becomes soluble due to conversion to gelatin. This soluble gelatin is often observed in cooking losses as a gel. The amount that is soluble depends upon the degree of cross-linking of the collagen. The remaining insoluble collagen imparts significant mechanical strength to the cooked meat (Powell *et al*. 2000), (Palka 1999), (Harris and Shorthose 1988) and (McCormick 1994).

There are three major sources of connective tissue within muscle. These are the epimysium, perimysium and endomysium. The epimysium primarily consists of type I collagen, the perimysium mainly consists of type I and some type III collagen and the endomysium is made up of type I, III, IV and small amounts of type V collagen (Totland *et al.* 1988). The collagen content of muscles ranges from about 2%-10% on a dry weight basis within an animal. No direct correlation exists for meat toughness and muscle collagen content, as the form of the collagen (i.e. extent and type of polymerisation) is important (Ledward et al. 1992).

About 95% of intramuscular collagen is accounted for by the perimysium, and as a consequence is considered to be very significant in determining the texture of meat after cooking. The epimysium is considered to be least important for cooking considerations as it is usually trimmed off. The perimysium connective tissue is composed of intermingling bundles of collagen and elastic fibres. The elastic fibres form an extensively linked crosslinked 3D network comprising about 50% of the volume fraction. The thickness of the elastic fibres varies from 6-8 μm in the primary muscle bundles, and down to 1-2 μm in strands surrounding the secondary bundles (Totland *et al.* 1988).

Muscles contain varying amounts of collagen and the degree of crosslinking also varies between muscles. Animal maturation results in collagen crosslinking within and between fibrils, but the rate at which the collagen matures varies between muscles. Collagen from the semimembranosus muscle (SM) matured at an earlier age than semitendinosus muscle (ST), biceps femoris (BF), longissimus dorsi (LD) and posais major (PM). This change is shown in Warner-Bratzler peak force, with ST muscles increasing markedly with age, but little change for SM muscle between lamb, hoggets and mature sheep (King 1987).

Large muscle to muscle variation in melting temperature (Tm) values for collagen exist. Most researchers explain the upward shift of denaturation temperature as due to increased crosslinking. For 18 month old steers, the amount of heat stable crosslinks was in the order ST > LD > PM. The same was found for hoggets. From Tm values the SM connective tissue is almost fully mature in lambs, whereas other muscles appeared to mature at slower rates (King 1987). Differences in maturing rates for collagen aren't clear, but it is believed that the differing growth rates of muscles may contribute (Monin and Ouali (1991), McCormick (1994) and Sims and Bailey (1981). For 9-15 month stears, the relative muscle growth rates were PM > BF > LD > ST > SM. This is almost the reverse of lamb Tm values SM > ST > BF > LD > PM. This could be due to more rapidly growing muscles containing a higher proportion of newly synthesised collagen with a lower Tm (King 1987).

2.2.4 Thermal denaturation of collagen

When collagen is heated to a temperature of around 60°C it denatures. This means that the heat applied to the collagen tissue causes the bonds holding the collagen together to be broken. As a result, the collagen can no longer support its original structure and subsequently contracts. Heating causes breakage of the hydrogen bonds in the tropocollagen molecule, resulting in a separation of the peptide chains. If there are no covalent linkages (cross-links) between the peptide chains, one molecule of TC will breakdown into three α-chains. If there are covalent intermolecular cross-linkages binding two chains together (two α-chains) then a β-component is formed. If all three chains are bound together then a γ-component is formed (Yannas 1972).

Thermally contracted collagen fibre becomes transparent or glassy and the helical structure disappears. The crystalline structure of the collagen is lost, and the filaments become randomly coiled (Yannas 1972). Heat breaks the hydrogen bonds holding the molecule together, but after contraction some covalent cross-links still exist. After thermal contraction, the fibre shows rubber like elasticity and if this is cooled, some of the helixes can reform. A greater proportion of helixes reform if the rubbery denatured collagen is stretched (self-alignment). If the temperature is maintained above 60°C, spontaneous relaxation occurs, or the rubber-like properties disappear. At this stage the crosslinks have been destroyed and complete dissolution of the original collagen results and gelatin is formed, (Laakkonen 1973). Gelatin is considered to be any semi-crystalline or amorphous state of collagen. It contains the same amino acid sequence as collagen, but lacks partially or completely in tertiary structure (triple helix), (Yannas 1972).

The pH of collagen and surrounding tissue can affect denaturation temperature and enthalpy, as can ionic strength and ionic composition (Horgan *et al.* 1991). Decreasing pH has been shown to reduce the Tm and To (onset of denaturation) of collagen in both tendinous and intramuscular collagen, about 2°C from pH 6.0 to pH 5.0 Horgan *et al.* (1991) also showed that the least stable collagen crosslinks (aldamine crosslinks) were more sensitive to pH decline. In general the denaturation temperature of collagen is lowered by addition of salts (to about 300mM i.e. for NaCl ~2%w/w). Above a concentration of 500mM the salts start to have a stabilising effect on collagen denaturation. Some salts (e.g. basic phosphorous salts) increase pH upon addition and so appear to increase Tm. Care has to be taken when comparing studies because different methods for separating collagen fractions exist, hence the environment upon analysis by DSC can vary, scanning rate can also effect denaturation onset temperatures. As a result exact temperatures and enthalpies can not be easily compared, but the trends hold true.

2.2.5 Denaturation kinetics of collagen

The kinetics of denaturation of type I collagen (the collagen was sourced from rat tail tendon), the main type present in the perimysium, have been determined by (Miles *et al.* 1995). They found that the denaturation followed first order kinetics with an activation

energy Ea = 521 kJ/mol and Arhenius constant ko = $1.11x10^{78}min^{-1}$ for collagen in water. The kinetic constants varied for collagen in 0.5M acetic acid, they are Ea = 1309kJ/mol, ko = $4.72x10^{216}$ min^{-1}. The kinetic constants for bovine lens capsule was found to be Ea = 860 kJ/mol and ko = $4.29x10^{135}min^{-1}$, Miles (1993). This kinetic data can be used to predict the amount of collagen that will be denatured for a given time and temperature profile (see Figure 2.1).

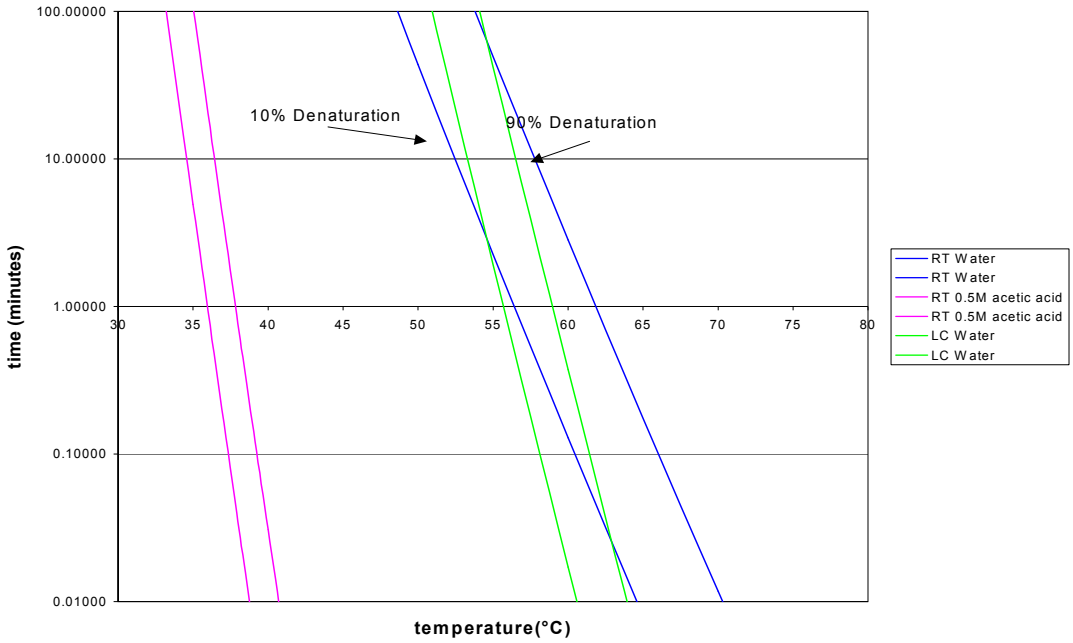

Figure 2.1: Denaturation kinetics of collagen

Figure 2.1 shows that the denaturation of collagen is dependent on pH and ionic composition. Collagen from rat tail in water (RT Water) has similar denaturation to collagen from lens capsule in water (LC Water). Whereas rat tail collagen in 0.5M acetic acid has a greatly lower denaturation time for a given temperature, compared to rat tail or lens capsule collagen in water.

The temperature for thermal denaturation, and the enthalpy of denaturation of the endomysial fraction of connective tissue has been found to be lower than that of the perimysial and epimysial fraction. This difference is thought to arise from the fact that endomysium contains type IV collagen unlike the other two. Type IV collagen exists in an open non-fibrillar meshwork arrangement, unlike types I and III collagen which form fibrillar arrangements which are more stable (Bernal and Stanley 1987).

2.2.6 Thermal shrinkage

The thermal shrinkage of the perimysium connective tissue results in the majority of the cooking losses. This is because the water that is expelled into the extracellular spaces upon myosin denaturation is squeezed out of the meat by the force generated from the collagen shrinkage (Ledward *et al.* 1992) and (Foegeding *et al*. 1996).

This thermal shrinkage of collagen occurs in two distinct phases. The first phase or "free contraction" corresponds to collagen contraction with little restraint from the underlying muscle fibres (due to myosin denaturation). The second phase or "forced contraction" corresponds to collagen contraction resulting in a compressive force being exerted on the muscle fibres, causing a deformation of them. The extent of this deformation depends on the compressive strength applied by the collagen fibres and the muscle fibres resistance to compression. This contraction is like a constrained contraction (i.e. collagen trying to contract around muscle fibres which are acting as a constraint) (Lepetit *et al*. 2000).

The perimysial collagen wraps around the muscle fibres with a wave like pattern. During the free contraction phase this wave like pattern disappears as the collagen contracts. This wave pattern allows contraction and stretching of the perimysium in living muscle. It has been calculated that the waviness allows a stretching of about 165% and about 50% contraction. During the "free contraction" stage of perimysium shrinkage, the waviness of the perimysium is lost (Lepetit *et al.* 2000).

The effect of restraining during the heat treatment of collagen is known to effect the resultant mechanical properties. Collagenous tissue restrained at a length equal or greater than its original length before heating, generates a greater tension. The effect is more pronounced the older the animal the collagen is extracted from Snowden *et al*. (1978), Snowden *et al.* (1977) and Allain *et al*. (1978). The thermal stability of collagen has been found to be greater in restrained samples than unrestrained samples. Samples with the greatest restrained length had decreasing quantities of melted collagen for a given heating regime (Snowden *et al.* 1978) This factor might be important when considering functional properties of meat attached to bone compared to excised muscles.

2.3 Myofibrillar proteins

2.3.1 Muscle fibre type

There are three main muscle fibre types; type I or slow twitch oxidative fibres (SO) (muscles predominantly containing SO are often called slow red muscles). Type IIA or fast twitch oxidative glycotic (FOG) (muscles predominantly containing this fibre type are often called fast red muscles). Type IIB or fast twitch glycotic fibres (FG) (muscles predominantly containing this fibre type are called fast white muscles). A number of other fibre types exist, but in muscle these are usually only present in very small amounts (Monin and Ouali 1991).

These different muscle fibres contain differing amounts of myoglobin, oxidative and glycotic enzymes and differing contractile proteins. The different fibres are adapted to the actions that different muscles have to perform. These differing muscle fibre types also demonstrate different post-mortem behaviours. The proportions of the different muscle fibre types are known to vary between muscles. Muscles involved in posture are more oxidative (contain higher percentage of type I fibre) than those used in movement (Monin and Ouali 1991). *Longissimus dorsi* (LD) is a white muscle (75% white fibre), *Vastus intermedius* is a red muscle (76% red fibre) while *Serratus ventralis* is intermediate (43% red fibre) (Maltin *et al*. 1997).

Muscle fibre types aren't randomly distributed within each muscle fibre bundle (fascicle). In all parts of the muscle, the type IIB fibres predominate in the periphery of each muscle fibre bundle, while type IIA and I make up the bulk of the central area.

Fibre type also varies within a muscle. Totland *et al*. (1988) investigated fibre type in Semitendinosus (ST) bovine muscle. Type I fibres made up 10% of the volume fraction in superficial portions of the muscle, but increased to 30% in the deeper parts. Type IIB fibres showed an opposite trend with 58% in the superficial layer and about 34% in the deeper layers. The medial parts of the muscle contained more type I fibres and less type IIB fibres than the lateral part. Type IIA fibres were approximately similar in all the samples from all parts of the muscle (Totland *et al.* 1988). This trend of increasing oxidative fibre type with muscle depth is observed for most muscles.

The tenderness of muscle is somewhat dependent on muscle fibre type. There are several possible explanations for this observation. As the muscle fibre types differ in diameter (Klont *et al.* 1998) and (Totland *et al.* 1988), it has been suggested that this is a significant source of variation in tenderness (Crouse *et al.* 1991). But there are conflicting results concerning fibre diameter and tenderness, the trend seems to hold true at extremes but fails for intermediate fibre diameters.

The ageing process is known to proceed more rapidly in fast twitch white muscles than in slow twitch red muscle. Sarcomere length is often associated with tenderness, shorter sacromere resulting in tougher meat. Oxidative fibres have been found to have a more intense shortening than glycotic fibres during rigor development (Monin and Ouali 1991) and (Klont *et al*. 1998).

The post-mortem process has been found to be more active in white muscles than red ones (Monin and Ouali 1991) and (Klont *et al*. 1998). This shows up in the rate of post-mortem pH fall being faster in white muscles. In slow red muscle, energy rich compounds like ATP are broken down faster than in white muscles, but this is slowed more by decreasing temperature than in fast-white muscle. Glycolysis and rigor-mortis onset appears to be faster in white muscles than red ones when kept in similar temperature conditions, but this relationship is often hidden by temperature gradients which exist when carcasses are being chilled. For a given amount of lactic acid production, ultimate pH varies as a function of buffer capacity, which is higher in white muscles than red ones. As a result muscles that are richest in red fibres tend to have the highest ultimate pH values (Monin and Ouali 1991).

Most research has shown an inverse relationship between fibre diameter and oxidative capacity of muscle fibre. Type I or slow oxidative (SO) are smallest, type IIB or fast glycotic (FG) are largest and type IIA or fast oxidative glycotic are intermediate. Type I and IIA have a greater lipid and myoglobin content than type IIB. The colour stability of meat has also been found to vary between muscles, (Klont *et al*. 1998) found that oxygen consumption was inversely related to the rate of decolourisation. Muscle type is believed to be a major factor affecting the rate of decolouration. Muscles with higher

percentage oxidative fibres are generally more colour stable than those with a high percentage of glycotic fibres (Monin and Ouali 1991).

2.3.2 Major composition of myofibrillar proteins

It is known that myosin (45%-50% of skeletal muscle protein) exists in different isoforms. These differences are seen according to which muscle fibre type the myosin originates from (myosin from red muscle is different from myosin from white muscle). The second most abundant myofibrillar protein is actin (~22% of skeletal muscle protein), is relatively identical between different muscle fibre types, (Xiong 1994). The different myosin isoforms denaturation characteristics are effected differently by pH and ionic environment. In general a decrease in pH decreases the denaturation Tm of the myosin head first peak on the DSC thermogram. While the myosin rod (second peak) denatures at a higher Tm. The amount that Tm changes by depends on the myosin isoform. The third peak assigned to actin denaturation reacts similar between different muscle types, (Ziegler and Acton 1984).

2.3.3 Thermal denaturation and gelation

Denaturation is a process in which the spatial arrangements of the polypeptide chains within a molecule are changed from a typical native state to a more disordered arrangement (Foegeding 1988).

Gelation is considered to be a two-stage process (1) Thermal unfolding of the protein molecules to expose specific binding sites (denaturation), and (2) coagulation and aggregation to form a gel matrix (Foegeding 1988) and (Xiong 1994).

After heating, a large complex protein molecule like myosin may undergo multiple conformational changes, attributable to the different thermal stabilities within the various structural domains. This means that more than one denatured state can exist for the molecule. Aggregation between myosin molecules can be initiated among partially unfolded protein molecules. The degree of unfolding depends greatly on the chemical environment, thermal conditions and the form of the protein itself. To form a gel with a high elasticity the unfolding step should occur first, and the aggregation step more

slowly to allow the denatured protein molecules to orient themselves and interact at specific points, forming an ordered 3D network (Foegeding 1988).

Xiong (1994) observed no significant differences in either thermal denaturation temperature (Tm) or enthalpy of denaturation between white and red myofibrils This is contradicts research by (Monin and Quali 1991) and (Egelandsdal *et al*. 1994) who found that red myofibrils are more heat stable than white myofibrils. This difference may be due to preparation technique, or different ionic strength, pH or species.

There are pronounced differences in the thermal aggregation of red and white myofibrillar proteins (Egelandsdal and Martinsen 1995), (Egelandsdal *et al*. 1994), (Robe and Xiong 1994), (Robe and Xiong 1992) and (Freitheim *et al*. 1986). This suggests that a main factor contributing to rheological variations between red and white myofibrils is contained within the second stage of gelation. During the aggregation process white myofibrils undergo two transitions (observed as significant changes in optical density (OD)) at pH 5.5, but three transitions occur at pH 6.0 and 6.5. At these three pHs, for red myofibrils only one major transition occurs. The activation energy is less for white myofibrils, indicating that less heat input is required for white myofibril aggregation (Xiong 1994).

Ionic environment and pH are very important to gelation and aggregation properties of myofibrils (Hermansson *et al*. 1986), (Ishioroshi *et al*. 1979) and (Siegel 1979). For bovine muscle white myofibrils are superior gel formers in NaCl above a pH of 5.8, but below pH 5.8 red myofibrils perform better (Fretheim *et al.* 1986).

For predominantly red porcine muscle Vastus intermedius (VI) (76% red) one transition exists at about 47°C. For mixed muscle Serratus ventralis (SV) (43% red) two peaks exist at 47°C and 58°C. For white Longissimus dorsi (LD) (75% white) two major transitions exist at 46°C and 55°C and a minor transition at 64°C (Xiong 1994). An increase in the activation energy is observed as the percentage of red fibre increases. This shows that the gelling and aggregation mechanisms are different for red and white muscle myofibrils (Xiong 1994) and (Robe and Xiong 1994).

The extent of aggregation occurring for proteins in solution is often observed by changes in the optical density (OD). The effect of temperature, salt concentration and pH is monitored by changes in OD. The greater the amount of aggregation the higher the OD. Rate constants or 'k' values for aggregation differ according to what muscle fibre the proteins were extracted from. This is because different isoforms of myosin exist and these will denature and aggregate differently. Due to the myosin isoforms having different structures, the way in which they unfold during denaturation will be different. Subsequent aggregation and gelation will thus be affected (Xiong 1994) and (Egelandsdal and Martinsen 1995).

White myofibrils develop a more elastic gel structure with a lower onset gelling temperature than red myofibrils. For white myofibrils aggregation has a major increase at about 41°C and another at 52°C whereas red myofibril aggregation starts at 46°C and increases almost linearly with heating (Xiong 1994).

The rate and extent of aggregation of myofibrillar proteins in solution follow first order kinetics, with the rate and extent of aggregation increasing with increasing red fibre content (Robe and Xiong 1994). Myosin, one of the major components of muscle, is known to be a good binder in meat products, whereas actin is believed to produce synergistic effects. This causes a reduction in the water holding capacity of gels. This is because the increased bonding between protein molecules reduces the protein's ability to hold water, due to protein to protein bonds occurring at the expense of protein to water bonds.

The ionic environment is also important in the gelation process. As the amount of added salt increases, the extent of protein solubilisation increases, which allows formation of better gels. This is because the proteins have more chance to align in solution when they denature, due to protein-water interactions inhibiting protein-protein interactions. Tripolyphosphate (TPP) suppresses the aggregation of proteins as indicated by lower OD in solutions. This is believed to be due to TPP's ability to maintain protein molecules in a soluble state. 0.5% TPP was found to lower the activation energy for all muscle type gels by about 10%, suggesting that TPP alters energy requirement for gelation by a similar mechanism to added salt (Robe and Xiong 1994).

Aggregation of bovine actomyosin from ST muscle had an apparent lower heat of activation at pH 5.5 than at pH 6.0-7.5. This resulted in a lower temperature at which protein-protein interactions proceeded. Two distinct transitions occurred at pH 5.5. Tm1 occurred at 43°C and Tm2 at 56°C. At pH 6.0 Tm1 occurred at 48.5°C and Tm2 at 57.5°C (Ziegler and Acton 1984).

The time after cooking that the rigidity of a meat batter is measured, can have a pronounced effect on the shear value recorded for fracture. Between the temperatures of 40°C to 75°C the shear values immediately after cooking are lower than those after the product is cooled to 20°C. This may be attributed to the fact that cooling effects the protein-protein interactions occurring. Also fat solidification within the protein matrix after melting may significantly affect the shear values obtained (Foegeding 1988). This is an important factor to consider when carrying out functional characterisation experiments.

2.3.4 Denaturation kinetics

The denaturation kinetics of the myofibrillar proteins have been studied intensively. The exact denaturation temperatures depend on the scanning rate used in the DSC run. The following is an example of the denaturation kinetics found for myofibrillar proteins from semitendinous muscle pH 5.6, (Wagner and Anon 1985).

Protein	**Tm (°C)**	**ko (min^{-1})**	**Ea (kJ/mol)**
Myosin I	57.8	$2.4x10^{36}$	227.8
Myosin II	63.9	$9.5x10^{39}$	255.0
Actin	74.2	$3.9x10^{57}$	378.7

Table 2.1 Denaturation Kinetics of myofibrillar proteins, from (Wagner and Anon 1985).

The rate constant ko and the activation energy Ea are both dependent on pH and ionic environment, as Tm has been shown to shift as pH and ionic environment change. This means that the parameters Ea and ko will also change.

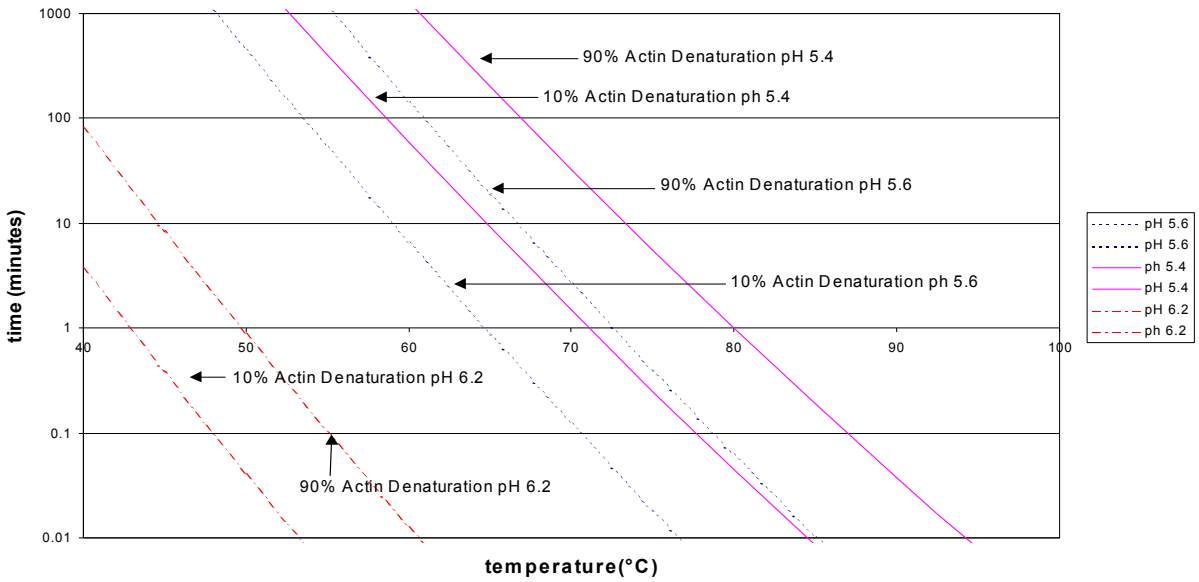

Figure 2.2: Denaturation kinetics of Actomyosin constructed from data from (Wagner and Acton 1985) and (Martens et al. 1982).

For Actin denaturation ko = 1.3×10^{52} min^{-1} and Ea= 349.9 kJ/mol at pH 5.4. At pH 6.2 ko = 9.2×10^{61} min^{-1} and Ea = 380.8 kJ/mol (Martens.H *et al.* 1982). The kinetic data from (Wagner and Acton 1985) and (Martens *et al*. 1992) is summarised in Figure 2.2 above. As can be seen from Figure 2.2, pH has a big influence on the denaturation reaction rate. This is not surprising given that pH changes the conformation of proteins and the net charge approaches zero as the pH approaches the isoelectric point of the protein.

2.3.5 Water holding capacity

The water holding capacity (WHC) of meat, is the ability for it to hold on to its own or added water during application of any force. As lean muscle contains ~75% water, WHC is a very important economic factor in meat production, for both raw and cooked meat products. WHC effects drip loss during storage of raw meat (frozen or chilled),

and cooking losses during cooking of further processed products (ready meals, sausages etc.). It is known that the myofibrillar proteins are primarily responsible for water binding in muscle. Two main types of water exist in meat that are important with respect to WHC. One is intracellular (interfilamental, interfibrillar, water in thick filaments) or bound water which makes up 5% to 15% of water in muscle. This water is located at the protein surfaces and is bound to the proteins, thus interfacial water has decreased mobility. The other water of interest is extracelluar or unbound water. This water is reasonably mobile, which means it is expressible or released from meat upon the application of force (Ledward et al. 1992).

The amount of intracellular and extracellular water has significant effects on the WHC of meat. The amount of drip loss expressed (the amount of water lost on application of force) increases with an increasing amount of extracellular water. Myofibrils make up about 70% of the volume of lean meat and most water is located within the myofibrils. Myosin which makes up 45%-50% of the myofibrillar proteins is believed to play a important role in meat WHC as myosin is known to have a great capacity to imbibe water. The state of water in meat (extra or intracellular) depends on the spatial arrangement of the myofibrils. Swelling of the myofibrils moves water from being extracellular to intracellular as more space is made available between the protein network. Addition of NaCl, increasing the pH when the meat is above the isoelectric point (IP), addition of ATP (pre-rigor) or pyrophosphate can achieve this. Shrinkage of the protein network moves water from the intracellular to extracellular state. This is achieved by lowering the pH when the meat pH is above the IP, adding NaCl when below the IP, association of thick and thin filaments during rigor mortis and heat coagulation and aggregation of proteins (Lawrie 1998).

2.3.6 Emulsification

When meat is comminuted for the production of emulsion products, the muscle cell wall which sheathes the myofibrils is destroyed, consequentially the myofibrillar system is in a state of unlimited swelling ability. At the surface of the swollen particles and surrounding fluid varying amounts of dissolved myofibrillar proteins are present. The extent mainly depends on the ionic strength, pH, and the presence of ATP or polyphosphates. During heating these dissolved myofibrillar proteins form stable gels.

This gel immobilises the water present and the dissolved myofibrillar proteins also have a high fat-emulsifying capacity.

Two characteristics of the dissolved myofibrillar proteins are thought to be responsible for this high fat-emulsifying capacity. One is that the comminuted meat represents a fat in water emulsion, in which the solubilised proteins act as an emulsifier (i.e. the dissolved proteins coat fat globules with a thin layer of protein which prevents the fat from coalescing out of the mixture). The other characteristic is that during heating, the coagulating network of proteins surrounds the fat cells in such a way that the melted fat cannot coalesce because of mechanical fixation within the meshes of the protein matrix. The size of the cavities (hence fat emulsifying capacity) formed by the protein network depends on the extent of swelling of the protein system (Siegel and Schimdt 1979).

2.4 Colour of meat

2.4.1 Meat colour

The primary pigment associated with colour in muscle tissue is the pigment myoglobin, which is located within the muscle cell. Myoglobin is a protein consisting of an iron-porphyrin compound, heme, combined with a single globin protein. The heme binds oxygen while the globin surrounds and protects the heme. The iron atom contained within the heme can exist in various oxidation states. It is these changes in the oxidation state of heme and its iron atom that affects the meat colour. In living tissue myoglobin exists in the reduced form (purplish-red). When exposed to oxygen myoglobin is oxygenated to oxymyoglobin and changes colour to bright red. This bright red colour is the colour most people associate with fresh meat. The resulting red oxymyoglobin is stable as long as the iron in the heme remains in the reduced state (Lawrie 1998).

When the iron within the heme is oxidised, the myoglobin is converted to the metmyoglobin moiety, which results in a colour change to a brownish-red. This reaction is reversible so long as there are reducing agents and the enzyme metmyoglobin reductase present in the meat. When the reducing ability of the muscle is lost, the colour of the meat remains brown, as the oxidised iron atom cannot be reduced. This brown colour is associated with old or off meat (Lawrie 1998).

2.4.2 Thermal denaturation of myoglobin

The first initial colour change that occurs during the cooking of meat is a lightening in colour. This is due to general protein precipitation. Further colour changes are associated with the denaturation of myoglobin, which results in a change of colour from a reddish-pink to a grey-brown. The reaction is temperature dependent and myoglobin has long been known as one of the most heat stable proteins in meat, (Geileskey *et al*. 1998).

When meat is subjected to heat, many reactions occur which affect its colour. The main effect is the denaturation of the globin moiety of myoglobin, thus its function of protecting the heme diminishes. This changes the chemical environment of the iron in the heme, and results in oxymyoglobin and myoglobin being converted to metmyoglobin. Once this reaction is completed muscle pigments and proteins within the muscle continue to denature. Also, the amine groups of amino acids can react with available reducing sugars, such as free glucose, and undergo a Maillard browning reaction (Lawrie 1998).

Myogoblin denatures at 65°C to 80°C (in solution), and as a result meat turns from a red to brown colour, but this colour change occurs at temperatures below this in meat. This colour change in meat is thought to be caused by a masking effect created by the aggregation/ co-precipitation of other myofibrillar and sacoplasmic proteins (Lawrie 1998).

Substantial denaturation of myoglobin, reflected as a change in meat colour starts to occur at around 60°C in meat. This is markedly lower than the temperature of 75°C at which significant denaturation of myoglobin occurs in solution at pH 5.5-6.0. This observation can be explained by the fact that myoglobin is thought to undergo a small conformational change at temperatures lower than the denaturation temperature. This conformational change permits other less stable proteins present (e.g. myosin) that are denaturing or denatured to attack the partially exposed haematin. This attack causes the globin moiety to be displaced, which spontaneously denatures. This leaves no protection to the iron protoporphyrin ring, meaning other proteins can bind to haematin. This leads to a change in the oxidation state of the iron from II to III, with a resultant colour

change from reddish-pink to a grey-brown (Ledward *et al*. 1992) and (Geileskey *et al*. 1998).

The environment that the myoglobin is surrounded by is important, as it effects the stability and hence denaturation characteristics of the molecule. The effects of salts and pH are known to affect the total amount of myoglobin denatured for a given time and temperature. Meat pH is known to be important for the end colour of cooked meat. The higher the pH the more red-pink the meat will be for a given time and temperature. This can be explained by the fact that as pH increases the amount of myoglobin denatured decreases (Trout 1989), (Trout 1990) and (Brewer and Novakofski 1999). This means that increasing pH has a stabilising affect on myoglobin denaturation. This is likely to be from the increased resistance to heat induced denaturation susceptibility of myoglobin as the pH moves away from its isoelectric of pH 5.0-5.2 (Brewer and Novakofsk 1999).

The presence of salts in meat products can also cause a significant change in the amount of myoglobin denatured and hence the colour of cooked meat. The amount of myoglobin denatured increases with addition of salts. This means the amount of red-pink colour will decrease with increasing salt content (Mendenhall 1989). On addition of 3%w/w NaCl to a minced meat there is a 25% increase in percentage myoglobin denatured (PMD). On addition of 1%w/w NaCl to minced meat a 15% increase in PMD is observed. On addition of 0.5%w/w tripolyphosphate (TPP) PMD increases by about 5-10%, all observations made when cooking to a temperature of 60°C. Beef colour score has been related to percentage myoglobin denaturation, beef colour = PMD^2 x – 0.000567 + 6.023. A score of 1 = no pink and 6 = extremely pink (Trout 1989). The water content effects the Tm of myoglobin in solution. The lowest Tm of 74°C was for a moisture content of 50% water, Tm increased linearly to 80°C at 100% moisture (Hagerdal and Martens 1976).

2.4.3 The kinetics of myoglobin denaturation

Myoglobin denaturation kinetics follow first order kinetics, and the Arrhenius law with respect to temperature. The pre exponential factor ko = 7.98×10^{43} min^{-1} and the activation energy Ea = 290kJ/mol for beef chuck myoglobin (Geileskey *et al*. 1998).

It can be seen from Figure 2.3 that the denaturation of myoglobin is very temperature dependent. At about 63°C it takes about a minute for a rare state (6.5 PMD) to be achieved in a piece of meat, whereas a well done (93 PMD) piece of meat takes more than 30 minutes at 60°C.

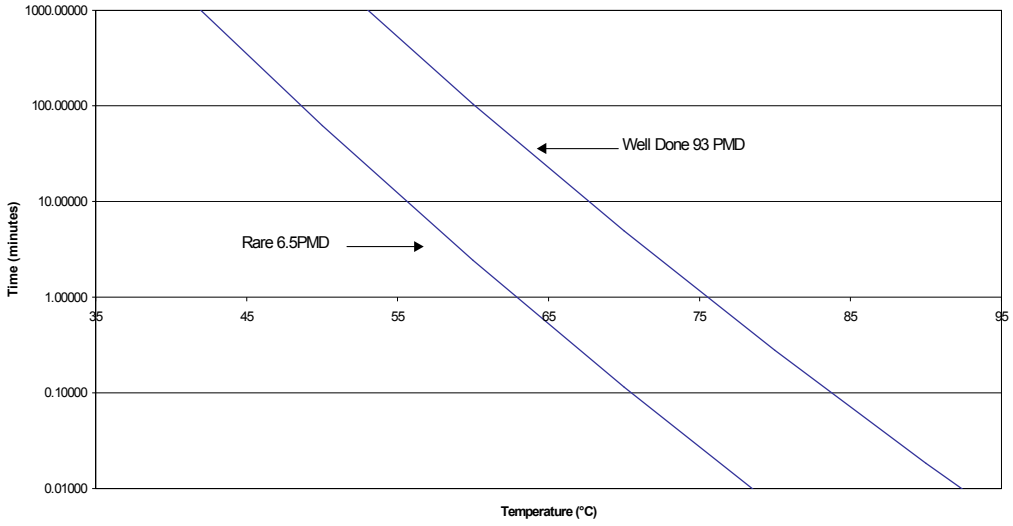

Figure 2.3: Kinetics of myoglobin denaturation constructed from (Geileskey et al. 1998).

2.5 Cooking of meat

2.5.1 Cooking effects

Physical and organoleptic properties of meat are known to be greatly affected by the heating regime used to cook the meat (i.e. heat source, rate of heating, final internal temperature, time of cooking e.t.c.). The cooking process brings about thermally induced changes in the structure and composition of the meat. The main changes of interest are tenderness, colour and cook yield (amount of weight loss during cooking). Most of the heat-induced changes can be associated with the physical and/or chemical

changes that occur within two major components of muscle tissue; collagen and myofibrillar proteins (Ledward *et al*. 1992) and (Foegeding *et al*. 1996).

2.5.2 Textural changes

Between the temperatures of 40°C and 90°C, several important changes are known to occur which affect the textural characteristics of the cooked product. At around 40°C to 50°C an increase in toughness is observed due to myofibrillar protein (light fractions) denaturation and subsequent coagulation. At around 58°C to 60°C a reduction in the toughness of the meat is observed, this is due to the heat denaturation and solubilisation of the collagen (collagen compounds containing heat labile 'aldamine' crosslinks are broken, and subsequently converted to gelatin which is soluble). At around 65°C to 75°C an increase in toughness is again observed, this is due to the further denaturation and aggregation of the myofibrillar proteins (heavier fractions). As well as collagen shrinkage (heat stable 'keto' crosslinks are not broken, hence they are insoluble) which causes contracture of the collagen sheath and squeezes water from the myofibrils, resulting in a toughening effect (Bertola *et al.* 1994), (Machlik and Draudt 1964), (Martens *et al*. 1982) and (Palka and Daun 1999).

2.5.3 Cooking losses

Upon heating, the volume of the myofibrils markedly decreases (by about 48%) and water is expelled to the outside of the cells (extracellular water increases, specifically water between myofibrils and endomysium). Between 43°C and 63°C this decrease in volume occurs without any shortening and originates from heat denaturation of myofibrils (which become more tightly packed) and partly from contraction of basement membrane collagen, which is believed to occur at a maximum between 57°C and 63°C. This denaturation of the myofibrillar proteins causes the actin and myosin complex to shrink within the collagenous endomysium sheath which is basically unaffected at this temperature. The endomysium is known to constrain the myofibrils from swelling, therefore when the myofibrils shrink the tension from the endomysium sheath may force fluid out of the extracellular space, accounting for the small fluid loss at this temperature (Bertola *et al*. 1994).

At around 60°C to 65°C the perimysium starts to greatly contract. This causes a shortening of muscle cells and an increase in the amount of fluid expelled. Some of the perimysium fibre denatures to gelatin. The perimysium changes from an opaque inelastic fibre to a translucent swollen elastic fibre. The shrinkage of the perimysium collagen generates a tension against the muscle fibres within the bundles surrounded by the perimysium. The fluid released into the extracellular space upon myofibrillar protein denaturation is forced out of the meat by the tension generated by the perimysium shrinkage. The tension generated by the perimysium is proportional to the amount of cross-linking. When the collagen is gelatinised a residual strength is retained, as heat stable crosslinks remain to stabilise the denatured fibre (Bertola *et al*. 1994), (Ledward *et al*. 1992) and (Foegeding *et al*. 1996).

Cooking losses are accompanied by shrinkage of the meat, shrinkage of the meat causes the water which is held between the myofibrils to be squeezed out due to a reduction in the space within the protein network. Cooking losses are reported to occur in two phases. At 45°C to 60°C shrinkage is primarily transverse to the fibre axis, while at 60°C to 90°C shrinkage is primarily parallel to the fibre axis (Offer *et al*. 1984), this could account for shortening in sarcomere length which occurs during the cooking process.

Myofibrillar proteins undergo further denaturation and dehydration at 65-70°C, resulting in increased cooking losses at these temperatures. Prolonged heating of meat at 70°C will eventually produce a reduction in shear value, this is due to cleavage of peptide bonds in collagen allowing more collagen to become soluble and reducing its mechanical strength. But this is accompanied by a significant increase in cooking losses (Foegeding *et al*. 1996).

The temperature at which heat denaturation of contractile proteins takes place and the enthalpy of denaturation of these proteins is muscle type dependent. Myofibrillar proteins from slow-twitch red muscles are more heat stable therefore less denatured than proteins from fast twitch white muscles during cooking of meat (Monin and Quali 1991). Weight loss from red muscle has been found to be greater for red muscle than from white muscle for 10 minutes boiling at similar pH. This difference in weight loss

may be due to red muscle fibres containing a higher lipid content than white muscle fibres, and hence upon heating a greater amount of lipid is expelled from the red muscle fibres accounting for the greater cook loss. However the role of fusion and expulsion of intramuscular lipids in cooking has not been elucidated so far, so how significant the contribution of this effect is to texture is unknown. This factor could account for some of the variation found between muscles (Monin and Ouali 1991).

The cooking process is known to increase the stiffness of the myofibrillar proteins and weaken the collaganous tissue. Both contribute to the final texture of the meat. It is known that the force required to pull meat apart is ten-times smaller transversely to the fibres than parallel to them. This indicates the perimysium binding the muscle fibres laterally is the weakest component. Electron-microscopy has shown that the point of first fracture is at the perimysial-endomysial interface (Dransfield 1997).

2.5.4 Extended low temperature cooking times

Cooking meat at low temperatures is known to have a beneficial affect on meat tenderness, but the advantages of extended low cooking temperature on tenderness can be outweighed by the fact that significant increases in cooking losses can occur, usually only a cooking temperature around 70°C. This means the yield is substantially reduced and the economic implications have to be investigated before such cooking regimes are implemented commercially (extra revenue for tender meat has to be greater than decreases in yield caused by increased cook losses). The temperature and time combination needed to kill micro-organism's (e.g. *E.coli*) also need to be considered for practical purposes when looking at cooking regimes.

2.6 Conclusions

It is apparent from the literature that there are a numerous reactions and interactions that occur between the meat protein components during cooking. There is a vast base of knowledge in the literature explaining the basic composition of meat and the chemistry of meat cooking. It is clear from the literature that the composition of meat is highly variable between species, muscles and even within muscles. This factor could go some way to explaining the highly variable functional properties that are found in meat studies.

It is also clear from the literature that in spite of the knowledge of meat chemistry there is no overall model that describes how meat composition and thermal history results in particular meat functionality. It is known that there are a lot of parameters than can affect the resultant functional properties (e.g. shortening, pH, collagen levels, cooking temperature e.t.c.) however bringing all this knowledge together into a complete model has yet to be done.

In order to add value to meat products, it is necessary to characterise the muscle functionality and to attempt to relate this to composition and thermal treatment the meat undergoes. This is best achieved by summarising the literature information into a conceptual model, which links the meat composition and chemistry information together. Once this is achieved, the model could be tested against the experimental data for the beef forequarter.

Chapter 3
Functional Properties of Beef Forequarter Muscles

3.1 Introduction

The primary objective of this section was to identify which muscles of the beef forequarter had the best potential to add value to. Most of the functional information available is for traditional manufacturing beef products (e.g. sausages and burgers). It is believed that some of the forequarter muscles may be better utilized compared to current practices. Instead of selling the muscles as grinding beef, they may be able to be sold as higher value convenience food products or further processed products. For this potential to be exploited it was necessary to measure the functional properties of a number of forequarter muscles so that muscles with potential for added value could be identified.

This was done by characterisation of the individual functional properties of selected beef forequarter muscles. The specific functional properties investigated were;

Cooking loss, this was chosen as it determines the yield of product achieved, which greatly affects the economic return of any further processed product

Tenderness, this is also an important functional property as it determines the potential uses of the muscle (e.g. tender muscles can be used in whole meat (non-comminuted) products).

Shrinkage, this functional property was also considered as a relatively important functional property as it affects portion control of a product.

Upon measurement of the functional properties a ranking system for the muscles could be devised, so the best muscles for potential added value could be identified. Such a system would include consideration of the functional properties of meat and also processing related factors.

It was expected from the various literature reports that there would be differences in the functional properties of the different muscles and more-over that there would be variation for the same muscle between carcasses. The variation can occur from the cooking regime used, as the temperature profile of the meat affects various reactions that govern the resultant functional properties. There are also a number of carcass/composition related differences that can cause variability in functional experiments. These include:

- Collagen (levels and amount of crosslinking)
- Sarcomere length
- pH

For this reason these compositional and physical factors were also measured in this study. The compositional information gathered for each muscle was used to try and explain the observed muscle ranking. Correlations between the meat properties and functionality of the meat may allow prediction of functionality in other muscles or meat species in the future.

3.2 Conceptual model development

3.2.1 Introduction

To aid in the analysis of the data a conceptual model was developed. This model took account of the various factors that are known to affect meat functionality. This section outlines the development of this conceptual model.

3.2.2 Key factors effecting functional properties

The functional properties of the selected forequarter muscles were expected to be mainly dependent on the following variables and interactions between these variables:

- Collagen levels
- Amount of cross-linking in collagen
- pH

- Sarcomere length
- Extent of protein denaturation
- Fibre length
- aging

3.2.2.1 Collagen levels

Muscles with a high collagen level are expected to have a higher peak force or lower tenderness ratings compared to a low collagen content muscle. It would also be expected that muscles with a high collagen content might have a higher cooking loss due to more collagen causing a greater tension upon shrinking therefore expelling more water from the cooked meat. Higher collagen levels would also expect to cause greater shrinkage in a piece of meat.

3.2.2.2 Collagen cross-linking

Meat samples with a higher amount of cross-linked collagen would be expected to have higher peak force or lower tenderness ratings than samples with a lower degree of cross-linking. This is due to the fact that cross-linked collagen is more resistant to denaturation and therefore imparts a greater residual strength after cooking. Cross-linked collagen generates a greater tension upon shrinking, therefore shrinkage and cook loss are expected to increase as the degree of cross linking increases.

3.2.2.3 pH

The pH is expected to effect both cooking loss and tenderness. The higher the pH the greater the water holding capacity of the meat and therefore the lower the cook loss expected. If the pH is higher than normal bur below pH 6.5 the tougher or less tender the meat becomes (Dark Firm Dry meat, DFD). This is due to the meat having a very high WHC which causes the meat to retain water very well, but causes the meat to have a dry texture when eaten (i.e. the meat isn't very juicy).

3.2.2.4 Extent of protein denaturation

The amount of protein denatured within the three major protein fractions of meat greatly effects the functional properties of cooked meat. The greater the amount of myofibrillar protein denatured the tougher the meat becomes and cook loss increases. Myosin (45% to 50% of the total myofibrillar proteins) denatures at around 50°C, while actomyosin

(22% of the total myofibrillar proteins) denatures at around 70°C. The other major fraction connective tissue (collagen) denatures at around 60°C. The more collagen that is denatured the greater the increase in tenderness. But there is also a substantial increase in cooking losses and shrinkage associated with collagen denaturation.

3.2.2.5 Fibre length

The sarcomere length is expected to significantly effect the tenderness of the selected muscles. A resting sarcomere is reported to be about 2.3 μm in length, (Herring *et al*. 1965b). Most meat shortens by 20% (1.84 μm) without any resulting increase in toughness. But up to a value of 45% (1.27 μm) shortening the toughness is known to increase substantially. The shorter the sarcomere, the greater the number of collagen fibers you have to cut through and hence the tougher the meat. After 45% shortening the toughness decreases again due to excessive shortening causing mechanical damage of the meat, (Herring *et al.* 1965a). Sarcomere length is also expected to influence the shrinkage. A piece of meat with shorter sarcomeres is expected to shrink less than a piece of meat with long sarcomeres. This is due to the fact that it is expected there is less room for contraction with short sarcomeres compared to long sarcomeres. This may also affect cooking losses as shrinkage is usually associated with the subsequent loss of water from the meat product.

3.2.2.6 Ageing

Aging of excised muscles (or whole carcasses) is known to significantly increase the tenderness of meat. Meat that has been conditioned (aged) at 4°C is significantly more tender than non-aged meat. The greatest changes occur within the first 7 days after which changes are still measurable up to 14 days. The changes have been attributed to changes occurring to the myofibrillar proteins and are believed to be due to degradation by enzymatic action.

3.2.2.7 Interactions between meat properties

A number of the functional properties are affected by the same reactions occurring during cooking. As a result a number of interactions are expected to occur (e.g. cook loss and shrinkage). It is expected that the muscles that shrink the most when cooked will also have the greatest cooking losses. Muscles with the greatest amount of shrinkage are expected to be tougher due to a greater concentration of fibers per unit

area. Also the shorter the sarcomeres the greater the concentration of collagen per unit area expected, which would be expected to increase toughness.

The chemical and physical components of the meat are themselves affected by the post-mortem treatment of the slaughtered animals. The way in which the animals are hung greatly affects sarcomere length. Different hanging techniques affect the resultant sarcomere lengths for different muscles (Hostetler *et al.* 1972). The closer a carcass is to the natural state of rest of a live animal the tenderer the muscles usually are. This is due to the fact that minimal compression of muscles occurs. When a carcass is hung (usually Achilles tendon) some muscles will be stretched but this results in others undergoing compression, and a less uniform product results. In addition the amount of stretching and compression will be different for different carcasses. Stretched muscles will have long sarcomeres and compressed muscles will have short sarcomeres. Cold shortening can also affect the sarcomere length. This can create differences between muscles and also within muscles (localised cold shortening).

The collagen levels between muscles are known to vary significantly. The collagen levels also vary between animals. It is expected that the trends (muscle collagen ranking) between muscles would be similar for any carcass. The amount of cross linking of collagen is also expected to differ between carcasses also, but it is unknown how much variation there is in cross linking of collagen between muscles from the same carcass.

The pH of muscles from the same carcass can vary, there can also be pH variations within a muscle. As expected there can also be pH differences between carcasses. The normal pH range for beef is 5.5-5.8. The pH is rarely below this range but it is not uncommon for it above this range (DFD > pH 6.0). The glycogen levels of the animal at slaughter govern the ultimate pH. The rate of pH drop also influences the functionality of the meat and is affected by electrical stimulation. This effect has been put down to the fact that the faster the pH drops, the less chance there is of cold shortening occurring before rigor mortis is complete. If the pH drop is too rapid, rigor mortis can be completed while the carcass is still “hot” which can cause denaturation of some proteins

(very rare in beef but can occur in pork i.e. dry soft exudative (DSE) pork), and can also cause hot shortening.

Different diets, environments and age all cause animal to animal variation. Diet and environment affect the growth rates of the animals. This can greatly affect the collagen within an animal. During growth a lot of newly synthesized collagen is present. This newly synthesized collagen has little cross-linking and is subsequently easier to denature and solubilise upon heating and has minimal residual strength left after denaturation. As animals age the rate of newly synthesized collagen slows dramatically (growth rates slow down) and the proportion of cross-linked collagen increases.

Differences in product quality can also arise due to the different boning techniques utilized after the animal has been slaughtered. Cold boning involves removing the various muscles once the carcass has been chilled for a significant amount of time (24 hours) and rigor has fully set in. Hot boning involves removing the various muscles from the carcass before it is completely chilled and rigor hasn't fully set in. Differences in product quality (such as tender, WHC) are attributed to the fact that with hot boning muscles are not stretched or compressed when going into full rigor as the case can be when the carcass are cold boned.

3.2.3 Conceptual model

From these observations it is possible to summarize the relevant factors into a semi mathematical description which could be used later to aid in data analysis. This conceptual model is summarized below.

Tenderness (myofibrillar) = f(fibre length (sarcomere length), pH, degree of aging, degree of myofibrillar protein denaturation and aggregation)

Tenderness (collagen) = f(quantity of collagen, collagen per fibre length, number of fibres, degree of cross linking, degree of collagen denaturation)

Cook loss = f(pH, shrinkage extent of collagen denaturation, Extent of myofibrillar protein denaturation)

Shrinkage = f(fibre length, collagen levels, degree of aging, degree of cross linking in collagen)

Sarcomere Length = f(cold shortening, fibre length into rigor (compressed or stretched)

Extent of protein denaturation = f(temperature and time)

3.3 Potential to add value

When investigating the potential to add value to a muscle, a number of factors have to be taken into account. These include, the functional properties of the muscles, size of muscle (weight), ease of further processing and current use (i.e. what products it is currently used for). Different weightings will be placed against each criterion depending on what industry considers most important and current practices.

It is expected that tenderness will have a significant weighting attached, but only up to a certain level (i.e. once an acceptable tenderness is reached the weighting would stay the same and another factor would be more important e.g. cook loss). Cook loss is expected to have a significant weighting attached as it is very important economically. The lower the cook loss, the higher the yield and subsequent return per processing time. Shrinkage would also be considered reasonably important for portion control, but not as important as cook loss as most products are sold on a weight basis.

The size of the muscle will also be an important consideration as the bigger the muscle the better. This is because more product can be made from a bigger muscle which means the cost of excising the muscle per product is lower. The ease of fabricating product from the muscles also has to be considered. Muscles with collagen seams running through them would be expected to be harder to fabricate with further processing as collagen seams (gristle) are undesirable in most added value products. Therefore the ease of removing any collagen seams if present has to be taken into consideration (especially if the process is a mechanical one). The current use of any muscles also has to be taken into consideration as there is more scope to add value to a

muscle currently used for grinding than a muscle which is already used for products that command a higher price than grinding beef.

3.4 Experimental characterisation of beef forequarter functionality

3.4.1 Muscle and carcass selection

It is known that different diets, environments and age all cause animal to animal variation. To help minimize this as much as possible, the muscles were all excised from 10 animals from the same mob (similar age, diets and environment). The animals used were all steers of approximately 14 to 18 months of age. This age group was selected as it is one of the most common slaughtered and believed to have the best potential for further processing applications.

The muscles to be excised and tested were selected according to ease of removal from animal (least disruption to normal practices), muscle size and current use. From this selection process the seven forequarter muscles tested were:

Supraspinatus (Chuck Tender)	(SP)
Triceps Brachi Long Head (Bolar Shoulder Clod)	(TBL)
Triceps Brachi Medial Head (Bolar Shoulder Clod)	(TBM)
Infraspinatus (Cross Cut Blade)	(INF)
Latissimus Dorsi	(LT)
Serratus Ventralis (Overlying Muscles of the Chuck)	(SV)
Pectorialis Profundus (Point End Brisket)	(PP)

The abbreviations above are used extensively throughout this chapter to identify each muscle type.

It is known that aging can have a significant affect on meat tenderness. To eliminate this effect all muscles were excised at the same time and then frozen at –30°C together. All muscles were thawed for the same amount (48 hours) of time at the same temperature (4°C) before cooking tests were conducted. Some muscles (from the same carcasses)

were stored frozen at -30°C for a longer than others (i.e. shortest was for 2 days longest for 12 days), but this was unavoidable and believed not to be to significant. All muscles from a carcass were treated under the same conditions, as the project was aimed more at investigating differences between muscles than differences between carcasses.

3.4.2 Experimental methods for functionality testing

3.4.2.1 Cooking

A standardised cooking temperature and time was utilized to remove the effect of variation in cooking regime. The cooking regime selected was a standard procedure, which is already routinely used by other researchers at Massey University. The results of this procedure are also directly comparable to those obtained using the MIRINZ tenderometer technique, which is routinely used in the New Zealand meat industry.

For the functional property measurements, 25mm steaks (~150g) were cut from the selected muscles and placed in thin polyethylene bags. The bagged steaks were then quickly immersed and hung in a well-stirred 70°C water bath (ensuring no air bubbles were trapped in the bag). The steaks were cooked in this way for 90 minutes. This cooking method meant there was no cooking loss due to evaporation. After 90 minutes the steaks were removed from the water bath and the cooking loss fluid was drained from the bags. The steaks were cooled for eight hours in a 4°C chiller. Chilling the steaks ensured that all the samples were at a uniform temperature before tenderness tests were conducted.

3.4.2.2 Cooking losses

Cooking losses were measured by weighing the steaks before and after cooking. After the cooked steaks had been cooled for eight hours they were lightly dabbed with tissue paper and weighed. The percentage cooking loss was calculated by dividing the difference between the cooked and uncooked steak by the uncooked steak weight. It was assumed that all losses were mainly water although it is likely that there was a small amount of lipid and protein present in the drip. Because of the cooking process, negligible evaporation occurred, therefore the cook losses were associated with the chemical reactions (protein denaturation and collagen gelatinisation) occurring during the cooking process.

3.4.2.3 Shrinkage

The amount of shrinkage that occurred during cooking was measured by comparing the dimensions before and after cooking. The width and length of the steaks were measured before and after cooking using a ruler (0.5mm graduations). The percentage shrinkage was calculated by adding the percentage change in each direction (i.e. change in length divided by original length). This is essentially a volume based shrinkage measurement. The change in thickness wasn't measured as it was small in comparison to the other dimensions and the error associated with each measurement was a magnitude similar to any detectable change in thickness (each steak was ~25mm thick).

3.4.2.4 Tenderness (Warner Bratzler Shear)

In the literature no standard cooking technique exists for tenderness measurements, as most researchers seem to use what is currently available to them or are testing for a specific cooking regime. When looking at differences between muscles, the majority of researchers cook 25mm steaks for a set time or to a certain internal temperature in water-baths, ovens or using electric broilers. Samples of the same size are then cut parallel to the fiber direction for tenderness measurements (usually with a Warner Bratzler shearing device), (Paterson and Parrish 1986), (Johnson *et al.* 1988). For this reason a method developed at Massey University was used in this study.

This method has been used extensively for similar research at Massey University and can be related directly to the MIRINZ tenderometer technique which is used as an industry standard in New Zealand. The Massey University technique is preferred by researchers here as it ensures even cooking. This means that tenderness gradients within the meat samples are not encountered. This can occur with the MIRINZ technique due to the cooking regime of 80°C for 30 minutes.

The tenderness of the cooked (cooking method as outlined in section 3.4.2.1) steaks were measured using a Warner Bratzler shear device. Once the steaks had been cooked, 13mm x 13mm blocks were cut parallel to the muscle fiber direction. These samples were then analysed using a Warner Bratzler shearing device fitted with a square blade travelling at 100mm a minute. The yield force and peak force for each sample were

recorded. At least 8 measurements per muscle sample were collected with 2 shear per core.

3.4.2.5 pH

The pH of the samples was measured by homogenizing 2.0 – 2.5g of muscle in 10ml of buffer solution (5mM iodoacetate and 150mM KCl, at pH 7.0). The pH of this was then measured using a freshly calibrated pH probe (Jenway 3020 pH meter). The pH measurements were made in duplicate. Method developed from (Dransfield E. 1997).

3.4.2.6 Sarcomere length

Sarcomere length was measured by teasing out a very thin slither of the meat sample onto a microscope slide. A few drops of solution (0.25M sucrose, 0.05M TMS and 1mM EDTA) was then applied on top of the teased meat sample. The sarcomere lengths were then measured by laser diffraction, method developed from (Bouton et al. 1981).

3.4.2.7 Collagen levels

Once the results for the functional properties were gathered the collagen levels of four carcasses were measured. Only four carcasses would be assessed due to the relatively high cost of analysis. The four carcasses were chosen according to the following criteria;

- One carcass with consistently high peak forces
- One with consistently low peak forces
- Two with average peak forces

Peak force was chosen as the basis for selection as it is the most commonly used parameters to describe tenderness and it was one of the most variable functional properties between carcasses. It was thought that the variability between carcasses might be able to be explained by the differences in collagen levels, pH and sarcomere length.

The Nutrition laboratory in the institute of Food, Nutrition and Human Health, Massey University conducted the collagen content determination of the selected muscles. Samples of the muscles were freeze dried and then ground very finely so they could

pass through a 1mm sieve. They were then digested and the amino acid content was analysed by HPLC. The amino acid hydroxyproline is unique to collagen with respect to meat proteins and comprises about 14% of the amino acid content of collagen (Sims and Bailey 1981). Therefore to calculate the amount of collagen, the hydroxyproline content was multiplied by 100/14.

3.4.3 Results

The various functional properties of Cook Loss and Tenderness were found to vary significantly between the various forequarter muscles. Table 3.1 shows the average values for the 10 carcasses;

	Peak Force (kg)		Yield Force (kg)		Cook Loss (g/g)		Shrinkage (%)		Moisture Before cooking (g/g)	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
IN	7.82	2.12	6.16	1.66	0.289	0.029	32.6	6.8	0.741	1.09
TBL	9.47	1.15	7.61	0.99	0.323	0.009	29.7	12.1	0.725	1.35
SP	10.60	2.70	8.36	3.05	0.332	0.017	36.9	9.9	0.736	1.66
TBM	10.85	1.65	8.23	2.09	0.303	0.013	33.3	-	0.730	3.20
LT	11.45	1.79	7.52	1.63	0.275	0.020	40.8	7.8	0.746	0.49
SV	12.70	2.37	9.81	2.17	0.325	0.021	32.2	9.9	0.729	1.37
PP	14.94	4.02	7.28	1.93	0.312	0.015	34.0	7.2	0.758	1.08

	Moisture After cooking (g/g)		pH		Sarcomere Length (μm)		Shortening (%)		Collagen (g/g muscle)	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	
IN	0.452		5.67	0.115	1.36	0.103	38.3	5.1	0.225	0.045
TBL	0.401		5.52	0.099	1.23	0.100	44.2	6.6	0.236	0.118
SP	0.404		5.67	0.215	1.10	0.062	49.8	6.4	0.317	0.072
TBM	0.426		5.60	0.131	1.18	0.085	46.2	5.3	0.272	0.018
LT	0.471		5.61	0.127	1.65	0.102	24.9	5.3	0.680	0.042
SV	0.404		5.68	0.088	0.84	0.035	61.7	5.6	0.303	0.064
PP	0.445		5.53	0.066	1.72	0.109	21.7	4.5	0.380	0.187

Table 3. 1 Average functional and compositional properties of beef forequarter muscles for the ten selected carcasses (4 four collagen).

From the averages given in table 3.1, it can be seen that the Infraspinatus (IN) and Triceps Brachi Longhead (TBL) are the more tender muscles (lowest peak forces). The tough muscles are the Latissimus Dorsi (LT), Serratus Ventralis (SV)and the Pectorialis Profundus (PP). The other muscles have intermediate tenderness and cannot be distinguished as being different from one another. The variability for the measured values is quite large, this is because the averages are made over ten different carcasses. Carcass to carcass variation for each muscle was believed to be the main cause of the high standard deviation in the results.

The cook loss range over the different muscles was between 27% to 33%. The Latissimus Dorsi and The Infraspinatus had the lowest cooking losses whereas the Supraspinatus had the highest. The remaining muscles had intermediate values for cook loss.

The yield force for most of the muscles were quite low (i.e. LT, IN, PP and TBL) but slightly higher for the other three muscles (TBM, SP and SV). In general, muscles with

higher yield forces resulted in higher peak forces, but there are exceptions. For example, PP has the second lowest yield force but highest peak force.

Differences in shrinkage were very hard to compare, as obtaining an accurate measurement of the dimensions of the raw meat sample was difficult. This is due to the fact that raw meat is quite easily deformed (i.e. squashed or stretched) easily. All steaks were cut to approximately 25mm. It was found that the length and the width of a sample could easily change by -/+ 10mm with minimal manipulation of the meat. Also raw steaks have no definitive edge, this caused measurements to only be accurate to +/- 5mm.

Once the steaks had been cooked, the dimensions also proved difficult to accurately measure. Unlike raw steaks, the cooked steaks were quite firm, but during cooking the steaks often became misshapen due to collagen denaturation and subsequent shrinkage not being uniform within a steak (whole meat portions are a non-homogenous material). This meant that the length and width measurements were difficult to obtain accurately. The edges also became slanted, making measurements difficult to assess with accuracy. For these reasons the shrinkage measured was used primarily as a qualitative representation of the shrinkage associated with each muscle. In spite of this the LT and SP muscles were observed to have the largest amount of shrinkage while TBM shrank the least. It is interesting to note that LT, although having the highest shrinkage, also had the least amount of observed cooking losses. The pH of the muscles were found to be very similar and in the expected range of 5.5 to 5.8 for most animals.

The sarcomere length was found to vary between muscles within a carcass by a substantial amount. The SV had considerably shorter sarcomeres than the rest of the muscles and the Pectorialis Profundus and Latissimus Dorsi had considerably longer sarcomeres. It is important to note that most of the measured sarcomere lengths were within the range of 1.1mm to 1.7mm, which corresponds to 52% to 26% shortening. This could be important as muscle can shorten by 20% without any change in tenderness, but up to 45% shortening toughness dramatically increases after which it subsides again, (Herring *et al*. 1965a).

3.4.4 Data analysis

The aims of the data analysis was twofold. Firstly, the muscles most suitable for adding value were to be identified. Secondly the collected data were to be used to attempt to validate the conceptual model of meat cookery described above and identify whether it would be possible to predict cooked meat functionality from muscles composition and cooking regime.

3.4.4.1 Peak force (tenderness)

Peak force is generally regarded as the best measurement for the tenderness of meat samples. This is because peak force is a measure of the overall tenderness imparted by the myofibrillar and connective tissue fractions of the meat. The peak force of the various forequarter muscles tested, were found to vary both between muscle type and animal. It was expected that there would be considerable variation between animals for tenderness. This is because of the variation in the animal genetics, ages, diet and slight differences in pH between different animals. This study was concerned more with the differences between muscles in the forequarter. The overall ranking for tenderness (peak force) of the muscles tested was: Infraspinatus, Triceps Brachi Longhead, Supraspinatus, Triceps Brachi Medialhead, Latissimus Dorsi, Serratus Ventralis and Pectorialis Profundus. This ranking was the same (or very similar) for most animals, but there are a few exceptions without any obvious explanations for them. These differences can be seen in Figure 3.1 below.

From Figure 3.1 it can be seen that there are some trends for tenderness i.e. Infraspinatus is consistently tender whereas the Pectorialis Profundus is consistently tough. But it can be seen that a large amount of the variability is due to the differences between carcasses

Of the muscles tested the Pectorialis Profundus was found to be the toughest and most variable for tenderness. This is due to the structure of the Pectorialis Profundus, which has quite a lot of connective tissue running through it (not tendons, the connective tissue is part of the muscle). This connective tissue causes the muscle to be quite tough and causes a high degree of variation, as not every Warner bratzler sample would have the same amount of connective tissue to cut through.

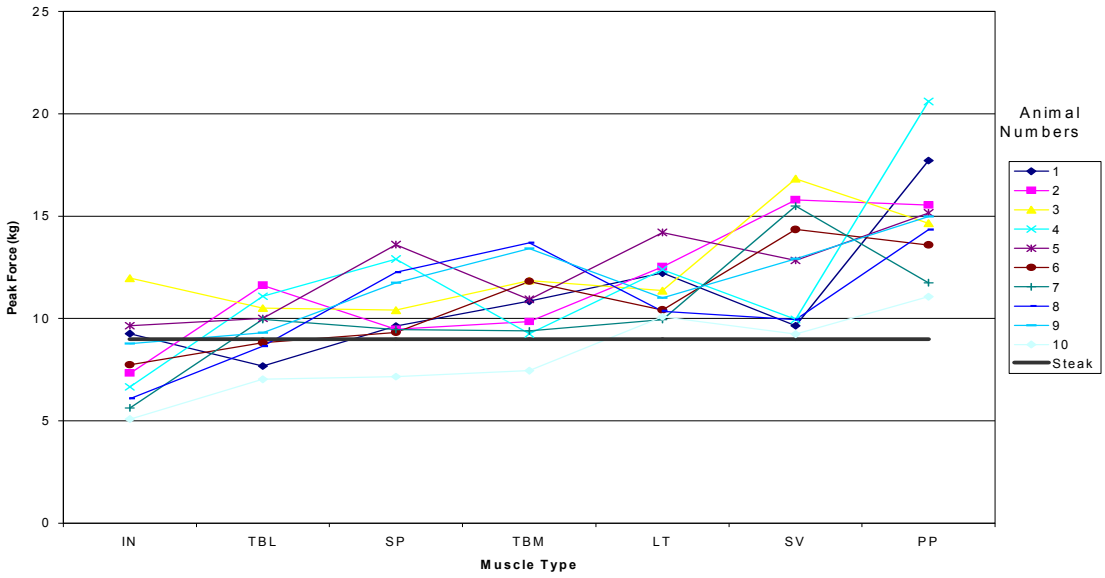

Figure 3.1: Graph showing the ranking of muscle types from peak force measurements for each animal.

The horizontal line representing a cut off peak force of 9kg represents the standard that has to be achieved for meat to be regarded as a product of consumer steak quality. It can be seen that the only two muscles which can achieve this standard are the infraspinatus and the triceps brachi longhead. About 70% of the Infraspinatus muscles attain the 9kg standard whereas only about 30% of the Triceps Brachi Longhead attain this standard.

3.4.4.2 Yield force

The yield force is generally regarded as a measure of the toughness imparted by the myofibrillar protein fraction of meat. The main contributing factor to myofibrillar toughness is pH and sarcomere length. All the muscles had fairly comparable pH's, but there was significant variation with sarcomere length (see table 3.1).

For the yield force, most of the values for the different muscles are fairly similar, except for the Serratus Ventralis muscle which has higher values for yield force compared to the others. This could to be due to the fact that the Serratus Ventralis had considerably shorter sarcomeres in general than the other muscles. Whether this arose from localised cold shortening or from the muscle being compressed when hung is unknown.

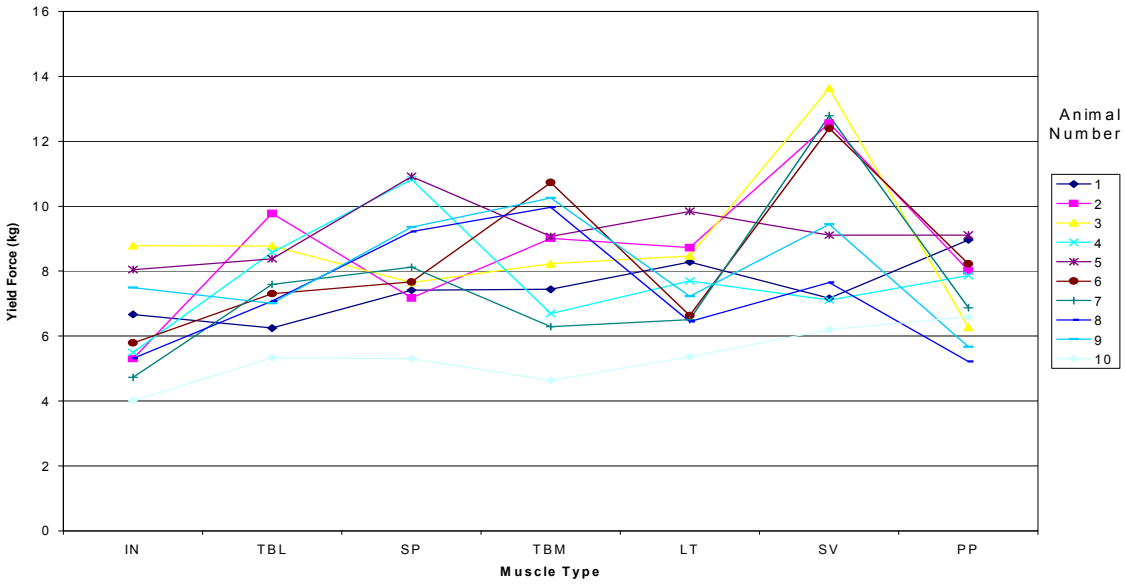

Figure 3.2: The variation of yield force between forequarter muscles for each animal (note the order of muscle type is that of ranking based on peak force).

Figure 3.2 summarises the yield force scores for each animal as a function of muscle type. Note the muscle type is the same order as the ranking based on peak force as discussed above. From Figure 3.2 it can be seen that there is considerable variation caused by the different carcasses. The trends tend to hold true for each carcass (e.g. SV often has the highest yield force).

3.4.4.3 Overall tenderness profile

Figure 3.3 below, shows the average tenderness measurements for both peak and yield force. From the graph the muscle tenderness trend is more evident, however due to the large amount of variation between carcasses it is not possible to statistically state any differences confidently. Before a clear ranking can be carried out the effect of animal variation must removed.

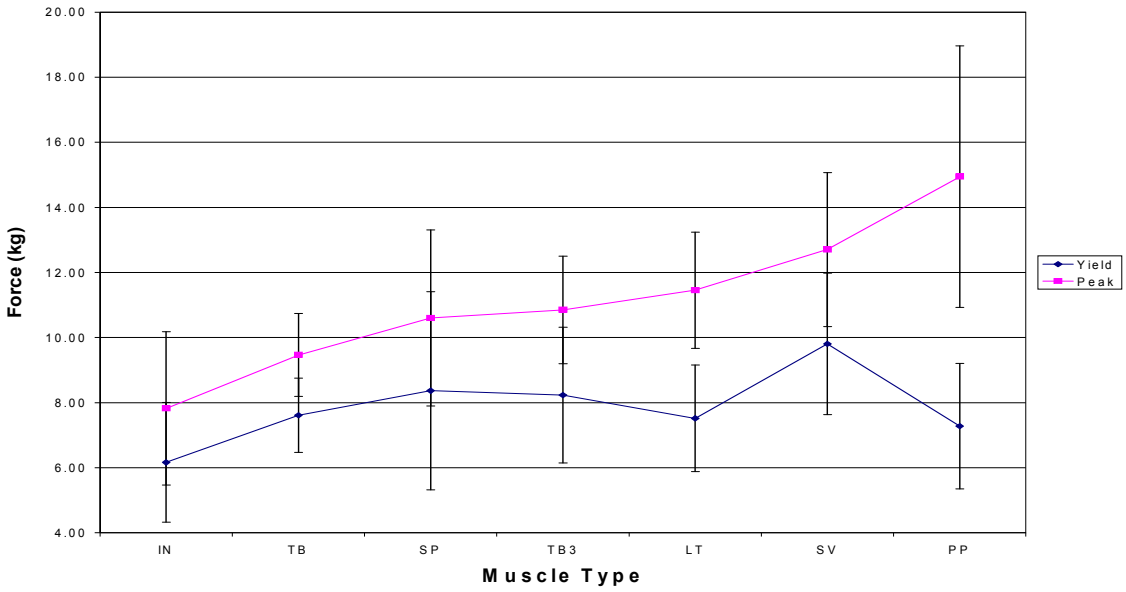

Figure 3.3: Average tenderness scores for each muscle type with SE bars.

3.4.4.4 Tenderness with animal variation removed

From the results it was noted that although trends were evident for the various functional properties between the different muscles, the variation caused by the different carcasses was larger than the trends. This meant that differences between muscles couldn't be made with any statistical confidence. To overcome this problem it was decided to analyse the results using the SAS statistical package (SAS, system release 8.1 (TS1MO)). Carcass was made an independent variable while peak force and yield forces were made dependent variables with respect to muscle type, all peak force and yield force measurements made for each sample were included (i.e. 8 or more per muscle, per animal).

3.4.4.4.1 Peak force once carcass variation removed

The SAS averages the values for each muscle but takes into account the variation caused by differences between the carcasses. The standard error is therefore based on the number of observations (number of muscles tested and number of tests per muscle). The standard error for the TBM muscle is higher due to the number of observations being lower than the rest of the other muscle. The TBM only had eight observations made while the other muscles all had ten observations made. The average value and variation with carcass effect removed is shown below in table 3.2;

MUSCLE	PEAK	Std Err
Type	LSMEAN	LSMEAN
IN	7.74	0.339
TBL	9.49	0.342
SP	10.48	0.335
TBM	11.58	0.619
LT	11.43	0.316
SV	12.63	0.029
PP	15.06	0.314

Table 3. 2 Mean peak force with carcass variation removed.

The second output obtained from the SAS analysis is a statistical comparison of the various muscle peak forces with carcass variation removed. Table 3.3 below shows this statistical output. If a number in a row of table 3.3 is below 0.05 then the muscle in the corresponding column can be said to have a different peak force with 95% confidence (1-.05). An example of this is for the row corresponding to the IN muscle, at the 95% confidence level in can be stated that it is different from all other muscles (all values in the row are less than 0.05).

	IN	LT	PP	SP	SV	TBL	TBM
IN	.	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001
LT	0.0001	.	0.0001	0.0403	0.0052	0.0001	0.8377
PP	0.0001	0.0001	.	0.0001	0.0001	0.0001	0.0001
SP	0.0001	0.0403	0.0001	.	0.0001	0.0377	0.1242
SV	0.0001	0.0052	0.0001	0.0161	.	0.0001	0.1217
TBL	0.0003	0.0001	0.0001	0.0377	0.0001	.	0.0031
TBM	0.0001	0.8377	0.0001	0.1242	0.1217	0.0031	.

Table 3. 3 Output for statistical analysis of peak force.

From the table 3.2 and table 3.3 it can be seen that the Infraspinatus is definitely the most tender muscle investigated. This is because it can be stated that it has a lower peak

force compared to all other muscles. The Triceps Brachi Longhead is the second most tender muscle. The Supraspinatus is the third most tender, but it cannot be said to be more tender than the Triceps Brachi Medialhead muscle. The Latissimus Dorsi is the fourth most tender muscle although it cannot be said to be more tender than the Triceps Brachi Medialhead muscle. The Triceps Brachi Medialhead is the fifth most tender muscle but cannot be said to be different from the Supraspinatus, Latissimus Dorsi or Serratus Ventralis. The Serratus Ventralis is the sixth most tender muscle, but cannot be said to be different from the Triceps Brachi Medialhead muscle. The Pectorialis Profundus is the seventh ranked muscle for tenderness and is different from all the other muscles.

When the SAS output is plotted on a graph the trend for peak force (tenderness) becomes quite clear as shown below in Figure 3.4.

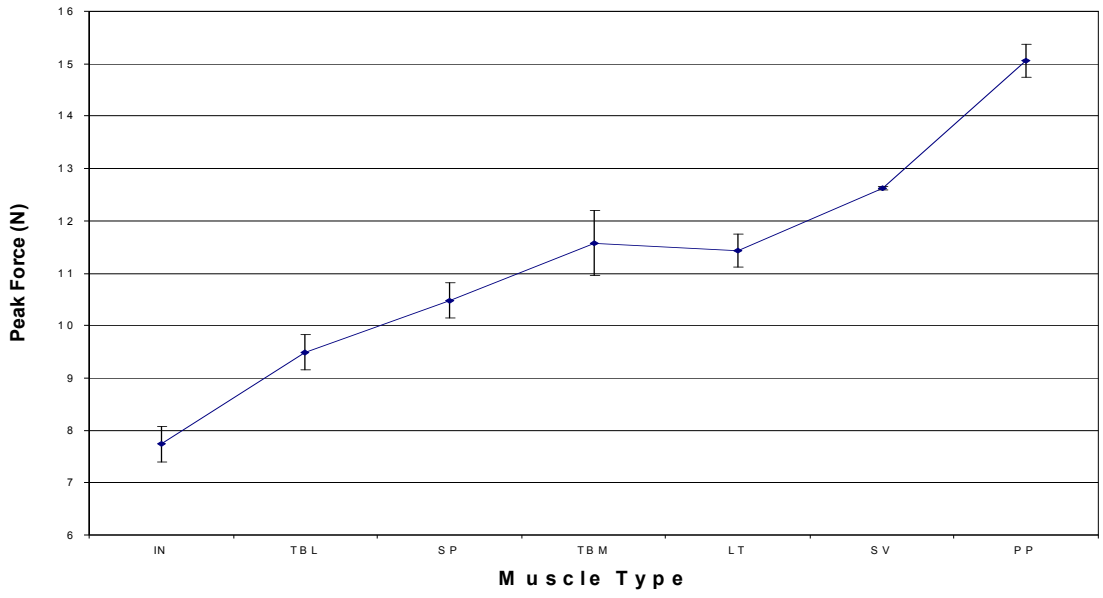

Figure 3.4: Peak force with the carcass to carcass variation removed (N=kg's).

The ranking of the muscles for tenderness is Infraspinatus, Triceps Brachi Longhead, Supraspinatus, Triceps Brachi Medialhead, Latissimus Dorsi, Serratus Ventralis and Pectorialis Profundus.

3.4.4.4.2 Yield force once carcass variation removed

A similar analysis to that described above for peak force was carried out for yield force to remove carcass to carcass variation (see tables 3.4 and 3.5 below). When the SAS output was analysed with respect to yield force there were some differences that were apparent. The main two was that the Serratus Ventralis has a higher yield force than all other muscles and the Infraspinatus had a lower yield force than all other muscles. The Triceps Brachi Longhead, Pectorialis Profundus and the Latissimus Dorsi muscles were indistinguishable from one another with regard to yield force. The Supraspinatus and the Triceps Brachi Medialhead were also indistinguishable from one another. This was surprising as yield force is regarded as a measure of the myofibrillar toughness, which is very dependent on the sarcomere length. As there was quite a range of values for sarcomere length between muscles it was expected that the yield force would also vary considerably between muscles, (Hostetler *et al*. 1972).

MUSCLE	Yield	Std Err
Type	LSMEAN	LSMEAN
IN	6.05	0.283
LT	7.52	0.265
PP	7.35	0.262
SP	8.33	0.279
SV	9.74	0.244
TBL	7.51	0.285
TBM	8.73	0.517

Table 3. 4 Mean yield force with carcass variation removed.

	IN	LT	PP	SP	SV	TBL	TBM
IN	.	0.0002	0.0008	0.0001	0.0001	0.0003	0.0001
LT	0.0002	.	0.6462	0.0361	0.0001	0.9717	0.0397
PP	0.0008	0.6462	.	0.0108	0.0001	0.6848	0.0183
SP	0.0001	0.0361	0.0108	.	0.0002	0.0402	0.5045
SV	0.0001	0.0001	0.0001	0.0002	.	0.0001	0.0781
TBL	0.0003	0.9717	0.6848	0.0402	0.0001	.	0.0386
TBM	0.0001	0.0397	0.0183	0.5045	0.0781	0.0386	.

Table 3.5 Output for statistical analysis of yield force.

Figure 3.5 summarizes the yield force results so that the trend of how yield force varies with muscle type can be seen.

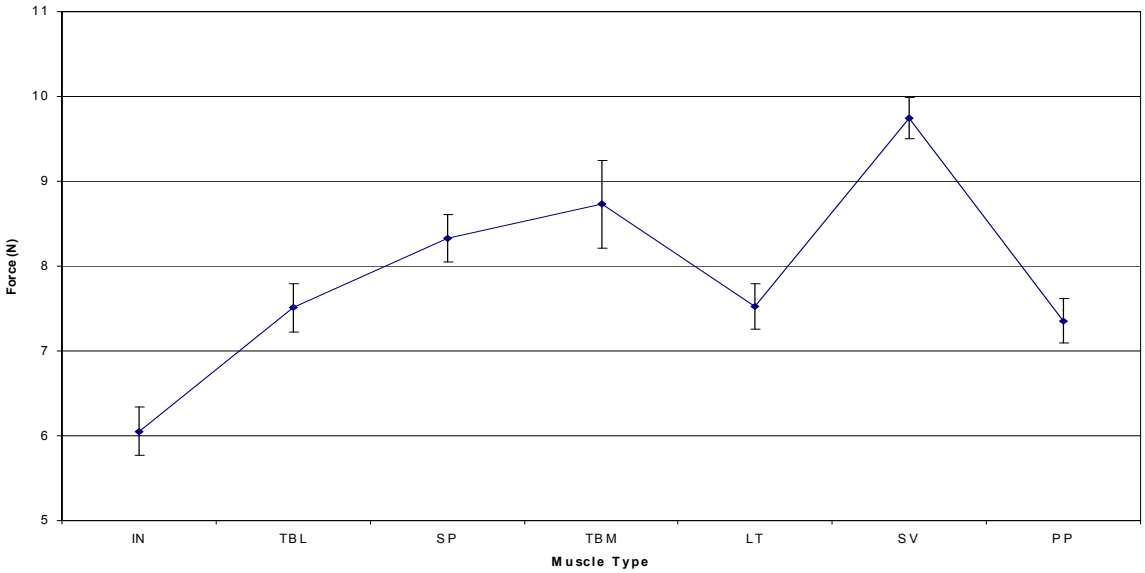

Figure 3.5: Yield force with the carcass to carcass variation removed (N=kg's).

From Figure 3.5 it can be seen that the Infraspinatus has the lowest yield force. The muscles with the second lowest yield forces are the Triceps Brachi Longhead, Latissimus Dorsi and the Pectorialis Profundus. The third ranked muscles are the Supraspinatus and the Triceps Brachi Medialhead, the muscle with the highest yield force is the Serratus Ventralis.

3.4.4.5 Cooking losses

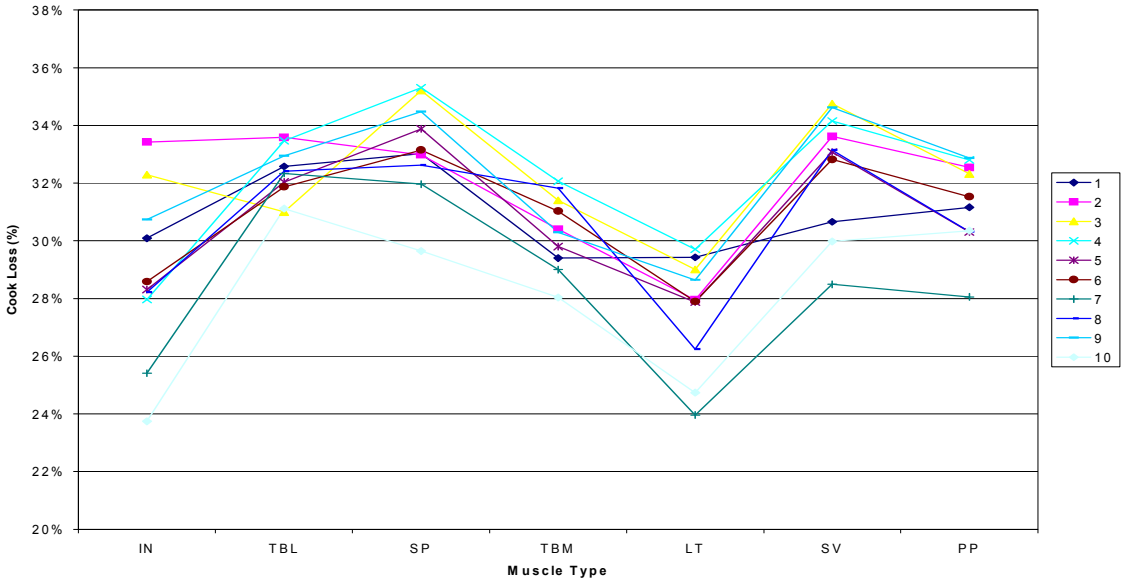

Figure 3.6: Cooking losses in various forequarter muscles for each animal studied.

Cooking losses were not found to vary between the different muscles. As can be seen from Figure 3.6, when the individual values for each muscle are plotted along side the values from different muscles from the same carcass, there are trends evident. Latissimus Dorsi is consistently low, whereas the Supraspinatus is consistently higher compared to muscles from the same carcass. It can be seen that a lot of the variation is caused by differences between carcasses. Again it would be useful to remove the animal variation effect to obtain a clearer picture of the muscle ranking according to cook loss.

A similar analysis to peak force was carried out for cook losses to remove carcass to carcass variation. The SAS output is shown below in tables 3.6 and 3.7. For cook loss there are no differences between the muscles. This is because the variation in cooking losses for each muscle is of the same order of magnitude or higher than the range of cook losses over all the muscles. This can be easily seen in Figure 3.7.

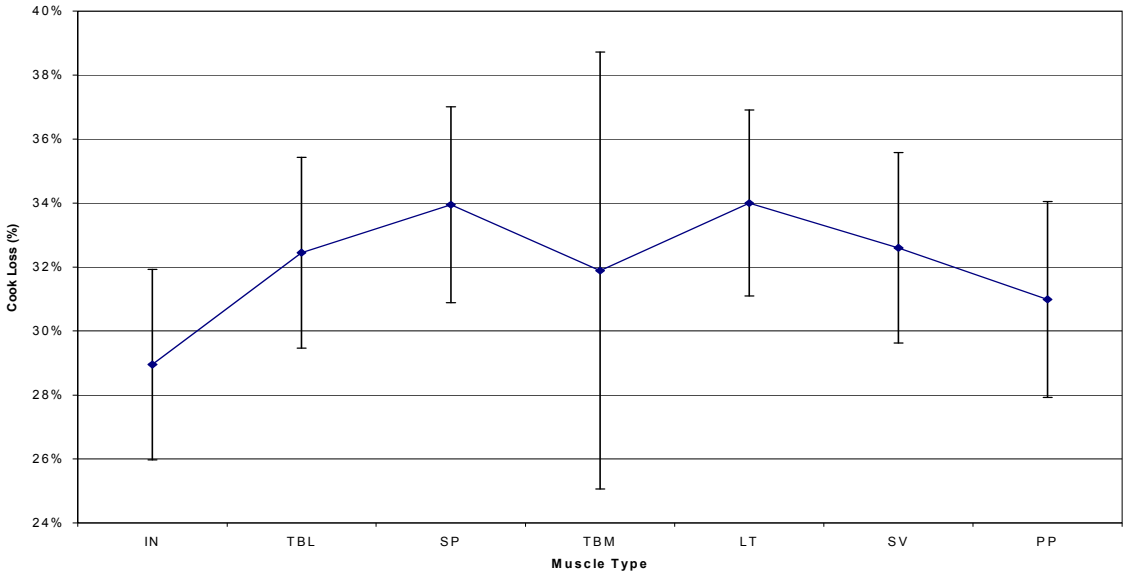

Figure 3.7: Cook loss with carcass to carcass variation removed.

MUSCLE	Cook loss	Std Err
Type	LSMEAN	LSMEAN
IN	0.2895	0.0298
LT	0.3400	0.0291
PP	0.3099	0.0306
SP	0.3395	0.0306
SV	0.3260	0.0298
TBL	0.3245	0.0298
TBM	0.3189	0.0683

Table 3.6 Cook Losses with carcass variation removed.

	IN	LT	PP	SP	SV	TBL	TBM
IN	.	0.2289	0.6346	0.2446	0.3886	0.4083	0.6941
LT	0.2289	.	0.4784	0.9918	0.7385	0.7116	0.7777
PP	0.6346	0.4784	.	0.4956	0.7069	0.7330	0.9045
SP	0.2446	0.9918	0.4956	.	0.7524	0.7260	0.7833
SV	0.3886	0.7385	0.7069	0.7524	.	0.9717	0.9243
TBL	0.4083	0.7116	0.7330	0.7260	0.9717	.	0.9403
TBM	0.6941	0.7777	0.9045	0.7833	0.9243	0.9403	.

Table 3.7 Output for statistical analysis of cook loss.

3.4.4.6 Shrinkage

Figure 3.8 shows the average shrinkage that occurred in the experiments carried out. The SV, IN, TBL, TBM and PP all had fairly similar shrinkage values of around 32% to 34%. The only muscles that seemed to perform differently in terms of shrinkage were the Supraspinatus with 37% shrinkage and the Latissimus Dorsi with 41% shrinkage.

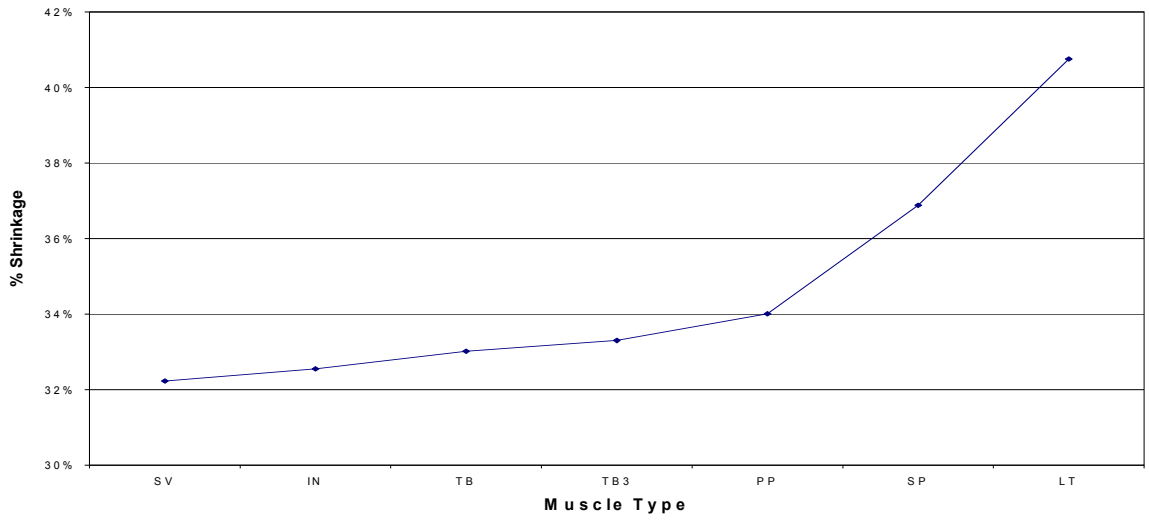

Figure 3.8: Average shrinkage value for each muscle type.

A similar analysis to peak force was carried out for shrinkage to remove carcass to carcass variation, the SAS output is shown below in tables 3.8 and 3.9 below.

MUSCLE	Shrinkage	Std Err
Type	LSMEAN	LSMEAN
IN	0.3245	0.1222
LT	0.4807	0.1196
PP	0.3600	0.1257
SP	0.3619	0.1257
SV	0.3220	0.1223
TBL	0.6043	0.1270
TBM	0.3114	0.3995

Table 3.8 Mean shrinkage values with carcass variation removed.

	IN	LT	PP	SP	SV	TBL	TBM
IN	.	0.3632	0.8398	0.8317	0.9885	0.1156	0.9750
LT	0.3632	.	0.4882	0.4957	0.3556	0.4801	0.6858
PP	0.8398	0.4882	.	0.9918	0.8287	0.1758	0.9077
SP	0.9317	0.4957	0.9918	.	0.8206	0.1780	0.9042
SV	0.9885	0.3556	0.8287	0.8206	.	0.1124	0.9798
TBL	0.1156	0.4801	0.1758	0.1780	0.1124	.	0.4858
TBM	0.9450	0.6858	0.9077	0.9042	0.9798	0.4858	.

Table 3.9 Output for statistical analysis of shrinkage.

The main output from the SAS analysis is that no muscle can be said to shrink significantly more or less than any other. The muscles cannot be distinguished from one another, as the range of shrinkage values is of the same order of magnitude as the variation. This is easily seen in Figure 3.9. This result is unexpected as the amount of shrinkage was thought to be related to the amount of collagen present. Shrinkage of meat is mainly due to collagen denaturation and subsequent contracture (as the structure can no longer support itself when it denatures). When the collagen contracts, the water expelled from the myosin denaturation (which occurs at about 45°C-55°C) is squeezed

out of the meat due to the pressure exerted as the collagen contracts. Therefore the more a piece of meat shrinks upon cooking the greater the cooking losses are expected to be. This may partially explain why no differences in cook losses were found as no differences in shrinkage were found.

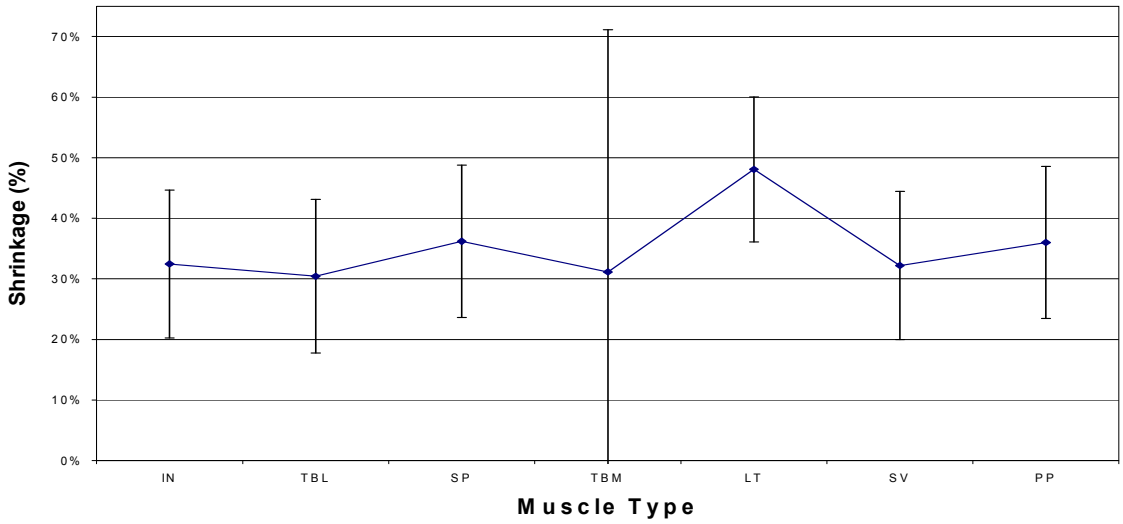

Figure 3.9: Shrinkage values with carcass to carcass variation removed.

3.4.5 Summary of functional properties

Upon completion of gathering all the functional properties data for the selected beef forequarter muscles, the muscles were ranked from best performing to lowest performing for each functional property as can be seen below in table 3.10;

Peak Force	Yield Force	Cook Loss	Shrinkage
IN	IN	IN	TBL
TBL	PP	PP	TBM
SP	TBL	TBM	SV
LT	LT	TBL	IN
TBM	SP	SV	PP
SV	TBM	SP	SP
PP	SV	LT	LT

Table 3.10 Functional properties ranking (ranked in ascending order).

To get an overall ranking a weighted factor had to be assigned to each of the functional properties according to their importance for use in further processed value added products. The variation inherent within a muscle and the amount of variation between carcasses also has to be considered (i.e. some muscle may have more constant functional properties within itself or between carcasses). Along with the functional properties other factors have to be taken into account to give a true picture of a muscles added value potential. These factors include ease of removal from carcass (i.e. how many, if any modification will have to be made to current boning practices). Production factors such as ease of processing have to be considered (i.e. structure of muscle will affect processing ease, a muscle with a thick collagen seam through the middle would be harder to process than a muscle without one). The size and shape of the muscles needs consideration, as a larger muscle would be more favorable than a small one and a regular shaped muscle is preferred to an irregular shaped one.

3.5 Potential for adding value

The functional property of tenderness was given a weighting of 5 due to it being important in that unless a certain tenderness is reached the muscle won't be suitable for its intended purposes i.e. ready meal applications. The tenderness variation was given a weighting of 2.5, as the consistency of product quality is also important. Cook loss was given an approximate weighting of two, as it is important for economical product yield. Shrinkage was given a weighting of 1, as it was only a qualitative measurement but has a slight importance for portion controlling (not too important as produce sold on a weight basis). The variable of ease of processing was given a value between 5 and 1, 5 being hard to process i.e. due to thick collagen seam in muscle and 1 being easy to process i.e. no collagen seam. The factor processing ease was given a weighting of 2.5. The size and shape of the muscle were also considered as a large round muscle has more potential uses than a small flat one. A flat small muscle was given a value of 5 whereas a large round muscle was given a value of 1.

Muscle Type	Peak Force	Peak Variation	Cook loss	Shrinkage	Processing	Size/ Shape	Score
IN	7.82	2.36	27.5%	25.0%	5	2	102.5
TBL	9.47	1.27	28.9%	32.0%	3.5	1	106.7
SP	10.59	2.70	31.0%	33.0%	1	2.5	116.0
TBM	11.17	1.16	31.0%	33.0%	4	2	121.3
LT	11.45	1.79	32.0%	34.0%	3.5	5	132.0
SV	12.7	2.37	33.0%	37.0%	1.5	3	132.2
PP	14.94	4.02	33.0%	41.0%	3	4.5	157.0

Table 3.11 Process ranking for the selected forequarter muscles after weighting factors applied (lower score equals a higher value muscle).

From the ranking process it was easy to see that the two muscles with the most potential were the Infraspinatus and the Triceps Brachi Longhead. The main reason was that these two muscles were the most tender, had slightly lower cooking losses than a lot of the others and the muscles were rather large and had a good shape. The only problem with the Infraspinatus is that it has a large collagen seam running through the middle of it. This could be expected to effect its processability, as consumers generally don't want too much collagen or "gristle" in meat products.

3.6 Conceptual model validation

Section 3.23 outlined the construction of a conceptual model that explains how muscle composition properties contribute to the functional properties of the cooked meat. This section assesses the validity of the conceptual model developed by testing the correlations between the functional properties of the meat samples tested as part of this work with the compositional properties. In this way it can be determined if it is possible to predict cooked meat functionality from properties of the uncooked meat. The relative importance of each factor on functional performance can also be assessed and this information used to aid the improvement of cooked meat quality.

3.6.1 Peak force comparisons

The conceptual model developed in section 3.23 suggests that the peak force tenderness score of a meat sample should be correlated with fibre length, number of fibres per unit area, pH, quantity of collagen, collagen per unit length. This section outlines attempts to validate this model by correlating the measured data to the structural and compositional factors measured for each sample. The degree of protein denaturation was not included as all samples were cooked to the same temperature for the same time. The extent of collagen crosslinking was also not included because it was not measured in this work.

The measured meat properties (pH, sarcomere length, shrinkage, shortening, collagen, moisture (after cooking), number of fibers and collagen per unit length) were analysed with SAS for correlation's with peak force. The number of fibers was not measured directly but a number proportional to the number of fibers was calculated by, number of fibers = sarcomere length * cook loss, because as the sarcomere length increases the number of fibers per unit increase and as cook loss increase the number of fibers per unit area also increases. Collagen per unit was not measured directly either but was calculated by, collagen per unit area = collagen / (sarcomere length * (1 – shrinkage)). This is because as collagen increases and sarcomere length decreases the amount of collagen per unit area increases. As the shrinkage increases the amount of collagen per unit area increases proportionally.

Using a linear model it was found that a correlation of about 0.60 was found between all the meat properties and peak force and that the most significant meat properties were number of fibers, collagen per unit length and sarcomere length. SAS was run again with just the most significant factors included to establish a model. The multiplication factor for each factor was given and the model was used to predict values. The correlation when only the significant terms were included was 0.38, which is quite low. It is clear from these results, that a simple linear model is not useful to relate the cooked meat functionality to the physical properties of the raw product.

The linear model equation is as follows: (from multiple regression techniques)

Peak Force = -9.71*(collagen) – 7.5*(moisture) + 25*(Number of fibers)
+ 11.33*(collagen per unit length) + 2.05

A logarithmic model was also established using a similar procedure (log values of the meat properties and peak force were used). When all terms were included the correlation was 0.66. The most significant meat properties were found to be collagen, moisture, number of fibers, collagen per unit length and sarcomere length. The multiplication factor (power value when log peak force converted back from logarithmic values to normal peak force values) was given when SAS was rerun with just the significant factors included and the model was used to compare predicted values and measured experimental. These results can be seen in tables 3.11. The correlation when only the significant terms were included was also 0.66.

The logarithmic model equation is as follows:

Peak Force = $\exp(5.95)*(\text{number of fibers})^{2.48}*(\text{sarcomere length})^{-3.14}*(\text{moisture})^{1.15}$
$*(\text{shortening})^{-0.57}*(\text{collagen})^{0.089}*(\text{collagen per unit length})^{0.49}$

Muscle	Animal 4		Animal 6		Animal 9		Animal 10	
	log	data	log	data	log	data	Log	data
IN	7.62	6.67	8.53	7.74	9.39	8.77	5.50	5.09
TBL	10.60	11.09	8.76	8.81	11.07	9.30	7.93	7.03
SP	11.40	12.91	11.14	9.32	12.38	11.74	8.59	7.17
TBM	-	9.25	9.41	11.81	8.74	13.42	7.48	7.46
LT	11.03	12.40	9.94	10.42	12.33	11.01	7.41	10.09
SV	10.90	9.95	12.05	14.35	12.47	12.91	8.97	9.24
PP	12.88	20.60	13.65	13.60	16.09	14.97	13.66	11.07

Table 3.12 Model differences for peak force (kg)

The logarithmic model was found to fit better than the simple linear model. The significant meat properties that had the most effect on the model were number of fibers and sarcomere length. The term for number of fibers meant that as the number of fibers increased the tenderness decreased, this is believed to be because the number of fibers that have to be cut increases. The term for sarcomere length was negative which meant that as the sarcomere length increased the tenderness increased (it is well known that meat with longer sarcomere length is generally more tender). The terms for collagen and collagen per unit length were positive thus as they increase the tenderness increases as expected. The term for shortening was negative which means that as the amount of shortening increases the tenderness increases which is unexpected. In the range generally encountered (20% to 45%) shortening the tenderness is known to decrease.

When the effect of non meat properties factors of carcass and muscle type were added to the significant terms in the models, the correlation became 0.87 for the linear model and 0.87 for the logarithmic model. This shows that there are still some differences between the carcass and muscles that can't be explained by the meat properties measured. Some significant unmeasured factor has not be included in the model, which is lowering the correlation between the measured meat properties and the functional property of peak force (tenderness).

When the original linear model is run with only the factor muscle added, the correlation becomes 0.735. When it is run with only the factor carcass added the correlation becomes 0.514. These results suggest that both factors contribute significantly to the model but the factor of muscle type has the greatest influence. When the original logarithmic model is run with only the factor muscle added, the correlation becomes 0.741. When it is run with only the factor carcass added the correlation becomes 0.599. These results again suggest that both factors (muscle type and carcass) contribute significantly to the model but the factor of muscle type has the greatest influence.

One meat property that we know that can effect the tenderness is the amount of cross-linked collagen contained within a piece of meat. The greater the amount of cross-linked collagen, the lower the tenderness becomes. This is because certain types of cross-linked collagen are not very susceptible to heat denaturation. The amount of cross

linked collagen can vary between animals due to age and growth rate differences (i.e. amount of cross linked collagen is generally lowest after an animal goes through a rapid growth stage). This is due to the fact that a substantial amount of newly synthesized collagen will be present, with minimal cross-linking and the cross-links will be mainly in a heat denaturable state. As the collagen (animal) ages, the cross-links become more thermally stable.

The differences in collagen cross-linking between the carcasses studied in this work is unknown. There may also be differences between the muscles for the amount of cross-linked collagen present. The effect of the carcass factor on the models may be lower than the muscle effect due to the fact that it was attempted to minimise this effect by selecting animals from the same mob, therefore similar age, diet and environmental conditions. This means would expect the differences in the amount of cross-linked collagen between animals to be small but may still be significant (unknown as cross-linked levels not measured). The effect of the muscle factor on the model could also be due to differences in cross-linked collagen levels, as they are known to vary between muscles (King 1987). Unfortunately no data could be found for how cross-linked collagen levels vary between the muscles investigated, but the model results suggest it could be very significant.

The factor of the amount and quality of the cross linked collagen is believed to account for some of the variation encountered between muscles and animals and explain why a complete model is unable to be established that predicts fairly accurately the functional properties of the muscles tested.

The amount of variation in functional properties within a muscle is also uncertain. It is known that sarcomere length and pH differences can occur within a muscle, so it is expected that the functionality would be affected by these. For the muscles tested no information could be found on how the functional properties vary within a muscle (i.e. where sample to be tested is removed from within a muscle). This may account for some of the variation in the functional properties as measured experimentally, and why the error bounds are quite large.

For further development of a model which can predict the functional properties of a selected muscle once the meat properties are known, it is recommended that the extent of cross linking be investigated as well as the variability within a muscle, and how these factors effect the functional properties.

3.6.2 Cook loss predictions

The conceptual model developed in section 3.2.3 suggests that cook loss after cooking of a meat sample should be correlated with pH, shrinkage, extent of collagen denaturation and extent of myofibrillar denaturation.

To test the measured meat properties (pH, sarcomere length, shrinkage, shortening, collagen, moisture (after cooking) and collagen per unit length) were analysed with SAS for correlations with cook loss.

Using a linear model it was found that a correlation of about 0.78 was found between all the meat properties and cook loss and that the most significant meat properties were shortening, moisture, collagen per unit length and sarcomere length. SAS was run again with just the most significant factors included to establish a model. The model was then used to compare predicted values to measured experimental data (seen in tables 3.12). The correlation when only the significant terms were included was 0.71.

	Animal 4		Animal 6		Animal 9		Animal 10	
	linear	data	linear	data	linear	Data	linear	data
IN	27.1%	28.0%	27.1%	28.6%	29.9%	30.7%	25.5%	23.7%
TBL	32.7%	33.5%	30.7%	31.9%	31.8%	32.9%	36.0%	31.1%
SP	33.5%	35.3%	33.1%	33.1%	32.8%	34.5%	31.2%	29.6%
TBM	-	32.1%	30.0%	31.0%	31.1%	30.3%	29.6%	28.0%
LT	29.5%	29.7%	28.7%	27.9%	28.8%	28.6%	26.8%	24.7%
SV	33.8%	34.2%	32.4%	32.8%	32.7%	34.6%	31.9%	30.0%
PP	30.5%	32.8%	31.3%	31.5%	32.4%	32.9%	30.1%	30.4%

Table 3.13 Model comparison for cook loss

The linear model equation is as follows:

Cook Loss = 0.377*shortening + -0.886*moisture + 0.022*(collagen per unit length) + 0.189*(sarcomere) + 0.278

A logarithmic model was also established using a similar procedure). When all terms were included the correlation was 0.58. The most significant meat properties were found to be moisture and collagen per unit length. The multiplication factor (power value when log cook loss converted back from logarithmic values to normal cook loss values) was given when SAS was rerun with just the significant factors included and the model was used to predict cook loss values (log) and measured experimental data. The correlation when only the significant terms were included was 0.36, which is quite low. The logarithmic model is not useful to predict the cook loss to the meat properties.

The simple linear model was found to fit better than the logarithmic model for cook loss. The term for shortening is positive which meant that as the amount of shortening increased the cook loss increased. However the term for sarcomere was also positive which means as the sarcomere length increased so did the cook loss, which is in contradiction to a positive term for shortening (shorter sarcomere). The moisture term was negative, this means that as the amount of moisture remaining after cooking increases the cook loss decreases as expected.

3.6.3 Shrinkage predictions

For shrinkage the linear model including all meat properties had a correlation of 0.4, meaning that the measured properties cannot predict shrinkage very well. This may be due to the fact the shrinkage data was difficult to accurately acquire due to the nature of meat itself as explained earlier in section 3.4.3. This meant the variation was of the same order of magnitude as the range of shrinkage values for all muscles. For the logarithmic model of shrinkage the correlation fell to 0.14 which means that no meaningful correlation exists.

3.6.4 Overall conceptual model performance

The conceptual model was able to explain up to 80% of the muscle to muscle variation caused by the chemical and physical properties of meat for peak force (tenderness). There are some other important factors that need to be investigated that were not covered in this work (i.e. collagen cross linking and differences in functionality within a muscle). These factors need to be investigated further to build on the model developed so far. It is realised that further work trying to predict shrinkage values for cooked meat may be difficult because of the errors involved during the measurement of raw and cooked meat samples.

There is some confidence that an overall model could be developed in the future once methods are developed to measure cross linked collagen and a better understanding of intramuscular differences is obtained.

3.7 Conclusions

Data was collected for the functional properties of tenderness, cook loss and shrinkage for the following selected beef forequarter muscles Latissimus Dorsi, Pectorialis Profundus (Point End Brisket), Infraspinatus (Cross Cut Blade), Triceps Brachi Longhead (Main muscle in Bolar Shoulder Clod), Supraspinatus (Chuck Tender), Serratus Ventralis and Triceps Brachi Medialhead (Muscle in Bolar Shoulder Clod.

For tenderness the ranking from highest to lowest was, Infraspinatus, Triceps Brachi Longhead, Supraspinatus, Latissimus Dorsi, Triceps Brachi Medialhead, Serratus Ventralis and Pectorialis Profundus.

For cook loss the ranking from lowest to highest was, Infraspinatus, Pectorialsi Profundus, Triceps Brachi Medialhead, Triceps Brachi Longhead, Serratus Ventrlis, Supraspinatus and Latissimus Dorsi. The actual differences in cook loss between muscles was quite small, the range of cook losses was 29% for Infraspinatus to 34% for Latissimus Dorsi. This range is of the same order of magnitude as the variation for the muscles, therefore statistically it cannot be said that the muscles perform differently with respect to cook loss.

For shrinkage the variation in the measured values is large. This meant that no differences could be distinguished between the muscles for shrinkage at all. All the muscles shrunk by at least 30% and the lowest variation was 12%, which is a variation of over a third of the actual value.

It has been identified that the Infraspinatus and the Triceps Brachi Longhead have the best potential for further processing into convenience food products due to their tenderness profiles and relatively large and regular size. To take further advantage of the work done in this study it is recommended that the functional properties specifically required for each end use should be identified (i.e. internal and external further processing customers). This would allow the data collected in this work to identify which muscles are suitable for each particular end use. The conceptual model was able to explain up to 80% of the variation caused by the chemical and physical properties of meat. Further investigations are needed to build on and improve the model developed so far.

The effect of temperature is not covered by the standard testing procedures used in this chapter. However it is known the cooking regime employed can greatly affect the resultant functional properties of a cooked meat product. By employing an optimal cooking regime it may be possible to improve the functional properties. This is the focus of the following chapter.

Chapter 4
The Effect of Cooking Regime on Meat Functionality

4.1 Introduction

Chapter three characterised the effects of muscle type on the key functional properties of meat muscle from the beef forequarter. This chapter summarizes work done on characterising the effect of cooking regime on the functional properties. In this way a clear indication of how optimal yield and functionality could be achieved for meat products intended for use in ready meal and other value added products.

The primary objective of this section was to investigate how the cooking regime affected the functionality of the product. Most industrial cooking situations only consider bacterial death as the controlling factor. This often leads to the cooked product not having optimum functionality. A change in cooking regimes can often substantially increase the yield of product and improve other desirable properties (e.g. tenderness). Any changes however must still take into account micro-organisms, as any product produced must meet health regulations and ensure public safety. As the kinetics for bacterial death are known, this can easily be taken into account.

From the earlier investigations on the functionality of beef forequarter muscles in chapter three, it was established that the Infraspinatus and Triceps Brachi Longhead had the best potential for adding value. This was due to their ranking which was founded on functional test performance and processing considerations. For this reason, these muscles were selected for this section of the project.

4.2 Conceptual model development

In order to get the maximum potential out of the muscles selected the correct cooking regime has to be used. From a quality and economic aspect the two most important functional properties after cooking are tenderness and cook loss (yield of product). It is known that these functional properties are primarily governed by a few key chemical reactions occurring within the meat when certain temperatures are reached. These chemical reactions involve the myofibrillar proteins (myosin and actomyosin) and connective tissue proteins (collagen).

Knowledge of what chemical reactions are occurring at any particular temperature allows us to construct a conceptual model for what is occurring during the cooking of meat. The following semi mathematical description outlines the parameters affecting meat quality, and how cooking regime affects these.

4.2.1 Myosin fraction

The myosin fraction of the myofibrillar proteins denature at a temperature of around 45° to 50°C. It is accompanied by a toughening of the meat and reduced water holding capacity. This is because the proteins aggregate together during and after denaturation and as these aggregated proteins are firmer, the meat becomes tougher compared to raw meat. This aggregation also decreases the amount of water binding sites available because of the number of protein to protein bonds that are formed increase at the expense of sites where water was or could bind to the protein. This is why there is some cooking loss at temperatures around 50°C or slightly lower.

4.2.2 Connective tissue fraction (collagen)

For the connective tissue fraction of meat, the main protein structure of interest is the collagen fraction. Collagen imparts a great deal of toughness to meat. It occurs in small quantities (2% to 10% on a dry weight basis) but it has a very high mechanical strength. This mechanical strength is greatly reduced upon denaturation. The denaturation of collagen occurs at around 60°C, and is accompanied by a reduction in the toughness of the meat compared to meat cooked at lower temperatures. This is due to the fact that denatured collagen has a greatly reduced mechanical strength. As the collagen denatures, it also loses the ability to support its own structure and hence the collagen shrinks. The main source of collagen in meat is the perimysium. The perimysium surrounds the myofibrillar proteins or muscle bundles. When the collagen contained in the perimysium denatures it causes the perimysium to shrink. This perimysium shrinkage exerts a pressure on the myofibrillar proteins it surrounds. The fluid between the perimysium and myofibrils (from myosin denaturation) is consequentially squeezed out of the meat and a large increase in cook loss is observed at and above 60°C.

4.2.3 Actomyosin fraction

The actomyosin fraction of the myofibrillar proteins denature at a temperature of 70°C. This causes a toughening of the meat and reduces the water holding capacity. This is again because of protein denaturation and aggregation, much like what happens for myosin, but at a higher temperature. This is why meat cooked at temperatures above 70°C is tougher and have lower yields than those cooked at temperatures between 60°C and 65°C (extended cooking times at high temperatures though can produce tender meat due to continued protein breakdown, particularly of crosslinked collagen. But this generally results in reduced yield).

4.2.4 Cooking method

The temperature profile of a cooked piece of meat will be dependent on the cooking technique (e.g. dry cooking such as oven roasting, moist cooking such as stew or water bath or frying). This is because the heat transfer rates will change with cooking technique. Therefore the rate of heating within the meat differs. Cooking technique can also affect cook loss as some techniques allow evaporation of water from the meat, which will increase cook loss. This is expected to occur for dry cooking techniques and to a lesser extent to frying.

4.2.5 Micro-organism death

The thermal death kinetics for the various organisms of concern are well known. By combining these kinetics with the heat transfer kinetics within meat, the time required to ensure all product is safe for the given cooking regime can be calculated. A lower temperature will result in a longer cooking time, but as a lot of product is produced in a continuous manner using water-baths, all that would be required is the extension of the length of time in the water bath to achieve the desired cooking time.

4.2.6 Conceptual Model

Quality = f(tenderness and cook loss)

Micro-organism death = f(temperature/time)

Tenderness = f(myosin/collagen/actomyosin denaturation = f(temperature/time))

Cook loss = F(myosin/collagen/actomyosin denaturation = f(temperature/time) and cooking technique)

Using the reaction kinetics for the various protein fractions of meat, myofibrillar and connective tissue proteins, it is possible to predict the amount of protein denaturation that has occurred for a particular time/temperature history. This was done for the 60 minutes cooking regime (cooking time used experimentally) and shown in Figure 4.1 below. The expected protein denaturation could then be compared to the functional properties found experimentally.

The kinetic data used to construct Figure 4.1 were taken from (Wagner and Anon 1985) for myosin and actomyosin, and (Miles et al. 1995) for collagen. These studies were reviewed in detail in chapter two. Only the two main myofibrillar proteins myosin (45% to 50% total myofibrillar proteins) and actomyosin (22% total myofibrillar proteins) were considered to make up the myofibrillar proteins for Figure 4.1. This was because myosin and actomyosin are considered the most important proteins governing functional properties (along with collagen), and kinetic information was available for myosin and actomyosin. Considering only myosin and actomyosin for the myofibrillar proteins gives 67% myosin (myosin fraction divided by myosin fraction and actomyosin fraction) and 33% actomyosin.

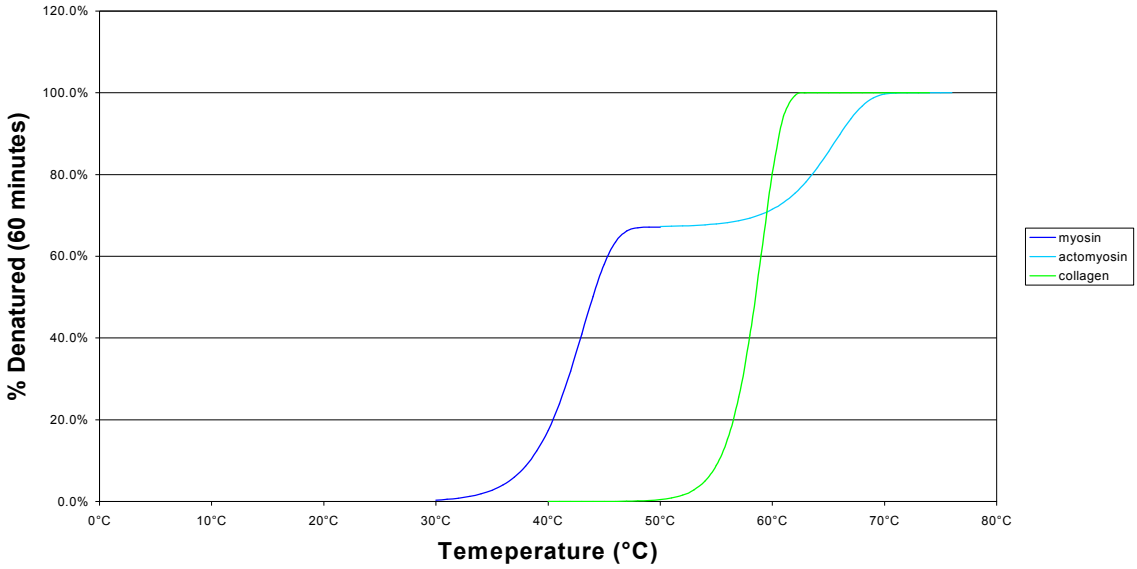

Figure 4.1: Fraction protein denaturation after 60 minutes cooking time for various cooking temperatures.

It can be seen from Figure 4.1 that the denaturation of the different protein fractions are very temperature dependent.

4.3 Cooking trial development

Several tests were employed to test how the cooking regime affects the functionality of the cooked meat. The project was directed at assessing how the selected muscles may perform for stir-fry style cooking and ready meal applications. Therefore tests were conducted in accordance with trying to relate to stir-fry style preparation. For stir-fry style cooking, strips of meat are cut with the fibre direction perpendicular to the meat strip length. Therefore, along with the usual Warner Bratzler shear tests (parallel to fibre orientation) strips with fibre orientation perpendicular would also be tested. Along with the Warner Bratzler shear tests, tensile strength tests were also conducted for meat strips with fibre orientation perpendicular to the strip length.

4.3.1 Sample preparation

To overcome the problem of animal to animal variation, each batch of cooking trials was carried out using the same muscle. The muscles were excised from steers of 14 to 18 months of age and frozen until used. Frozen muscles were thawed at 4°C for approximately 12 hours. At this stage the muscle was still frozen, which facilitates easier cutting of the meat into uniform strips. The muscles were first cut into steaks using a bacon-slicer to a thickness of 9mm. This was done both perpendicular and parallel to the fibre orientation.

The steaks with fibre orientation perpendicular to length were cut into approximately 9mm width strips (perpendicular to fibre orientation). The resulting strips were all approximately 9mm x 9mm (width x thickness). These strips were subjected to tensile strength test measurements after cooking.

The steaks with fibre orientation parallel to length were cut into approximately 9mm width strips (parallel to fibre orientation). The resulting strips were all approximately 9mm x 9mm (width and thickness). These strips were subjected to Warner Bratzler shear test measurements after cooking.

The length of both types of strips varied slightly but this is not a problem. This is because it won't effect the heat transfer during cooking. It just means that some strips could have a few more tests conducted on them (only for Warner Bratzler measurements).

4.3.2 Heat rate during cooking trials

In order to quantify the kinetics of the changes occurring in meat functionality, it was important to achieve rapid heating of the samples. If this was not achieved it would be difficult to separate apparent time dependent functionally changes from the rate of heating of the sample. To check how long the meat strips would take to heat up to the desired temperatures in the water bath, it was decided that this should be modeled using heat transfer equations and then checked experimentally. This was done to investigate

how changes in the thickness of the meat strip would affect the heat transfer and hence the temperature profile of the meat strips.

4.3.2.1 Mathematical model

The heating of a meat strip can be approximated using the solution for an infinite 2 dimensional slab of thickness' 2R, exhibiting the first kind of boundary condition (that being a fixed surface temperature), (Carslaw and Jaeger 1959). Using the formulation for conductive heat transfer through a slab it is possible to predict the temperature profile of the meat for different meat thickness', time and water-bath temperatures. The following assumptions were made during the model formulation.

The meat strip is considered to be a 2 dimensional slab (this is because the width and thickness are relatively the same, but the length is at least four times greater)
The slab maintained constant thermal properties.
The surface of the meat strip is at a constant temperature with respect to the water-bath temperature. This was appropriate as vigorous mixing was maintained in the waterbath during subsequent trials.
Uniform initial temperature in slab.

For an infinite slab of thickness 2R, and the first kind of boundary condition the mathematical formulation is:

$$C\frac{d\theta}{dt} = \lambda\frac{d^2\theta}{dx^2} + \lambda\frac{d^2\theta}{dy^2} \qquad \text{for } t > 0 \text{ at } 0 < x < R \text{ and } 0 < y < R$$

$$\theta = \theta a \qquad \text{for } t > 0 \text{ at } x = Rx,\ 0 \le y \le Ry \text{ and } y = Ry,\ 0 \le x \le Rx$$

$$\frac{d\theta}{dx} = 0 \qquad \text{for t > 0}$$

$$\text{at } x = Rx$$

$$\text{and } 0 \le y \le Ry$$

$$\frac{d\theta}{dy} = 0 \qquad \text{for t > 0}$$

$$\text{at } y = Ry$$

$$\text{and } 0 \le x \le Rx$$

$$\theta = \theta i \qquad \text{for t = 0}$$

$$\text{at } 0 \le x \le Rx$$

$$\text{And } 0 \le y \le Ry$$

An analytical solution exists for this model (Carslaw and Jaeger 1959), this is given below.

$$Y = \frac{4}{\pi}\sum_{m=0}^{\infty}\frac{(-1)^m}{2m+1}\cos[(2m+1)\frac{\pi}{2}\frac{x}{R}]\times\exp[-(2m+1)^2\frac{\pi^2}{4}Fo]$$

where Fo = Fourier number $= \frac{\alpha t}{R^2} = \frac{\lambda t}{\rho c R} = \frac{\lambda t}{CR^2}$

and Y = fractional unaccomplished temperature $= \frac{(\theta - \theta a)}{(\theta i - \theta a)}$

and t = time (s)

θa = external medium temperature (°C)

θi = slab initial temperature (°C)

R = slab half thickness (m)

λ = solid thermal conductivity (W/m°C)

C = volumetric specific heat capacity (J/m^3°C)

p = solid density (kg/m^3)

c = specific heat capacity (J/kg°C)

α = thermal diffusivity (m^2/s)

Because this is the solution to the one dimensional heat transfer problem, the two-dimensional result is obtained using the following relationship.

$$Y = Yx \times Yy$$

Using the numerical solution for this model it was possible to determine the fraction of the heating process that has been accomplished and the internal temperatures within a meat strip of a given thickness at various times.

4.3.2.2 Thermal properties

The thermal properties, volumetric heat capacity, C, and thermal conductivity, λ, were required before any simulation could be carried out (Rahman 1995).

4.3.2.2.1 Specific heat capacity

The specific heat is defined as the amount of heat necessary to raise the temperature of unit mass of the material by one unit degree and is therefore measured in J/kg°C (Rahman 1995). For beef chuck the specific heat is 3.56KJ/kg°C. For the analytical solution the volumetric specific heat was required. This is calculated by multiplying the specific heat by the density of meat which is 985 kg/m^3 for whole beef chuck (Rahman 1995). Therefore volumetric specific heat is 3506.6 kJ/m^3.

4.3.2.2.2 Thermal conductivity

The thermal conductivity is a measure of the ability of a material to conduct heat. (Rahman 1995) gives the thermal conductivity for whole beef chuck as 0.484 W/mK.

4.3.2.3 Experimental center temperature

The temperature of 9mm by 9mm strips was used to test the model. The centre temperature for 9mm by 9mm meat strips was measured by inserting thermocouples in the centre of two meat strips. The temperature of the strips was followed using a TC-108 data logger. Temperature readings were taken every second for ten minutes. Experimental data and analytical solutions were plotted and compared on Figure 4.2. It was found that the experimental results and analytical solution agreed closely, and the model could be used to predict with sufficient accuracy, how long it would take meat strips of various thicknesses' to reach the water-bath temperature.

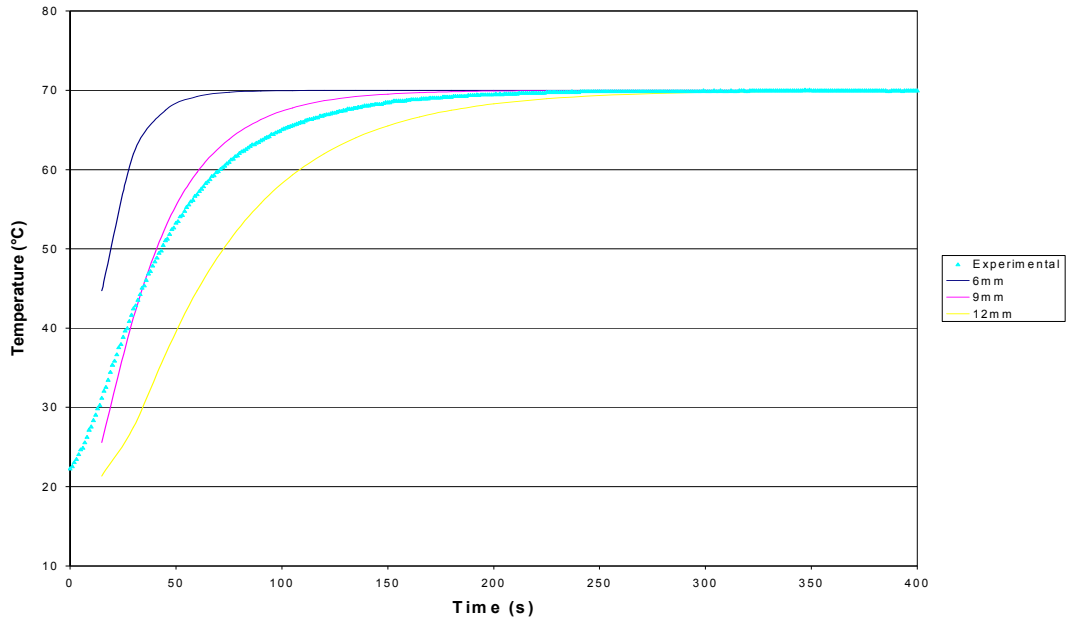

Figure 4.2: Centre temperature of meat strips of varying thickness, comparison of experimental data and calculated heat transfer rates (infinite 2 dimensional slab of thickness' 2R heat transfer model).

4.3.3 Selection of meat strip thickness

The model was used to predict how long it takes for meat strips of varying thickness to reach the water-bath temperature. It was found that for meat strips up to 12mm thick that the centre temperature would be the same as the water bath's after 5 minutes and that most of the temperature change (80%) occurred within three minutes.

It was decided that 9mm by 9mm strips would be cut from the steaks for the investigation into how cooking regime affects the functional properties of meat. This was because the thick strips are easier to test in the Warner Bratzler shear machine. To ensure rapid heat transfer it was decided to use strips narrower than 12mm. Therefore 9mm strips were chosen as being the most suitable for our application.

To investigate if the characteristic meat reactions were time dependent cooking times of 5, 10, 25 and 60 minutes were used. Due to the activation energy of most of the reactions being quite high (mainly collagen and actomyosin) they are very temperature dependent. It is thought that once these temperatures are reached, the reactions are fairly rapid and occur within a few minutes or less. This means there should be little

difference for functionality between meat strips cooked for 10, 25 and 60 minutes. There may be differences for 5 minutes as the centre temperature has only just reached the water-bath temperature at this cooking time.

Any differences in tenderness could be explained by further collagen solubilisation which would be expected to only occur for the longer cooking times of 60 minutes. Little could be found for any collagen solubilisation kinetics with regard to meat cookery so whether this effect will be significant or not is unknown. In this way the conceptual model for meat cookery outlined in section 4.2 above could be validated.

4.4 Tenderness measurements

4.4.1 Tensile strength

Tensile strength measurements were used as it was thought that the strength of the meat strip would decrease with cooking when the fibres are perpendicular to the strip length. This is because the connective tissue (perimysium and endomysium) are responsible for holding the meat together in this direction (i.e. hold the muscle fibres together), (Ledward et al. 1992). So when the cooking temperature is high enough to denature collagen (main connective tissue component) there should be a decrease in the force needed to break the meat strips when pulled under tension. The strength of the myofibrillar proteins, which aggregate and strengthen upon denaturation would then be avoided. In this way the suitability for stir-fry applications could be better assessed.

4.4.1.1 Cooking regimes

Strips of meat with the fibre orientation perpendicular to the length were cooked at different temperatures for different lengths of time. The temperatures used were 50°C, 60°C and 70°C. These temperatures were initially chosen as it was expected that the major changes to the muscle structure occurred in this range. If this was found to be true further investigations at other temperatures would be conducted. At each temperature 6 meat strips (packaged in thin polyethylene bags) were cooked for 5, 10, 25 and 60 minute intervals. Upon cooking the meat strips were cooled in ice water while still inside the bags. This was done to cool the meat strips rapidly and stop further reactions taking place as quickly as possible.

4.4.1.2 Testing procedure

The tensile strength of the cooked meat strips was tested using a TX2 Texture Analyser. Pinch rollers were used to secure the meat strips. The length held between the rollers was 200mm. The meat strips were stretched at a rate of 10mm/minute until the strips broke. The force versus distance stretched (time) was recorded.

4.4.2 Warner Bratzler shear test

Warner Bratzler shear tests are often used to determine the tenderness of meat samples. Normally samples are tested with the muscle fibres running parallel to the strip length (i.e. the fibres are cut through by the blade). Little information could be found for tenderness information for shearing between fibres (i.e. fibres perpendicular to the fibre length). Therefore Warner Bratzler shear tests were conducted on two types of meat strips, those with fibre orientation perpendicular and those with fibre orientation parallel to the strip length.

4.4.2.1 Cooking regimes

All strips of meat for a test came from one muscle only. This was done so the variation caused by different animals (apparent in chapter three) was eliminated. A fixed cooking time of 60 minutes was employed, this was to ensure uniform cooking of the meat strips, so no gradient effects were present. Six strips were used for each cooking temperature. Each strip allowed multiple shear tests to be conducted on it.

For the Infraspinatus muscle a cooking regime of 50°C, 60°C and 70°C for 60 minutes was used on 9mm x 9mm strips. This test was conducted as a preliminary test to see if any changes in tenderness could be detected. Further tests at cooking regimes of 50°C, 55°C, 60°C, 65°C, 70°C and 75°C for 60 minutes were then carried out. Upon completion of cooking, the bags were removed from the water-baths and cooled in ice water. The cook loss was allowed to drain, then the bags of meat were cooled for 8 hours or greater at 4°C.

4.4.2.1.1 Testing procedure

An Instron Warner Bratzler shearing device was used. A square blade was fitted and a cross head speed of 100mm/minute was used. The strips when tested were placed so that the strip length was perpendicular to the blade when tested.

4.5 Cook loss

The weight of the meat strips was recorded before (raw) and after cooking. After the meat strips had been cooked the initial cook loss was allowed to drain from the bag. The meat strips were then cooled. After cooling and before tenderness measurements were conducted the strips were removed from the bag. After removal the strips were gently blotted on tissue paper and weighed. The percentage difference between the two weights was recorded as the cook loss (i.e. difference (cooked and raw) divided by raw weight).

4.6 Results

4.6.1 Cooking losses

The cooking losses were found to change greatly with cooking temperature as was to be expected, but the cooking losses varied little with time, as can be seen in Figure 4.3 and 4.4. Within the first 10 minutes the majority of the cooking losses had occurred (i.e. approximately 80% within 10 minutes after which the cooking losses increased only slightly with respect to the cooking time).

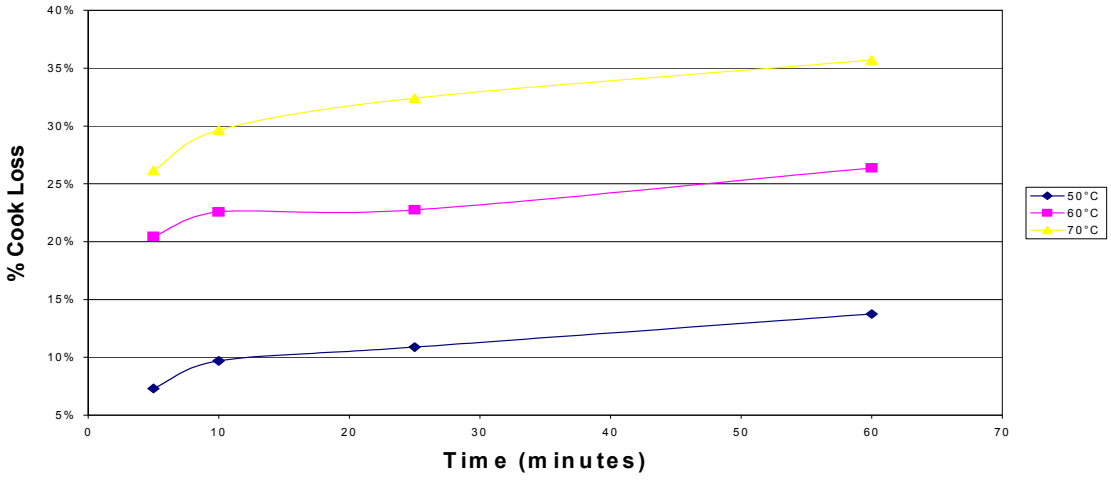

Figure 4.3: Cooking loss versus time for Infraspinatus.

For the Infraspinatus (Figure 4.3) the rapid increase in cooking losses within the first 5 minutes was believed to be due to the rapid increase in the temperature of the meat for the first few minutes. Which results in significant denaturation of some myofibrillar proteins (myosin).

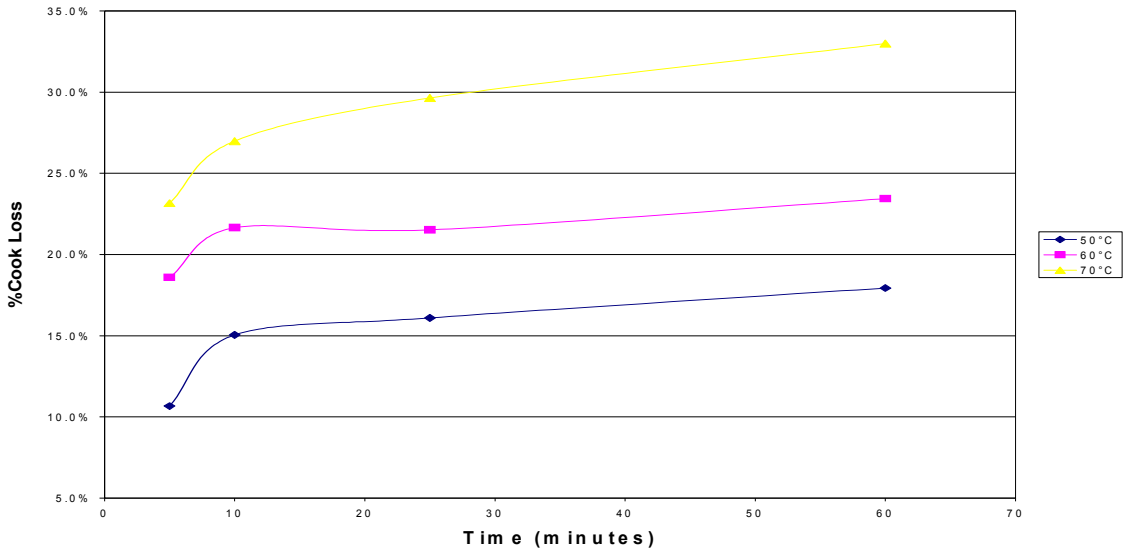

Figure 4.4: Cook loss versus time for Triceps Brachi Longhead.

The subsequent increase in cook loss at 50°C is believed to be due to either further denaturation of myofibrillar proteins or the fact that diffusion is limiting the cook loss (i.e. takes time for the cook loss to diffuse out of the meat). The cook loss at 60°C is higher than at 50°C because of collagen denaturation and subsequent contracture forces more cook loss out from the meat by a squeezing effect The increase in cook losses with time at 60°C is believed to be due to diffusion resistance as all the myosin and collagen will have denatured completely and the temperature isn't high enough to initiate substantial actomyosin denaturation.. At 70°C the increase in cook loss is believed to be due to continual denaturation of actomyosin and diffusion resistance. The continual denaturation of actomyosin would explain why the slope of cook loss versus time (from 10 minutes to 60 minutes) is higher at 70°C than the other temperatures. Figure 4.1 shows than by cooking at 70°C it takes about one hour for all the actomyosin to be denatured.

Similar observation were made for the Triceps Brachi Longhead (Figure 4.4 above). The cooking losses occurring at 50°C are believed to be due to myofibrillar protein denaturation (myosin), which reduces the ability of the proteins to bind water. The increase in cooking losses at 60°C are believed to be due to further myofibrillar protein denaturation, collagen denaturation and subsequent contracture. The increase in cooking losses at 70°C is believed to be due to further denaturation of myofibrillar proteins (actomyosin). These results show that there are definite changes in cooking losses with temperature, which can be associated with the denaturation of the different protein fractions.

The cook loss for the parallel fibre orientation was found to follow similar trends to the perpendicular fibre orientation samples as shown in Figure 4.5. The cooking regime used for these strips was to cook at a specified temperature for 60 minutes. When the 60 minute points from the perpendicular fibre orientation cook losses (Figure 4.3 and Figure 4.4) are included with the results for parallel fibre orientation cook losses the trends are very similar, as can be seen it Figure 4.5.

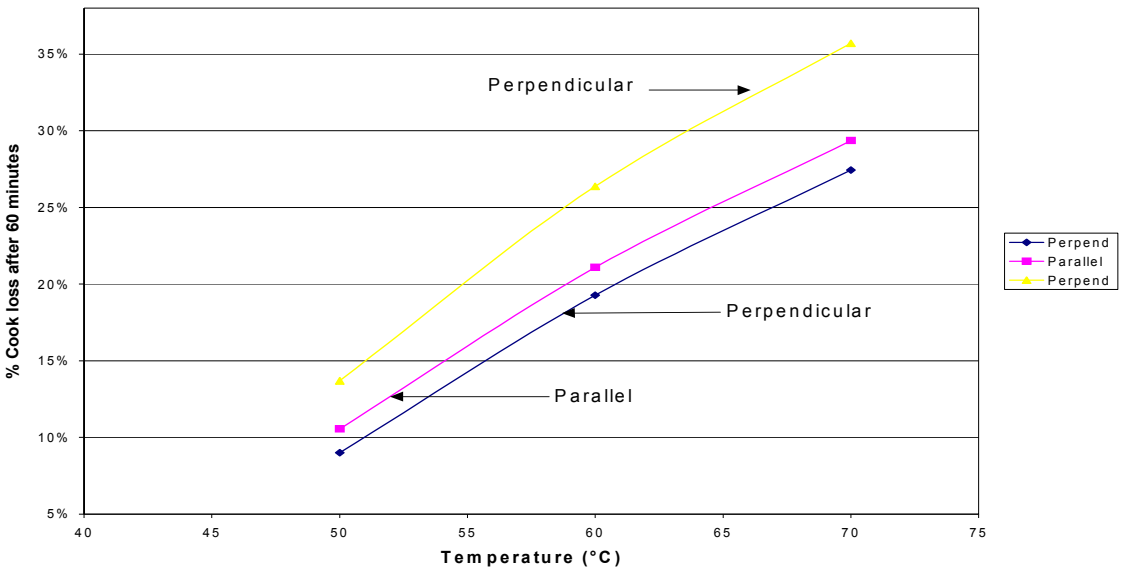

Figure 4.5: Parallel and perpendicular fibre orientation cook losses.

The actual differences are likely to be due to the fact that different muscles had to be used so that an adequate number of samples could be cooked. But it can be seen that the trends are very similar in that major changes in cook loss occur with increasing temperatures of the meat.

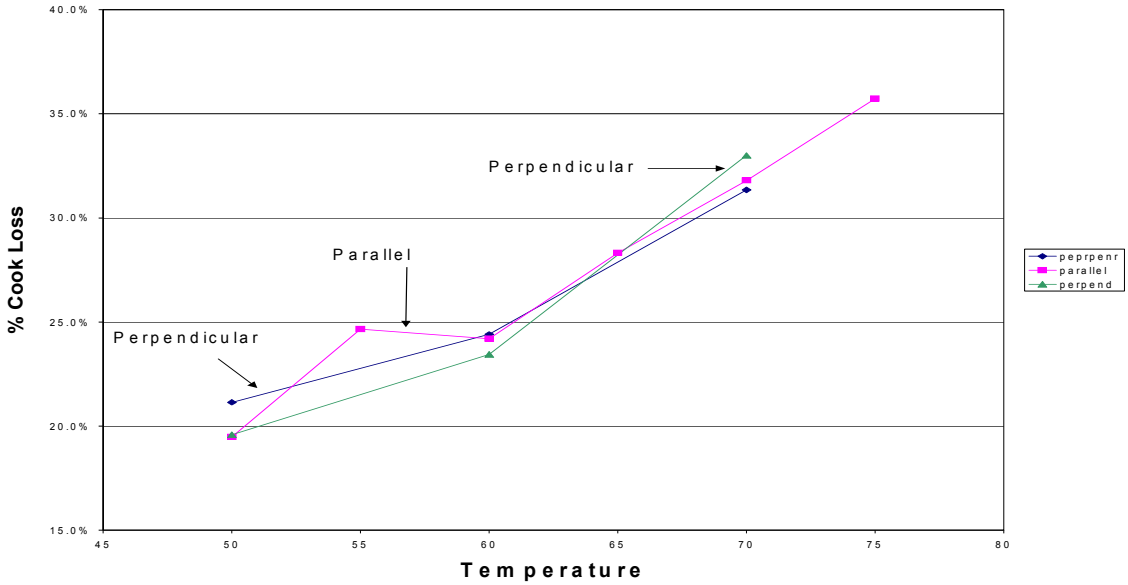

Figure 4.6: Cook loss versus temperature (60 minutes cooking time).

Figure 4.6 shows additional cooking loss data for intermediate temperatures. It can be seen that the first step in cooking loss change occurs up to a temperature between 55°C and 60°C. This step accounts for about 69% of the cooking losses that occur (when cooked to 75°C). The second step accounts for about 31% of the cooking losses (when cooked to 75°C). This ratio (69:31) is similar to the ratio of myosin to actin (45%-50% myosin, 22% actin) ratio of about 67-69:33-31. This supports the idea that the cook loss is attributed to the denaturation of the myofibrillar proteins, which decreases their ability to bind water and collagen denaturation and contraction squeezing cook loss out of the meat.

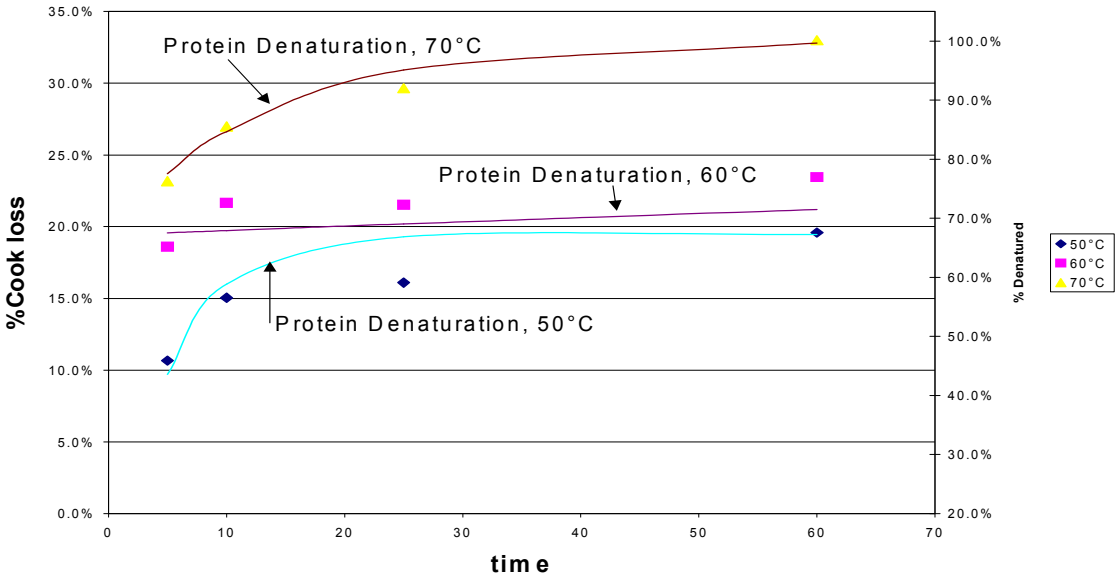

Figure 4.7: Graph of protein denaturation and cook loss.

The protein denaturation curves for the various temperatures and cooking times are plotted against the experimental cook loss data, Figure 4.7. On Figure 4.7 the points represent the experimental cook loss data, and the curves (i.e. 50°C Protein) represent the amount of myofibrillar proteins (myosin and actomyosin only as in Figure 4.1) denatured at that particular temperature and time. From Figure 4.7 it can be seen that as the amount of denatured protein increases the amount of cook loss also increases. This is especially true for the myosin and actomyosin protein fractions where the cook loss and protein denaturation trends are very similar.

The myofibrillar protein myosin is the main protein of concern for denaturation at 50°C, therefore the 50°C protein curve represents mainly myosin denaturation. Similarly the 70°C Protein curve represents mainly actomyosin denaturation. This is because at 70°C the myosin and collagen would have rapidly denatured (explains why at 70°C the cook loss rises very rapidly initially, due to rapid denaturation of myosin and collagen). There is minimal increase in cook loss with time and protein denaturation at 60°C. This is because the myosin rapidly denatures at 60°C but actomyosin doesn't readily denature at this temperature. The cook loss at 60°C is higher than at 50°C because the collagen denatures rapidly at 60° (from Figure 4.1), this causes a rapid and substantial increase in cook loss explains why cook loss at 60°C is greater than at 50°C.

4.6.2 Tensile strength

The peak force needed to break the meat strips apart was found not to vary with temperature and time. The results for each temperature/time combination were also found to be very variable (no difference was found as the error bounds were very large). There was no real trend for peak force and cooking regime (time and temperature) as can be seen in Figure 4.8. This was unexpected as the peak force was expected to be related to the cooking regime. This is because the main component holding meat together perpendicular to the fibre direction is the connective tissue fraction of meat. This mainly comprises collagen and it is known that collagen denatures at a temperature of around 60°C. Presumably any meat sample cooked to this temperature or higher would be expected to have a lower peak tension force due to the collagen being denatured and weakened. This was found not to be the case though. This can be partially explained by the fact that the tension isn't transmitted evenly through raw/rare meat samples, causing a decrease in the peak force expected.

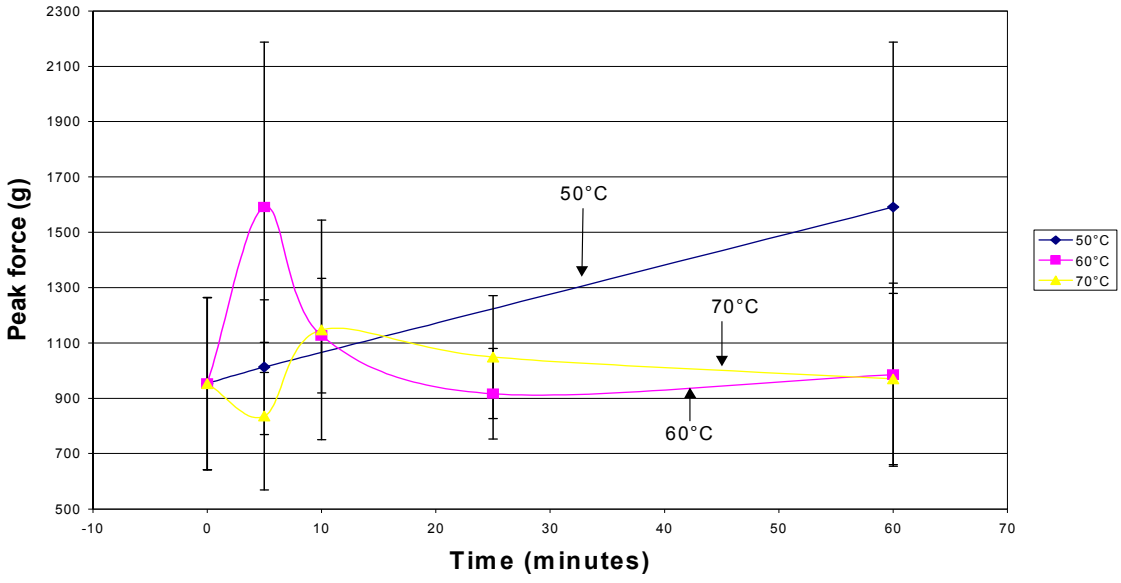

Figure 4.8: Tensile strength for various cooking times with SE bars.

But the way in which the meat strips behaved during stretching was quite different. Raw and rare samples of meat did not tear at one individual point in unison. Instead the meat would be pulled apart piece by piece. This was happening because the raw meat is

very soft and therefore the tension experienced by the raw/rare meat is not very uniform. As the meat is soft to touch and not firm the tension is not transmitted evenly through the meat strips, therefore sections within the meat strip break individually, after which the tension is taken up by another individual section until finally the meat strip breaks completely (Dransfield 1997). This explains the jagged appearance of the raw/rare force versus time/distance graphs and why there is not a clean break and subsequence rapid drop once the peak force is reached for raw samples as seen in Figure 4.9.

This non-uniform tension force is expected to be exaggerated for meat strips that are not held at right angles to the pinch rollers, which are used to hold the meat samples. This is because the loading of the stress distribution over any cross-section of the meat sample would be non-uniform. This would result in the peak force not being attained in all fibres of the meat sample simultaneously. Although even if the meat sample was held perfectly perpendicular to the pinch rollers, the non-homogenous nature of meat would result in a similar phenomenon.

For well-cooked meat samples the same problem is not encountered as often. This is due to the fact that the meat samples are firm to touch and hence the tension is more uniformly transmitted through the whole sample. This results in a fairly well defined climb in the force versus distance/time graph for well done samples. Once the peak force is reached there is a rapid decrease in the force. This is due to the fact that well done meat has a fairly clean break when stretched under tension. Occasionally the force doesn't drop straight back to zero due to a very small collagen strand still holding on but the force is still low during the occurrence of this event. Figure 4.9 shows typical force/time curves for raw and cooked meat samples under tension.

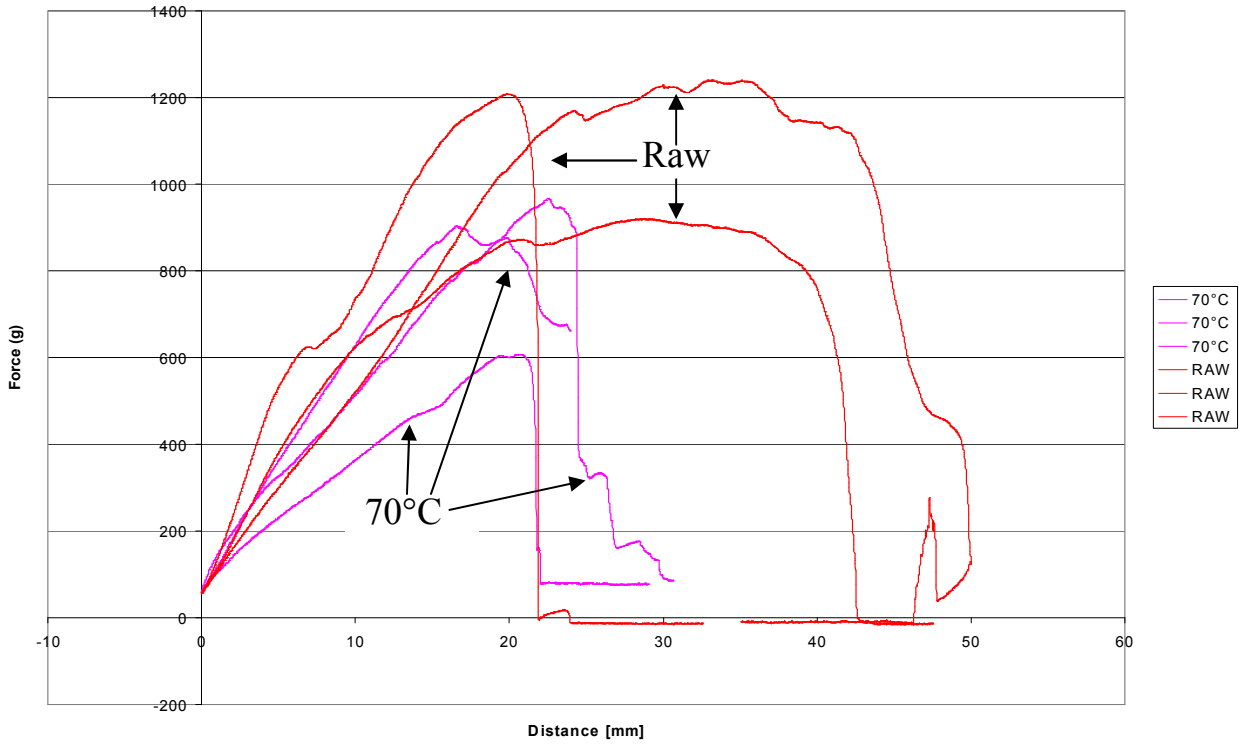

Figure 4.9: Typical force versus distance (time) graphs for tensile strength of meat strips cooked at different temperatures.

The Young's modulus or the initial slope of the force versus distance/time graph is generally different for the different cooking temperatures, (Figure 4.9). Raw samples and samples cooked at 50°C have a higher Young's modulus than those cooked at 60°C or 70°C. Materials with a higher Young's modulus take more force to stretch per unit distance and they possess a lower elasticity or extensibility.

Overall the tensile test doesn't provide any good quantitative analysis of changes in the functionality of the meat (tenderness). This is due to the structure of meat itself and that is doesn't transmit tensile forces through its structure evenly. This causes the results to have a lot of variability. Due to the high degree of variability encountered by this method differences between meat cooked to different temperatures cannot be distinguished. As a result no further tensile measurements were undertaken.

4.6.3 Warner Bratzler shear (tenderness)

4.6.3.1 Fibre orientation

It was found that the fibre orientation has a major influence on the results for tenderness. When the fibres are perpendicular to the strip length no differences are observed for the different cooking temperatures. But there are definite differences when the fibre orientation is parallel to the strip length. The reason that no differences are picked up when the fibre orientation is perpendicular is believed to be due to the fact that the Instron isn't sensitive enough as the forces required to cut through the meat are minimal. For the fibre orientation parallel the forces required to cut the meat samples are much greater and therefore differences can be observed.

4.6.3.2 Tenderness (parallel fibre orientation)

The tenderness profile as affected by temperature is shown in **Error! Reference source not found.**. The tenderness of the muscles seemed to decrease (increase in peak force) from raw to 55°C as measured by peak Warner Bratzler shear force but the amount of variation encountered was high so no confident statement can be made. The tenderness didn't change significantly between 50°C and 55°C. Once the temperature reached 60°C the tenderness was found to dramatically decrease. Above 60°C it appears as if the toughness was increasing again (increasing peak force), qualitatively the samples cooked at 65°C and above were a lot firmer to touch than those cooked at 60°C. Due to the amount of variation encountered it can not be said that there is any significant difference between the temperatures of 60°C, 65°C, 70°C and 75°C for tenderness.

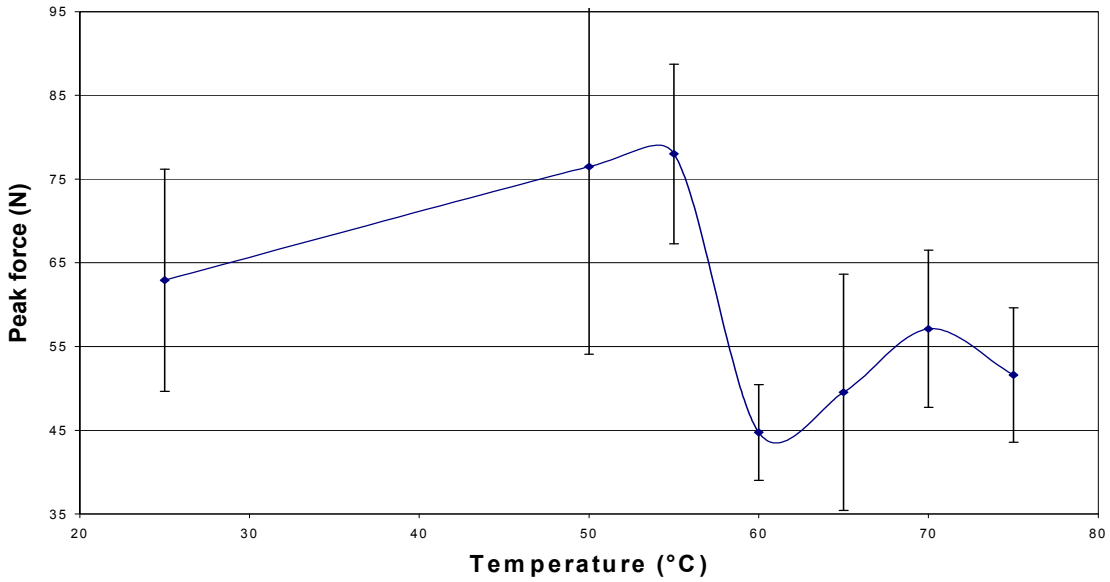

Figure 4.10: Tenderness profile as affected by temperature (parallel fibre orientation).

From Figure 4.11 it can be seen that the major tenderness increase (decrease in force) is associated with the denaturation and subsequent weakening of the collagen fraction of the meat proteins. The other two phases of apparent tenderness decrease are associated with the denaturation of the myofibrillar proteins, myosin below 55°C and actomyosin above 65°C.

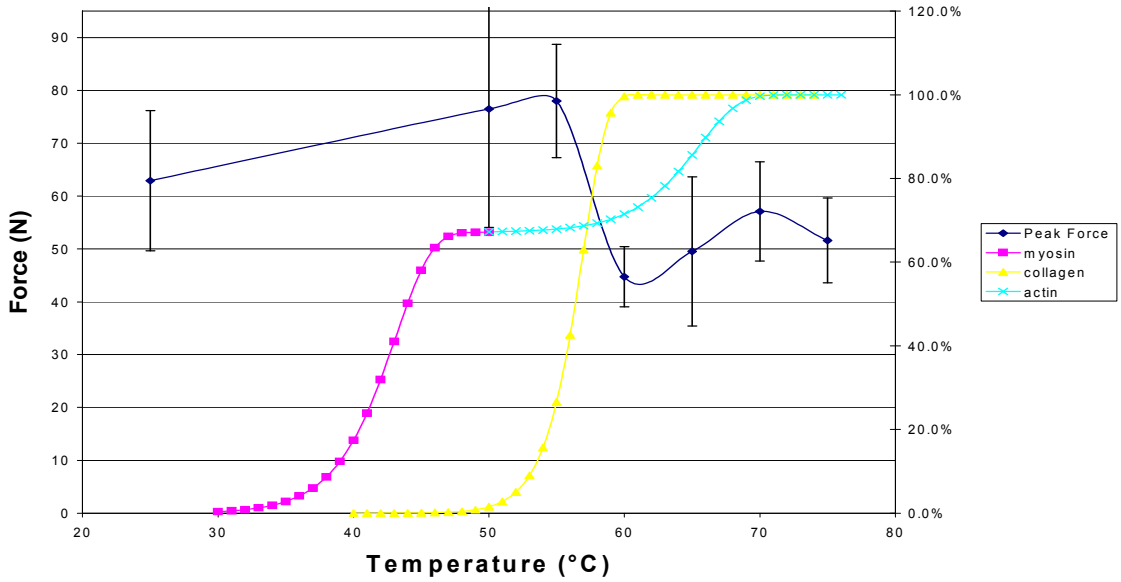

Figure 4.11: Tenderness and denaturation comparison.

In the present study the variability encountered was quite high. It was thought that instead of measuring peak force the shear should be calculated (force divided by cross sectional area). But the graph for shear vs temperature, Figure 4.12, has the same trend as the force graph. It was also found that measuring the dimensions of raw and cooked meat (for CSA calculations) was difficult (i.e. raw meat is quite soft whereas cooked meat is firm but often not of a regular shape).

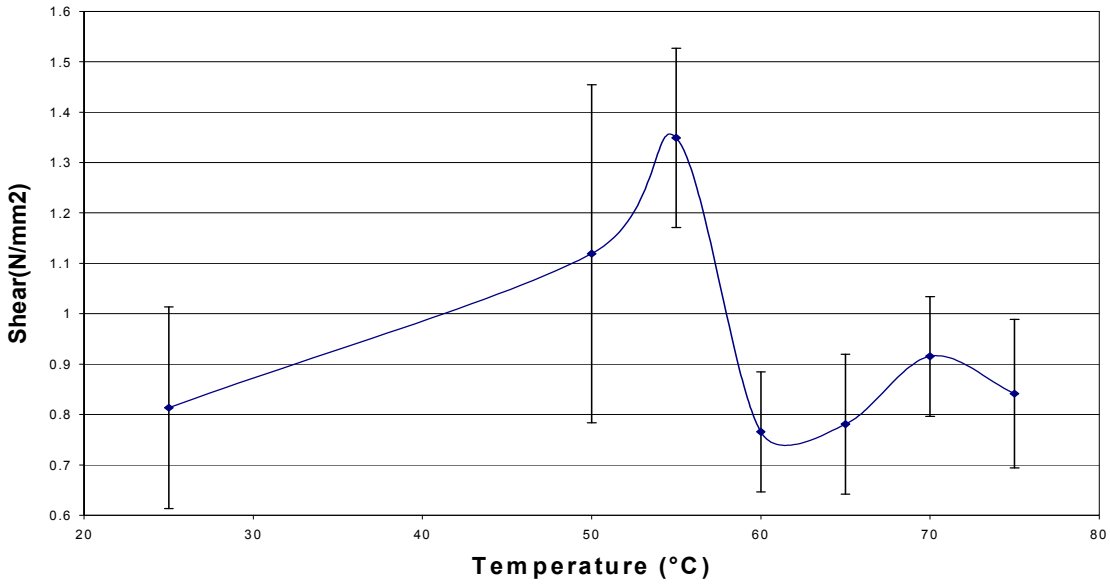

Figure 4.12: Shear versus temperature after cooking.

The reason for trying to measure the cross-sectional area was because meat shrinks different amounts at different temperatures. By cutting samples to the same size before cooking ensures approximately the same number of fibres are being cut through per sample. Often tenderness measurements are done on meat samples cut to the same size after cooking. However due to different amounts of shrinkage occurring for different temperatures means that the number of fibres cut through won't be the same. By measuring the cross sectional and converting force (N) to shear (N/mm2) this effect could be investigated. However due to the measurements of CSA being difficult to measure accurately this cannot be readily done.

All the meat samples tested came from the same muscle (i.e. right triceps muscle of one animal) and were from steers 14-18 months of age, so the problem of animal differences and the possible problem of extensively cross-linked collagen were not present. But it is unknown how variable the muscles investigated (Triceps and Infraspinatus) are. Some of the variability may be due to localised cold shortening or pH differences within the muscle, but this could only be found out if every meat strip had pH and sarcomere length measurements done on it (a major undertaking).

4.6.3.3 Qualitative observations

For the raw and 50°C meat strips is was noted that the meat strip was not fully cut through after the peak force had been attained. Instead of cutting completely through the meat strip a sheet of connective tissue (collagen) was left behind which had had most of the red meat component (myofibrillar proteins) stripped off it. This is thought to be due to two physical properties of the meat. It may be due to the fact that the meat is soft and therefore instead of being cut when the Warner Bratzler blade slides through the gap, the meat is squashed through as the myofibrillar proteins aren't stiff enough to impart enough brittleness necessary for cutting. Or that the connective tissue (collagen) is too strong (as no denaturation has taken place) to be cut through by the Warner Bratzler blade.

At 55°C the meat strip was completely cut through about 75% of the time, the remainder had a few collagen strands left behind that were uncut. At this temperature the collagen would still be in an undenatured form but the myofibrillar proteins would be a lot more denatured, and the meat significantly firmer.

At temperatures of 60°C and higher all the meat strips tested were completely cut through. There was no collagen strands left behind uncut. At the temperature of 60°C it is expected that some or all of the collagen will have denatured but that the actomyosin would not have. The samples at 60°C were noticeably softer than the samples cooked at the higher temperatures. The 65°C sample was noticeably softer than the samples cooked at 70°C and 75°C, but no difference could be noted between samples cooked at 70°C and 75°C.

The differences in firmness are believed to be due to the amount of actomyosin denatured and the total amount of liquid lost. The more denatured the actomyosin the more aggregation can occur hence a firmer meat strip. Also the less water present the firmer the meat, as water acts as a plasticiser in many food products and the more water lost the more densely packed the meat becomes.

4.6.3.4 Comparison to literature results

These results agree with some researcher's results and disagree with other researchers results. Machlik and Draudt (1963) found that for pieces of raw semitendinosus meat cut to the same size (origins of animals unknown) that the minimum tenderness values (shear values from Warner-Bratzler tests) were obtained in the 60° to 64°C range. The same results of minimum tenderness values (Warner-Bratzler) were also found between 60°C and 64°C by (Bertola et al. 1994). They also cut meat samples to the same size raw from semitendinosus muscles from steers 400 days old. (Christensen et al. 2000) found in meat samples cut to the same size after cooking from semitendinosus steaks from a 2-2.5 year old heifer, that the minimum tenderness was found at 60°C (only used 10°C intervals from 40°C to 80°C). Califano et al. (1997) found that meat cooked to a temperature of 65°C gave them the most tender product (cooked meat in temperature range of 65°C to 100°C. These results are consistent with the observations in this work. However (Davey and Gilbert 1974) found that tenderness had a minimum at between 40°C and 50°C. The tenderness then increased until 65°C were it plateaued off, when the temperature reached 75°C the tenderness started decreasing again. They used the sternomandibularis muscles from large bulls.

Some of the above mentioned studies used samples from more than one animal to compile the data, yet the variation they give are quite low. Even though the variation between animals is known to be quite large (Machlik and Draudt 1963) and this work.

Bouton et al (1981) showed that peak shear force (Warner-Bratzler) increased from 40°C to 85°C for cold shortened Longissimus dorsi from 8-15 year old cows and veal, samples cut to size after cooking. The same study also showed that for stretched semimembranosus muscle, that maximum peak shear force was reached at 50°C for veal after which the peak shear force rapidly decreased at 60°C. For old cows 8-15 years old the peak shear force increased up to 50°C then kept increasing significantly up to 60°C.

The peak shear force then decreased until 70°C but only decreased to the same value as obtained at 50°C. These results may explain why (Davey and Gilbert 1974) didn't find a decrease in tenderness at 60°C-65°C as they were using muscle from large bulls, which may mean older bulls but age was not given.

The tenderising effect at 60°C-65°C is believed to be due to collagen denaturation. There are two competing effects for collagen occurring in meat at this temperature, the mechanical strength of the collagen is being reduced due to denaturation (improving tenderness). But this also causes the collagen to shrink (decrease in tenderness). The final resultant strength imparted from the collagen is dependent on how much residual strength the collagen retains. The amount that denatures depends on the amount of stable cross-links contained within the collagen, which generally increases with animal age. So for cooked meat the toughness increases with collagen shrinkage, but if the collagen has little cross-links the loss in mechanical strength (more tender) is greater than toughness caused by shrinkage. This explains why younger animals have more tender meat than older animals, even though the same process of collagen denaturation is occurring. It may also explain why meat from old animals doesn't become tender at 60°C to 65°C, as toughness incurred from shrinkage is greater than the tenderising effect of collagen denaturation (weakening), due to less collagen denaturing as cross links stabilize a large amount of the collagen.

Christensen et al. (2000) carried out investigations that support this theory. They showed that the strength of perimysial connective tissue increased up to 50°C, at 60°C or higher the strength decreased with increasing temperature due to denaturation. This was for single strands of perimysial collagen isolated from meat.

The decrease in tenderness at 50°C found in this and nearly all other studies is thought to be due to myosin denaturation. The other decrease in tenderness at temperatures above 65°C is thought to be due to actomyosin denaturation. The other major change occurring in meat is at 60°C to 65°C, this is were differences in studies usually arise. Nearly all researchers assign the transition to the connective tissue (collagen) fraction of meat. But the actual effect of a decrease or increase in tenderness can vary between studies. A lot of research into meat cookery techniques is often done with the

Semitendinosus, Longissimus Dorsi or Semimembranosus Muscles. These muscles are often used, as they are relatively large and thought to have a reasonably consistent tenderness throughout the muscle.

Little information can be found regarding meat cookery techniques using different muscles. Some information can be found on the tenderness of different muscles, but these studies were done using only one cooking regime (i.e. more along standard procedure lines). Johnson et al. (1988) cooked meat in a water bath to 70°C over a 45 minute period. Paterson and Parrish (1986) used 2.5cm steaks oven broiled at 204°C to an internal temperature of 70°C. McKeith et al. (1985) broiled samples on open hearth electric broilers to an internal temperature of 70°C. These studies looked at the tenderness of various muscles from beef (steers). The tenderness rankings that the muscles received from the various studies differ as can be seen in table 4.1.

This Study	Johnson et al 1988	Paterson & Parrish 1986	McKeith et al 1985
INF	LGD	INF	INF
TBL	INF	LGD	LGD
TBM	TBL	TBL	TBL
LT	SSP	DPT	SSP
SV	DPT	SSP	DPT
PP			

Table 4.1 Tenderness ranking comparison to literature tenderness rankings. Ranked in descending order.

Even though the studies cooked to a similar temperature (70°C) the different cooking techniques would have resulted in different heat gradients in the cooked meat samples. Whether these differences would account for the different rankings is unsure. The variability inherently associated with some muscles may also be the reason why the rankings are different.

4.6.4 Bacterial death kinetics

By using bacterial death kinetics the period of time that a meat product has to be cooked for at a particular temperature to ensure regulations are met can be calculated. The data used to calculate the bacterial death kinetics was obtained from the USDA Food and Drug Administration website (2000), (for whole beef and corned beef roasts) and used to construct Figure 4.13, data in table 4.2. The data is based on the times required to achieve a 7D bacterial death reduction of Salmonella. This is because Salmonella is relatively more heat resistant than most other bacterial pathogens (USDA Food and Drug Administration website 2000).

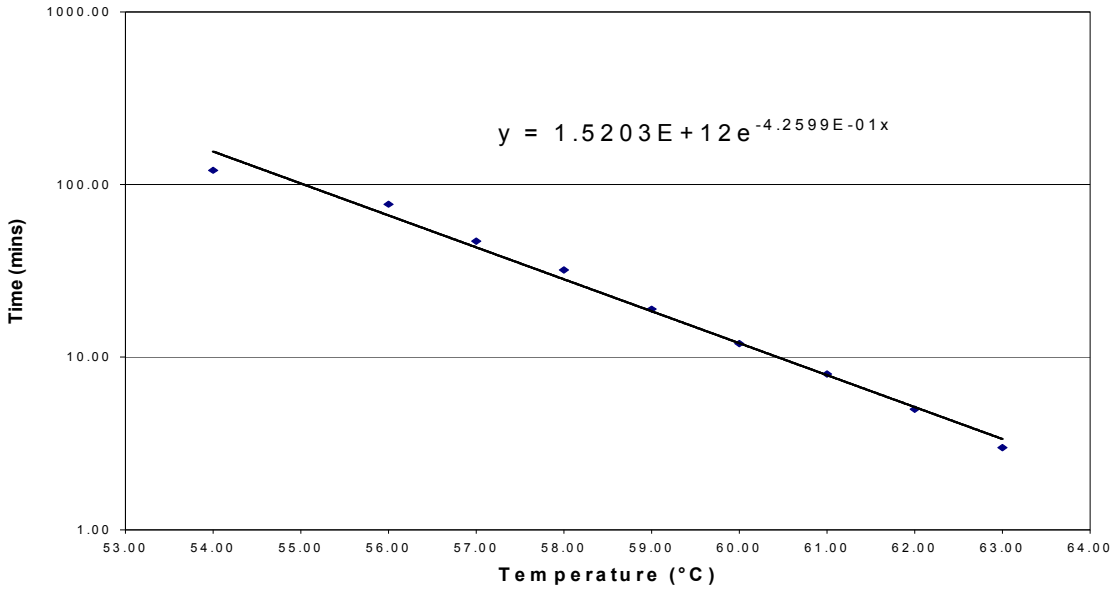

Figure 4.13: Bacterial death kinetics.

From Figure 4.13 and table 4.2, it can be seen that the bacterial death rate is very temperature dependent. The higher the temperature the greater the rate of bacterial death. However, the functional properties are also heavily governed by the temperature profile the meat experiences during cooking. Therefore the cooking regime should be designed taking into account both these factors. The priority is bacterial death to ensure a safe product, but this shouldn't be the sole parameter considered when proposing a cooking regime. The functionality of the product should also be considered. By considering both factors a cooking regime can be devised which delivers a safe product with optimal functionality (i.e. as tender as possible with highest yield possible).

Temperature (°C)	Time (minutes)	Time (seconds)
54.00	121.00	7260.00
56.00	77.00	4620.00
57.00	47.00	2820.00
58.00	32.00	1920.00
59.00	19.00	1140.00
60.00	12.00	720.00
61.00	8.00	480.00
62.00	5.00	300.00
63.00	3.00	180.00
65.00	1.43	85.98
67.00	0.61	36.67
69.00	0.26	15.64
70.00	0.17	10.22
71.00	0.11	6.67
73.00	0.05	2.85
75.00	0.02	1.21

Table 4.2 Bacterial death kinetics (shaded values are extrapolated).

4.7 Optimal cooking regime

It has been identified that the optimal cooking temperature for tenderness is around 60°C to 65°C and that the cooking losses can be greatly reduced if the cooking temperature is kept below the temperature required for actomyosin denaturation, which is around 70°C. Therefore a cooking temperature of around 62°C is recommended. This will result in a product with optimal tenderness, cook yield and is also above the minimal temperature of 60°C recommended by the USA food and drug administration office (2000). At a temperature of 62°C the meat has to be held for 5 minutes at this temperature to ensure an adequate bacterial death reduction is achieved (7D).

The yield of product by cooking at 62°C can be substantial. It is known that the percent cook loss is about 28.3% when cooking at 65°C (Figure 4.6, so the cook loss at 62°C will be at most the same if not less. To demonstrate the benefit of a reduced cooking temperature it will be assumed the cook loss at 62°C is also about 28.3% (conservative estimate as can only be lower not higher). The cook loss at 75°C cooking temperature is about 35.7% and at 70°C cooking temperature the cook loss is about 31.8% (all cook losses for one hour cooking period). It can be seen that there is a significant difference in the cook losses for different temperatures, when these cook losses are converted to overall difference's in product yield, the differences are even greater as can be seen in table 4.3. The difference in cook loss column is comparing to cooking at 62°C and the bacterial death column represents the time needed for a 7D bacterial reduction.

Cooking Temperature (°C)	Cook Loss (%)	Difference in cook loss (%)	yield compared to 62°C yield (%)	Bacterial Death Cooking time (min)
60	24.2	4.1	105.7	12
62 (65)	28.3	0	100.0	5
70	31.8	3.5	95.1	0.17
75	35.7	7.4	89.7	0.02

Table 4.3 Comparison of cooking yield and bacterial death times.

From table 4.3 it can be seen that significant increases in yield can be made by cooking at a temperature of 62°C compared to a cooking temperature of 70°C or 75°C. Cooking at 75°C reduces the yield to 89.7% of the yield compared to cooking at 62°C (cooking at 62°C increases yield by 10.3% compared to cooking at 75°C). Cooking at 70° reduces the yield to 95.1% of the yield compared to cooking at 62°C (cooking at 62°C increases yield by 4.9% compared to cooking at 70°C). This shows the obvious benefits on yield alone of cooking at lower temperatures. Cooking at the lower temperatures of 60°C to 65°C also produces meat with optimum tenderness. The only drawback to cooking at lower temperatures is the increase in cooking time needed to ensure an adequate bacterial death reduction has occurred.

For a 7D bacterial death reduction cooking at 75°C requires 0.02 minutes cooking time, 0.17 minutes at 70°C and 5 minutes at 62°C. Therefore it can be seen that the cooking time increases significantly with reducing temperature. The actual cooking time required is dependent on a number of factors, dimensions of meat to be cooked, size or weight of meat, type of cooking (effects heat transfer i.e. oven or water bath). Depending on these factors the increase in cooking time to ensure adequate bacterial death may not be too significant (i.e. time to heat meat up may be significantly longer than holding period to ensure adequate bacterial death reduction). These are factors that will need investigation to see how much the cooking times would change.

It is recommended that any cooking regime that is to be used for further processed higher value products (i.e. ready meals), should be developed so that the temperature of the meat doesn't exceed 65°C. The time needed to heat a piece of meat of known dimensions can be easily estimated with available heat transfer models and/or easily experimentally tested. The time needed to heat the slowest heating region (normally the centre) to 62°C should be calculated and tested experimentally (extra confidence and easily done). The total cooking time should the time needed to heat all the meat to 62°C or above, plus five minutes to ensure adequate bacterial death. This has a built in safety factor, as the meat will continue heating above 62°C once this temperature is reached. The difference of 3°C between designed temperature of 62°C and maximum temperature of 65°C ensures a temperature driving force is always present and allows for temperature fluctuations within the cooking medium.

Chapter 5
Nutritional Properties of Export Lamb

5.1 Introduction

Supplying the nutritional information of meat products is another way in which value can be added to meat products. The modern consumer is becoming more and more health conscious with more and more emphasis being placed on low fat, high nutrient diets. By supplying the nutrient content of meat products, the meat processor can promote its products as healthy, particularly with respect to iron, protein and B-group vitamins.

Nutrient information via labels is of most value for products that are marketed to consumers in the form provided by the meat companies. Adding value in this way is more difficult to achieve for ingredient meat that is further processed (e.g. manufacturing beef). This is because the proximate composition may be changed by manufacturers (e.g. fat trimming). Other ingredients could be added and such products often contain higher fat levels (a nutrient not currently fashionable). For this reason, nutrient information should be focussed on high value consumer products such as export quality lamb, beef and venison and the information be displayed on the label.

When considering the labelling of any food product regulations must be adhered to. Each country can have different regulations as to what information must be supplied and how it is listed on the label. Of these, the guidelines of the United States Department of Agriculture (USDA) are most appropriate as a starting point as they are some of the strictest to follow and because the USA is a significant export market for New Zealand meat products.

Because of the wide variety of consumer meat products produced in New Zealand, the focus of this work was to develop methodologies, which would allow Richmond to build a database of nutritional properties of its products. The methodologies developed would ideally minimise cost of analysis and be adaptable for different species and their

assorted meat cuts. They must also consider the variability of the product with respect to species and grade.

As a model system to work within this industry, the lamb saddle was chosen. This section of the animal contains a variety of high value consumer products which can be supplied from a variety of grades of carcasses. Once methodologies have been developed for these products, they could then be used on forequarter and hindquarter cuts.

5.2 USDA labelling guidelines

In order to collect the appropriate nutritional information for New Zealand meat products it is important to understand the requirements of labelling legislation first. The USDA labelling requirements state what nutrients must have declarations made and the compliance levels that have to be met. They also give guidelines on voluntary nutrient declarations, and advise on analytical methods to use for nutritional analysis of food (USDA 2000).

The USDA guidelines state that if any nutritional claims are made on the nutrient levels contained within a food, then there are a number of nutrients for which it is mandatory to declare. These are:

Total Fat	Iron	Dietary fibre
Saturated fat	Calcium	Vitamin C
Cholesterol	Sodium	Sugars
Protein	Vitamin A	Total Carbohydrates
Calories		

Table 5.1 Mandatory nutrients that must be declared on food label.

Along with these mandatory declarations it may be beneficial to include information on the levels of other nutrients on the label that are perceived as beneficial to health. For meat products, the following nutrients are considered as beneficial:

Zinc	Potassium	Magnesium
Niacin (B3)	Thiamine (B1)	Riboflavin (B2)
Vitamin B6	Vitamin B12	

Table 5.2 Beneficial nutrients for meat products (voluntarily labelled).

Meat is known to be a good source of these nutrients especially the B group vitamins and the minerals zinc and phosphorous as they occur in significant quantities with respect to recommended dietary intake.

5.2.1 Compliance levels

Nutrients considered to be beneficial must reach a compliance level of 80% (i.e. 80% of stated value must be present). This includes vitamins, minerals, protein, total carbohydrate, dietary fibre, other carbohydrate, polyunsaturated or monounsaturated fat and potassium. Nutrients considered undesirable must have a compliance level of 120% i.e. not more than 120% of the stated value must be present. This includes sugars, total fat, saturated fat, cholesterol and sodium USDA (2000). These compliance levels allow for the natural variation that occurs in food products. For any nutrient that occurs in low levels a declaration can be made that states the product is not a significant source of the nutrient in question.

5.2.2 Recommended analytical methods

The USDA guidelines state that they do not regulate how manufacturers should conduct analyses. But state that the producer responsible for labelling the food is accountable for the accuracy of the nutrient analysis and ensuring the product complies with the nutrient declaration. This means the producer is responsible for any nutrient declarations appearing on its labels.

For compliance testing the USDA generally uses appropriate methods for nutrient analysis according to the “Official Methods of Analysis” of the Association of Official Analytical Chemists (AOAC) International. Where no AOAC method exists then analysis is performed by other reliable appropriate procedures. In the event of the

USDA finding a non-compliance, producers will be expected to provide reputable and referenced evidence to support their label data.

5.3 Nutrient information available in the literature

A literature search was conducted to find what nutritional information there was for lamb products, especially New Zealand lamb products. The data that was found was tabulated so that the data from the different studies could be compared easily. The summary is given below as table 5.3.

Mandatory	1	2	3	4	5	6	7	8
Protein (g)	21.35	20.3	20.8	21.24	21	20.4	21.2	19.6
Fat (g)	6.31	5.03	7.4	4.6	6.24	2.67	4.4	3.6
Carbohydrate (g)	0	0	0	0	0	0	0	0
Sugars (g)	0	0	0	0	0	0	0	0
Dietary fibre (g)	0	0	0	0	0	0	0	0
Calcium (mg)	10	16	6.8	-	15	12.6	15	5.4
Iron (mg)	1.3	1.8	1.3	-	1.79	1.7	1.77	1.7
Sodium (mg)	70	73	52	-	75	69.9	45	68.7
Saturated fat (g)	2.11	1.86	-	1.8	2.61	0.975	1.9	1.34
Cholesterol (mg)	66	67	-	78.8	64	75	80	-
Voluntary								
Zinc (mg)	2.6	3.3	2.1	-	2.69	2.75	2.36	2.52
Phosphorous (mg)	199	180	192	-	200	209	203	-
Niacin (mg)	6.02	7.02	-	7.06	7.28	5.76	6.97	6.71
Thiamine (mg)	0.14	0.13	-	0.15	0.18	0.175	0.16	-
Riboflavin (mg)	0.19	0.27	-	0.37	0.31	0.193	0.35	-
Vitamin B6 (mg)	-	-	-	0.15	0.49	0.343	0.15	-
Vitamin B12 (μg)	2.1	2.3	-	2.27	1.85	3.08	2.3	-

Table 5.3 Comparison of nutritional values of lean tissue from loin region of lamb, all per 100g ('-' represents data not reported).

Key: 1: Ono *et al.* (1984), American lamb, 4 to 4.5 months old

2: Ono *et al.* (1984), American lamb, 8 to 9 months old

3: Chrystall and Winger (1986), New Zealand Lamb, YM Grade

4: Lin *et al*. (1988), New Zealand Lamb, 7 to 8 months

5: Hoke *et al.* (1999), Australian Lamb, no age or grade given

6: Badiani *et al.* (1997), Italian Lamb, 3 months old

7: USDA Database, NZ Lamb, no age or grade given

8: This investigation, NZ Lamb, PX and YX grade

From the available literature for nutritional properties of lamb, it was found that most of the nutrients measured were of the same order of magnitude. When the nutrient values were compared as %RDI then the values agreed very closely, as shown in table 5.4.

Mandatory	1	2	3	4	5	6	7	8
Protein (g)	42.7%	40.6%	41.6%	42.5%	42.0%	40.8%	42.4%	39.2%
Fat (g)	9.7%	7.7%	11.4%	7.1%	9.6%	4.1%	6.8%	5.5%
Carbohydrate (g)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Sugars (g)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Dietary fibre (g)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Calcium (mg)	1.0%	1.6%	0.7%	-	1.5%	1.3%	1.5%	0.5%
Iron (mg)	7.2%	10.0%	7.2%	-	9.9%	9.4%	9.8%	9.4%
Sodium (mg)	2.9%	3.0%	2.2%	-	3.1%	2.9%	1.9%	2.9%
Saturated fat (g)	10.6%	9.3%	-	9.0%	13.1%	4.9%	9.5%	6.7%
Cholesterol (mg)	22.0%	22.3%	-	26.3%	21.3%	25.0%	26.7%	-
Voluntary								
Zinc (mg)	17.3%	22.0%	14.0%	-	17.9%	18.3%	15.7%	16.8%
Phosphorous (mg)	19.9%	18.0%	19.2%	-	20.0%	20.9%	20.3%	-
Niacin (mg)	30.1%	35.1%	-	35.3%	36.4%	28.8%	34.9%	33.6%

Thiamine (mg)	9.3%	8.7%	-	10.0%	12.0%	11.7%	10.7%	-
Riboflavin (mg)	11.2%	15.9%	-	21.8%	18.2%	11.4%	20.6%	-
Vitamin B6 (mg)	-	-	-	7.5%	24.5%	17.2%	7.5%	-
Vitamin B12 (μg)	35.0%	38.3%	-	37.8%	30.8%	51.3%	38.3%	-

Table 5.4 RDI comparison of nutritional values of lamb lean loin tissue per 100g (USDA RDI levels).

5.4 Factors affecting nutritional values

Attributing significant differences in compositions between animals to certain factors is a complex task, as there are many factors that can affect the nutritional composition. An example is in the assessment of nutritional value of lamb based on different ages, different environmental factors may also account for differences (i.e. hot weather, feed shortage, drought) so care has to be taken when making comparisons Ono *et al.* (1984). The major factors are discussed below.

5.4.1 Meat cut

Meat cut is a very influential factor on the nutritional value of meat. The main difference arises in the amount of extra-muscular fat contained in different cuts. This is due to the fact that lean and fat tissues have significant differences in their nutritional values. Lean has more protein, minerals and water soluble vitamins than fat tissue, whereas fat tissue has more lipids, saturated fat and slightly more cholesterol (Lin *et al.* 1988). There are also some significant differences in lean tissue nutritional values for different cuts i.e. hindquarter cuts have slightly different mineral and vitamin nutritional values compared to saddle region lean tissue.

5.4.2 Sex class

The main difference between sex classes is that female animals tend to have a higher fat tissue to lean tissue ratio than their male counterparts, (Chrystall and Winger 1986).

5.4.3 Age

Some minerals, mainly zinc and iron tend to increase with age, but the changes are not great when compared as % RDI values (<5%). This effect is not too relevant for lamb as differences normally only show up in animals that are relatively old (i.e. 16 month old steers and 48 month old steers) but still the differences are usually less than 5% RDI values Ono *et al*. (1984).

5.4.4 Seasonal and geographical variations

Some studies, (Chrystall and Winger 1986) and (Ono *et al*. 1984) have stated that there are differences in nutritional values caused by seasonal and geographical differences. But after comparing the literature values collected it is believed that these differences arise from differences in the lean tissue to fat tissue ratio of animals from different regions. These differences in lean to fat ratio can be attributed to climate, diet and sex differences.

5.5 Methods used for analytical analysis

5.5.1 Proximate composition

Proximate composition was analysed by AOAC methods at the Richmond Takapau meat laboratory, Takapau, Hawkes Bay.

Moisture	AOAC 934.01
Fat	AOAC 920.39
Ash	AOAC 942.05
Protein	AOAC 984.13

5.5.2 Calories

The number of calories present in a food sample can be calculated on a per gram basis from fat, carbohydrate and protein. For labelling purposes 1g of fat contains 9 calories, 1g of carbohydrates contains 4 calories and 1g of protein contains 4 calories. Using

these figures the calorific content of the selected meat cuts can be calculated, USA Food and Drug Administration (FDA) website (2000).

5.5.3 Mineral analysis

Mineral analysis was conducted at Massey University by following AOAC method 968.08. Briefly the samples were ashed in a furnace, then the ashes were digested in HCl. This digest is then filtered and diluted to fall into a standard curve concentration (as outlined by the manufacturer guidelines for Atomic Absorption Spectroscopy determination of mineral concentration, for the particular Atomic Absorption Spectrophotometer used). The minerals analysed were: Iron, Sodium, Calcium, Magnesium, Potassium, Zinc.

5.5.4 Vitamin analysis

5.5.4.1 Vitamins A,C,E

Vitamins A, C, E were not tested for as the amounts contained in lamb meat are too small to be claimed for any health benefits to consumers. For a 100 gram serving less than 2% of the recommended daily intake is consumed. As the level is below 2% of recommended daily intake, it can be claimed as 0% RDI on the label, or alternatively a statement at the bottom of the label declaring “not a significant source of the vitamin in question” can be made (e.g. “not a significant source of Vitamin A”).

5.5.4.2 B-Group vitamins

It is known that red meat is a good source of B group vitamins, therefore the more that can be stated on a label would be beneficial in terms of marketing value. The only problem is that many of the vitamins contained within meat are expensive to test for as they either require microbiological assays, where a specific micro-organism has to be purchased to analyse each different vitamin. Microbiological assays are also very time consuming as well as costly. Other techniques involve using high performance liquid chromatography (HPLC), but as meat contains large quantities of different proteins there is a lot of interference encountered when samples are analysed unless the sample is cleaned up first using a solid-phase extraction process, (Vidal-Valverde and Reche 1991).

Vitamin B1 (thiamine) and vitamin B2 (riboflavin), both provide about 10% RDI per 100 gram serving in lamb meat. HPLC analysis techniques are available for the determination of these vitamins. The sample is first digested in acid (HCL or H_2SO_4) and then digested enzymatically to release the vitamins from the meat matrix. A solid phase extraction process is then required to purify the sample before HPLC analysis. This purification step is done to remove interfering compounds contained in meat being detected on the column at the same time the vitamin of interest is detected. Test analyse were required to determine whether the techniques are reproducible and reliable enough for labelling requirements. Niacin is present at 20% RDI or greater per 100 gram serving. The technique for Niacin analysis is similar to that for vitamin B1 and vitamin B2. Except that the clean-up phase can use an ion-exchange resin instead of a solid-phase extraction procedure, (Vidal-Valverde and Reche 1991).

The levels of vitamin B12 in a 100 gram serving is very high in terms of recommended daily intake (35% RDI or greater), but the actual amount contained in meat is in the microgram range. This means tests for vitamin B12 are difficult. At the moment no reliable HPLC or similar test is available for the determination of vitamin B12. There is currently a significant amount of research being conducted to find such a technique. At the moment vitamin B12 analyses require microbiological assay techniques. These are time consuming (days involved) and are expensive analytical procedures, which would require a substantial investment to be made, so it was decided that it was best not to try to test for vitamin B12 at present.

Vitamin B6 is present in meat at about 12% RDI per 100 gram serving. There are six active vitamers of vitamin B6, which makes it difficult to test for. There are HPLC techniques for determining vitamin B6, but due to the complexity involved it was decided not to analyse for vitamin B6 until repeatable results were obtained for niacin.

Niacin was analysed by an HPLC method. First the niacin was extracted from the meat sample by acidic and enzymatic digestion, then purified by passing through an ion-exchange column (Dowex 1-X8, BDH, 18-52 mesh in acid form). The extract from the column had the water removed by freeze drying. The residue was then dissolved in a known amount of buffer mixture. The mobile phase (pH 4.72) was prepared by

dissolving tetrabutylammonium bromide (0.005mol/L) in a mixture of 1:9 v/v of methanol and 0.01mol/L sodium acetate. The pH was adjusted using acetic acid. Standard solutions of niacin (nicotinic acid) were used to obtain a calibration curve by plotting peak area versus concentration. The concentration of the extract (and hence sample) was calculated using the calibration curve obtained from the standards. Full details of the method followed are described by (Vidal-Valverde and Reche 1991).

It was decided that niacin would be the easiest B group vitamin to test for. Once the analysis results for this vitamin were available, a decision would be made on the feasibility and necessity to try and analyse for other vitamins. If the values for niacin were similar to literature values already listed it may not be necessary to analyse for the other vitamins, and literature values may be able to be used instead.

5.5.5 Saturated fat analysis

The fatty acid profile from which the amount of saturated fat can be calculated was analysed by the Nutritional Laboratory of the Institute of Food Nutrition and Human Health at Massey University. Samples were freeze-dried, digested and the fatty acid profile was determined by gas chromatography (GC).

5.6 Sample collection

After reviewing the literature available for the nutritional properties of lamb, it was obvious that nutritional values vary primarily because of the differences in the fat tissue to lean tissue ratio. The fat to lean ratio of the meat cuts varies with respect to animal age, sex and feed availability, but the grading system used within the meat industry groups carcasses into similar levels. The processing method will also alter the lean tissue to fat tissue ratio. A good example is frenched racks or cutlets, which can be frenched to different levels by removing more or less intercostal tissue and fat tissue from the rib bones. Similarly the fat cap can be removed or kept on the lamb racks.

Because there is such a wide variety of products produced, and grades of carcasses used in the meat industry (even for the lamb saddle region only), it would be impractical to conduct nutrient analysis for every product. For this reason a simple yet apparently novel approach was developed in this work.

Because a large number of the products are derived from the saddle region of lamb carcasses, meat products are made of the same constituent components (e.g. eye muscle, fat cap, intercostals, fatty tissue and bone). This meant that the constituent components could be yielded out and analysed for their nutritional properties. The nutritional value of each whole product could then be calculated from the constituent components nutritional values and the yields for each constituent component contained within each product.

	Constituent components (Edible basis only: no bone)			
Product	Eye Muscle	Fat Cap	Intercostals	Fatty tissue
PX 75mm Rack:	41.8%	37.7%	12.3%	8.3%
PX 75mm Rack: Frenched 25mm Cap On	51.8%	31.2%	10.1%	6.8%

Table 5.5 Example of yielding constituent components.

Table 5.5 shows a PX grade 75mm rack. Nutritional values would be calculated by taking 41.8% of the eye muscle nutritional values, 37.7% of the fat cap nutritional values, 12.3% of the intercostal nutritional values and 8.3% of the fat tissue nutritional values. A similar approach would be taken for PX grade 75mm Rack, frenched 25mm with cap on except the percentage of each constituent component would change.

5.6.1 Nutritional information

The use of the matrix approach to calculate the nutritional values, meant that instead of testing all the possible lamb cuts separately, each lamb cut had to broken down into their constituent components, and the yield of each constituent component measured. This approach has the benefit of greatly reducing the number of nutritional analyses that have to be carried out which are very costly, as a number of constituent components are common to a number of products. The only extra work involved is yielding of the different lamb cuts when samples are collected, but a few hours (for one worker) in the boning room is better than the few thousand dollars it would cost for extra nutritional analysis. In this way Richmond can build its product nutritional database with minimal

cost, it also allows easy nutritional characterisation of new meat cuts that may be developed in the future.

By testing the individual components of each cut it is also possible to assess where the variability between the selected cuts and lamb grades arise from. If, instead of using the matrix approach, individual cuts would be tested, any differences in cuts or grades wouldn't be able to be conclusively prescribed to any particular source.

The constituent components tested for nutritional information were:

- Tenderloin
- Loin eye (saddle and rack section)
- Intercostals
- Fat cap and fatty tissue

The nutrients tested for were: protein , fat calcium, iron, saturated fat, zinc, sodium, potassium, magnesium, and niacin.

Nutritional information was collected for both the YX and PX lamb grades (YX are 20.5kg carcass or over with mm fat at the 12 rib, PX are 16.5kg to 20kg with mm fat cover at the 12 rib (NZ Meat producers board 1991). This was done to see if there were any significant differences between the grades for nutritional information. These particular two grades were concentrated on, as a significant amount of total production falls into these categories, and they are the most common grades exported to the USA markets. Table 5.6 below gives the proximate compositions for each of the constituent components of the lamb saddle.

		Composition							
Constituent		%moisture		% fat		%protein		%ash	
Rack eye muscle	PX	73.5%	74.2%	4.1%	3.2%	20.2%	21.1%	1.8%	0.9%
	YX	75.3%	70.6%	2.5%	3.8%	20.8%	21.3%	2.0%	1.4%
Saddle eye muscle	PX	75.9%	75.5%	2.5%	3.0%	20.5%	20.4%	1.8%	2.1%
	YX	76.4%	76.0%	3.4%	2.3%	18.8%	20.5%	2.0%	2.3%
Tenderloin	PX	75.3%	75.8%	3.5%	2.4%	20.1%	20.2%	1.4%	2.2%
	YX	78.6%	76.0%	3.4%	2.4%	17.1%	20.3%	1.6%	2.1%
Cap		30.4%	29.8%	61.3%	59.1%	9.4%	10.7%	0.3%	0.5%
Intercostal		55.3%	58.6%	24.9%	23.1%	18.1%	18.3%	0.6%	1.0%

Table 5.6 Proximate composition of constituent components.

As can be seen from table 5.6 there is not very much difference between the different types of lean tissue, rack eye muscle, saddle eye muscle, tenderloins and it doesn't matter whether it's from PX or YX grade lambs. The lean tissue values are very similar to those found by other studies for lamb loin lean tissue, as can be seen in table 5.3. The highlighted value for YX rack eye muscle moisture content of 70.6% seems lower than it should be, probably due to an experimental error.

	Mineral composition (per 100g)					
Constituent	Ca (mg)	Mg (mg)	Zn (mg)	Fe (mg)	K (mg)	Na (mg)
PX Rack eye muscle	8.33	7.13	2.65	1.74	333.33	54.59
YX Rack eye muscle	10.47	3.86	2.81	1.65	278.49	56.11
PX Saddle eye muscle	1.64	60.10	2.36	1.71	294.19	86.36
YX Saddle eye muscle	5.26	57.59	2.07	1.71	298.06	87.87
PX Tenderloin	4.25	20.77	2.55	1.69	354.04	51.02
YX Tenderloin	2.28	50.66	2.69	1.70	289.49	76.21
Cap	6.01	129.81	1.67	1.17	145.95	127.00
Intercostal	20.99	78.67	3.58	1.38	190.16	114.62

Table 5.7 Mineral composition of constituent components

Table 5.7 summarises the mineral levels in the constituent components of the lamb saddle. The values found for iron, zinc and sodium (main minerals of interest) in lean tissue are very similar to those found by other studies for lamb loin lean tissue, as can be seen in table 5.3. The zinc and calcium levels are higher than expected for the intercostals. This is due to the fact that there may have been some very small bone scrapings included in the analysis as the intercostals had to be cut from the rib bones and the knife would have subsequently scraped along the bone. Table 5.8 below summarises the lipid make up of in the different constituent components of the lamb saddle.

	Composition (g/100g)		
Constituent	Saturated fat	Monounsaturated fat	Polyunsaturated fat
PX Rack eye muscle	1.76	1.78	0.30
YX Rack eye muscle	1.56	1.49	0.26
PX Saddle eye muscle	0.98	0.83	0.23
YX Saddle eye muscle	1.50	1.28	0.30
PX Tenderloin	1.13	1.08	0.23
YX Tenderloin	1.11	0.96	0.22
Cap	32.41	25.95	2.18
Intercostal	14.28	11.20	1.93

Table 5.8 Lipid composition of constituent components.

The average saturated fat levels (main lipid of interest, as it has to be reported) for the lean tissue was slightly lower than most values reported by other studies, as can be seen in table 5.3. The actual difference is about 0.6g/100g which is small when compared as an RDI value of 3.5%, so it is recommended that the slightly higher values found in other studies be used for extra confidence. There is quite a noticeable amount of

variability for measured saturated fat levels, but the value of 1.9g/100g is recommended to be used so compliance can be assured. This is because it is slightly higher than all measured values and compliance levels are set at 20% above this (i.e. 2.3g/100g), but the actual differences to RDI levels is small. Table 5.9 summarises the measured niacin levels for the lamb constituent components.

	Niacin (mg/100g)			
Constituent	**Analysis 1**	**Analysis 2**	**Analysis 3**	**Average**
PX Rack eye muscle	6.60	7.20	6.60	6.80
YX Rack eye muscle	7.00	5.20	6.80	6.33
PX Saddle eye muscle	6.60	-	-	-
YX Saddle eye muscle	5.30	-	-	-
PX Tenderloin	7.20	6.90	6.10	6.73
YX Tenderloin	7.10	7.00	6.80	6.97
Cap	1.50	2.60	2.20	2.10
Intercostal	5.50	4.10	5.40	5.00

Table 5.9 Niacin composition of constituent components.

For the niacin analysis there was quite a lot of variability encountered when analysis was performed on the same homogenised sample. But this was due more to the technique used, which was very time consuming and had the potential for losses to occur, bringing the measured value down (as was believed to have happened a few times). The values measured are very close to literature values stated, so the literature values can be used confidently.

The values determined for proximate composition, saturated fat and mineral levels are similar to those reported in the literature. There are slight differences in the proximate

composition (i.e. 1%-5% higher), which subsequently makes the protein and fat values slightly lower by 1%-2%. Such variations are well within those allowed for compliance to the USDA standards. The minerals of main interest, iron and zinc are comparable to those already reported.

Since the literature values and the measured values are similar, and most variation is caused by differences in lean tissue to adipose tissue, it is recommended that already known literature values be used as a source for further nutritional information. This will allow the inclusion of more B group vitamins and other nutrients that are expensive to test for (e.g. B12, B6, thiamine, riboflavin, niacin and cholesterol). The amount of resources (time consuming and expensive tests) required to test for these other nutrients cannot be justified, as the information available (other studies, mainly USDA database) is more than accurate enough for the labelling requirements. Since most variation is caused by the variation in fat to lean tissue ratio, it is recommended that resources be concentrated on collecting yielding information for further products.

5.6.2 Nutritional values for lean, adipose and intercostal tissue

Most of the nutrients measured in this study agree closely with other studies. It was found that the current study had very similar values to those reported on the USDA database for New Zealand loin lean tissue. A comparison of the current investigation to the USDA database can be seen in table 5.10.

From table 5.10 it can be seen that the current investigation and the USDA database investigation have very similar nutritional values. The main difference of concern is the amount of saturated fat, as stated in section 5.6.1 it is best to use the slightly higher value of 1.9g/100g to ensure compliance.

Using both these sources of data a table (table 5.11) was compiled for the nutritional composition of the constituent components,, which could be used along with yielding data to calculate the nutritional value.

Mandatory	USDA database	Current investigation
Protein (g)	21.2	19.6
Fat (g)	4.4	3.6
Carbohydrate (g)	0	0
Sugars (g)	0	0
Dietary fibre (g)	0	0
Calcium (mg)	15	5.4
Iron (mg)	1.77	1.7
Sodium (mg)	45	68.7
Saturated fat (g)	1.9	1.34
Cholesterol (mg)	80	-
Voluntary		
Zinc (mg)	2.36	2.52
Phosphorous (mg)	203	-
Niacin (mg)	6.97	6.71
Thiamine (mg)	0.16	-
Riboflavin (mg)	0.35	-
Vitamin B6 (mg)	0.15	-
Vitamin B12 (μg)	2.3	-

Table 5.10 Comparison of current study and USDA database for lean loin tissue.

Mandatory	Lean		Fat Cap		Intercostal	
	Per 100g	%RDI	Per 100g	%RDI	Per 100g	%RDI
Protein (g)	20	40	8	16	18	36
Fat (g)	4	6.2	65	100	25	38.5
Carbohydrate (g)	0	0	0	0	0	0
Sugars (g)	0	0	0	0	0	0
Dietary Fibre (g)	0	0	0	0	0	0
Calcium (mg)	10	1.0	10	1.0	10	1.0
Iron (mg)	1.7	9.4	1.15	6.4	1.38	7.67
Sodium (mg)	80	3.4	120	5.0	94	3.9
Saturated Fat (g)	1.9	9.5	32.5	162.5	12.61	63.05
Cholesterol (mg)	80	26.7	90	30	83.5	27.83
Voluntary						
Zinc (mg)	2.4	16	0.85	5.67	1.86	12.4
Phosphorous (mg)	200	20	40	4.0	144	14.4
Niacin (mg)	6.9	34.5	2.5	12.5	5.38	26.9
Thiamine (mg)	0.15	10	0.05	3.33	0.12	8.0
Riboflavin (mg)	0.35	20.6	0.12	7.06	0.27	15.88
Vitamin B6 (mg)	.015	7.5	0.03	1.5	0.11	5.5
Vitamin B12 (μg)	2.3	38.3	1.0	16.67	1.85	30.83

Table 5.11 Nutritional values of the constituent components.

When assigning the nutritional values to use, the compliance levels were also considered. It was decided than when two values were slightly different it was best to use the value that would be closest to compliance levels e.g. the USDA value for lean saturated fat of 1.9g/100g was used instead of this investigation's value of 1.34g/100g. The actual difference is quite small but 1.9g/100g has a compliance level of up to 2.28g/100g, whereas the value of 1.34g/100g has a compliance level of up to 1.6g/100g. This is why values closest to compliance level were used to make sure the values fell

well within the compliance level requirements. For some nutritional values an average was used but the compliance levels were always kept in mind to make sure the values fell well within them. A similar process was carried out for the fat cap tissue for assigning nutritional values.

For the intercostal values for which no literature information was available a weighted value from lean and fat tissue values was made. As the intercostal is about 35% fat tissue and 65% lean tissue this ratio was used to calculate nutritional values for the intercostal tissue. As the intercostal never made up more than 15% of any selected lamb cut (14.7% in 75mm rack frenched 25mm cap off) these values only have a minor effect on the overall nutritional values for the selected lamb cuts.

5.6.3 Yielding information

Yielding information was collected to allow the application of the matrix design approach for calculating the nutritional value of lamb cuts. This yielding information measured the fraction of each constituent component present within the selected lamb cuts. The yielding information was collected by dissecting five PX grade and five YX grade saddle regions (shortloin and rack section) cuts into the constituent components. The weight of each constituent component was recorded. This was used to calculate the ratio or percentage of each constituent component contained within each lamb cut (on an edible basis i.e. without bone). Yielding information was collected for the following selected cuts:

75mmShortloin Section	**75mm Rack Section**	**75mm Rack (Frenched 25mm)**
Tenderloin	Loin Eye	Loin Eye
Tenderloin side	Fat Cap	Fat Cap (if on)
Loin Eye	Intercostal	Intercostal
Silverskin	Fatty tissue	Fatty tissue
Fat Cap		

Table 5.12 Constituent components yielded from the selected cuts.

For the purpose of collecting nutritional information, tenderloin sides and fatty tissue were designated the same as fat cap (subcutaneous fat is fairly uniform in composition, and percentage yield of tenderloin sides and fatty is tissue small in comparison to fat cap). The intercostal is the tissue held between the rib bones found in the rack section. Silverskin was designated as lean tissue as during yielding it was totally stripped of fat while connected to the loin eye muscle. When the silverskin was "skinned off the loin eye it still had a significant amount (a thin coating) of lean tissue (red meat) adhering to it, which would have significantly increased its yield value. This is a further reason for it being labelled as lean tissue. Table 5.13 below summarises the yielding information for the PX grade saddle region.

75mm Shortloin Section	Mean	STDEV	99% CI	Upper	Lower
Tenderloin	11.9%	2.2%	2.5%	14.4%	9.4%
Tenderloin sides	7.2%	1.5%	1.7%	8.9%	5.5%
Eyemuscle	38.9%	3.7%	4.3%	43.2%	34.6%
Silverskin	8.6%	1.0%	1.2%	9.8%	7.4%
Fat cap	33.4%	6.9%	8.0%	41.4%	25.5%
75mm Rack section	**Mean**	**STDEV**	**99% CI**	**Upper**	**Lower**
Fat cap	37.7%	6.3%	7.2%	44.9%	30.5%
Eyemuscle	41.8%	5.5%	6.3%	48.0%	35.5%
Intercostals	12.3%	1.4%	1.6%	13.8%	10.7%
Fatty tissue	8.3%	1.3%	1.5%	9.7%	6.8%
Boneless loin with silverskin	**Mean**	**STDEV**	**99% CI**	**Upper**	**Lower**
Eyemuscle	81.9%	1.3%	1.6%	83.4%	80.3%
Silverskin	18.1%	1.3%	1.6%	19.7%	16.6%

75mm Rack frenched 25mm cap on	Mean	STDEV	99% CI	Upper	Lower
Fat cap	31.2%	5.2%	6.0%	37.2%	25.2%
Eyemuscle	51.8%	6.8%	7.8%	59.6%	44.0%
Intercostals	10.1%	1.1%	1.3%	11.4%	8.8%
Fatty tissue	6.8%	1.1%	1.2%	8.1%	5.6%
75mm Rack frenched 25mm cap off	**Mean**	**STDEV**	**99% CI**	**Upper**	**Lower**
Eyemuscle	75.3%	9.8%	11.3%	86.6%	64.0%
Intercostals	14.7%	1.7%	1.9%	16.6%	12.8%
Fatty tissue	9.9%	1.5%	1.8%	11.7%	8.2%

Table 5.13 Yielding data for PX grade lamb

CI stands for confidence interval. Table 5.14 below summarises the yielding information for the YX grade saddle region.

75mm Shortloin Section	Mean	STDEV	99% CI	Upper	Lower
Tenderloin	11.3%	0.9%	1.1%	12.4%	10.3%
Tenderloin sides	7.3%	1.3%	1.5%	8.9%	5.8%
Eyemuscle	39.5%	1.5%	1.8%	41.3%	37.7%
Silverskin	8.8%	1.8%	2.1%	10.9%	6.7%
Fat cap	33.1%	3.7%	4.2%	37.3%	28.8%
75mm Rack section	**Mean**	**STDEV**	**99% CI**	**Upper**	**Lower**
Fat cap	34.0%	2.5%	2.9%	36.9%	31.0%
Eyemuscle	43.4%	1.8%	2.1%	45.5%	41.3%
Intercostals	13.5%	1.0%	1.1%	14.6%	12.3%
Fatty tissue	9.1%	1.6%	1.8%	10.9%	7.3%

Boneless loin silverskin	Mean	STDEV	99% CI	Upper	Lower
Eyemuscle	81.9%	3.2%	3.7%	85.5%	78.2%
Silverskin	18.1%	3.2%	3.7%	21.8%	14.5%
75mm Rack frenched 25mm cap on	**Mean**	**STDEV**	**99% CI**	**Upper**	**Lower**
Fat cap	27.9%	2.3%	2.6%	30.5%	25.3%
Eyemuscle	53.5%	1.9%	2.1%	55.6%	51.4%
Intercostals	11.1%	0.7%	0.8%	11.9%	10.2%
Fatty tissue	7.5%	1.3%	1.5%	9.0%	6.0%
75mm Rack frenched 25mm cap off	**Mean**	**STDEV**	**99% CI**	**Upper**	**Lower**
Eyemuscle	74.2%	1.5%	1.8%	76.0%	72.5%
Intercostals	15.4%	0.6%	0.7%	16.0%	14.7%
Fatty tissue	10.4%	1.8%	2.1%	12.5%	8.3%

Table 5.14 Yielding data for YX grade lamb.

As can be seen from tables 5.13 and 5.14 there can be considerable variation in the amount of fat tissue to lean tissue ratio for the various products. For example an average PX grade Shortloin section has 33.4% fat cap which contributes 21.7g/100g of fat to the shortloin section. If the upper 99% confidence level of 41.4% fat cap is used, it contributes 26.9g/100g. This represents a difference of over 5g/100g, which is a considerable difference. The amount of variability in yield (standard deviation (STDEV)) is significantly less for YX grade lambs compared to PX grade lambs. The reason for this difference is unsure, but it may be due to lambs falling in the PX grade category naturally varying more than those in the YX grade category.

5.7 Sources of variability in nutritional levels

It was known that there were two possible sources of variation in the collection of nutritional information for lamb cuts. These are variation in measured nutritional levels between carcasses and grades, and variation in the ratio of constituent components

making up a selected lamb cut due to carcass differences (i.e. amount of fat cap to loin eye ratio).

From the nutritional analysis conducted it was found that the nutritional levels in lean tissue from lamb rack and shortloin sections were very similar. The lean tissue from tenderloin, saddle loin eye and rack loin eye had similar nutritional, and grade had little influence. As expected there are significant differences between lean tissue and adipose tissue (fat cap). The main differences were in the levels of lipid, protein, mineral and vitamin levels. This data can be seen it tables 5.6 to tables 5.9.

From the yielding experiments conducted it was found that there is significant differences in the ratio of the constituent components (lean and fat tissue) making up the lamb cuts as can be seen it tables 5.13 and 5.14. This means for instance, that for a shortloin chop the ratio of fat cap to loin eye varies significantly. There is variation within a grade and there is also variation between grades (i.e. PX grade lamb cuts usually have a higher fat cap ratio than YX grade lamb cuts).

The key factor noted here was that there are significant differences between cuts due to trimming, frenching, and rib length etc. during processing. For lamb cuts such as Shortloin section, Rack section and French Racks this variation in the yield of lean tissue, fat tissue and intercostal tissue causes significant variation in the nutritional levels for these selected cuts. This is because of the differences in nutritional levels between lean tissue and adipose tissue. For cuts such as tenderloin and boneless loin this yield variation doesn't exist as they are made up of one tissue type.

This demonstrates the advantage the matrix design has over testing whole products. The variation caused by the ratio of fat tissue to lean tissue within a grade wouldn't have been identified, only the variation between grades. PX grade cuts would still have been found to contain higher fat levels on average than YX grade cuts, but the variation within a grade being caused by varying adipose to lean tissue ratios was only discovered due to the approach taken in this work.

5.8 Nutritional values of selected lamb cuts

Using table 5.11, the nutritional values of the constituent components and the yielding information in tables 5.14 and 5.15, the nutritional value of any saddle section lamb cut can be calculated for which yielding information exists. This has been done for the 75mm Shortloin Section (whole section and individual chops), 75mm Rack section (whole section and individual chops) Tenderloins, Loin Eye and 75mm Racks frenched 25mm (cap on and off). Shown below in table 5.15 for PX grade lamb and Table 5.16 for YX grade lamb.

	Shortloin Section	Rack Section	25mm Frenched Rack Cap on	25mm Frenched Rack Cap off	Tenderloin or Boneless Loin
Mandatory	Per 100g	Per 100g	Per 100g	Per 100g	Per 100g
Protein (g)	15.39	14.55	15.53	18.55	20.00
Fat (g)	27.42	33.07	27.83	12.96	4.00
Carbohydrate (g)	0.00	0.00	0.00	0.00	0.00
Sugars (g)	0.00	0.00	0.00	0.00	0.00
Dietary Fibre (g)	0.00	0.00	0.00	0.00	0.00
Calcium (mg)	10.00	10.00	10.00	10.00	10.00
Iron (mg)	1.49	1.42	1.47	1.60	1.70
Sodium (mg)	95.36	99.09	95.65	85.91	80.00
Saturated Fat (g)	13.65	16.51	13.87	6.42	1.90
Cholesterol (mg)	83.84	84.77	83.91	81.48	80.00
Calories	308.37	355.86	312.63	190.84	116.00
Voluntary					
Zinc (mg)	1.80	1.66	1.79	2.17	2.40
Phosphorous (mg)	138.56	123.63	137.39	176.36	200.00
Niacin (mg)	5.21	4.80	5.18	6.25	6.90
Thiamine (mg)	0.11	0.10	0.11	0.14	0.15
Riboflavin (mg)	0.26	0.24	0.26	0.32	0.35
Vitamin B6 (mg)	0.10	0.09	0.10	0.13	0.15
Vitamin B12 (μg)	1.80	1.68	1.79	2.11	2.30

Table 5.15 PX grade lamb nutritional values for selected products.

	Shortloin Section	Rack Section	25mm Frenched Rack Cap on	25mm Frenched Rack Cap off	Tenderloin or Boneless Loin
Mandatory	Per 100g	Per 100g	Per 100g	Per 100g	Per 100g
Protein (g)	15.62	15.00	15.93	18.73	20.00
Fat (g)	26.25	31.02	25.96	12.21	4.00
Carbohydrate (g)	0.00	0.00	0.00	0.00	0.00
Sugars (g)	0.00	0.00	0.00	0.00	0.00
Dietary Fibre (g)	0.00	0.00	0.00	0.00	0.00
Calcium (mg)	10.00	10.00	10.00	10.00	10.00
Iron (mg)	1.50	1.44	1.49	1.60	1.70
Sodium (mg)	94.59	97.75	94.43	85.42	80.00
Saturated Fat (g)	13.06	15.48	12.94	6.05	1.90
Cholesterol (mg)	83.65	84.44	83.61	81.35	80.00
Calories	298.76	339.17	297.39	184.79	116.00
Voluntary					
Zinc (mg)	1.83	1.71	1.84	2.19	2.40
Phosphorous (mg)	141.63	128.99	142.29	178.32	200.00
Niacin (mg)	5.29	4.95	5.31	6.30	6.90
Thiamine (mg)	0.11	0.11	0.11	0.14	0.15
Riboflavin (mg)	0.27	0.25	0.27	0.32	0.35
Vitamin B6 (mg)	0.11	0.10	0.11	0.13	0.15
Vitamin B12 (μg)	1.83	1.72	1.83	2.12	2.30

Table 5.16 YX grade lamb nutritional values for selected products.

Any other products from the saddle section can easily have their nutritional properties characterised, as long as the yielding information for that particular product is collected (e.g. french racks, frenched to different levels or shortloin chops cut to different rib lengths or trimmed to different external fat levels). The nutritional value of similar

products trimmed to different fat thickness' can also be calculated as long as yielding information for these products is collected.

As the amount of adipose tissue (fat cap) is critical to the nutrient levels of the selected lamb cuts, nutrient values for the lowest expected lean tissue to adipose tissue ratio were compiled. The 99% confidence levels for upper fat tissue and lower lean tissue from tables 5.13 and 5.14 were used to calculate the critical levels i.e. worst case scenario of very high fat tissue to lean tissue ratio. This value was then compared to the compliance levels. Table 5.17 below shows an example comparison for PX grade Shortloin section.

Mandatory	Expected	Compliance	Critical
Protein (g)	14.55	11.64	13.57
Fat (g)	33.07	39.69	39.15
Carbohydrate (g)	0.00	0.00	0.00
Sugars (g)	0.00	0.00	0.00
Dietary Fibre (g)	0.00	0.00	0.00
Calcium (mg)	10.00	8.00	10.11
Iron (mg)	1.42	1.14	1.39
Sodium (mg)	99.09	118.91	103.89
Saturated Fat (g)	16.51	19.81	19.55
Cholesterol (mg)	84.77	101.73	86.61
Calories	355.86	427.03	406.58
Voluntary			
Zinc (mg)	1.66	1.33	1.53
Phosphorous (mg)	123.63	98.90	109.93
Niacin (mg)	4.80	3.84	4.44
Thiamine (mg)	0.10	0.08	0.09
Riboflavin (mg)	0.24	0.19	0.22
Vitamin B6 (mg)	0.09	0.07	0.08
Vitamin B12 (μg)	1.68	1.34	1.58

Table 5.17 PX grade rack section nutritional values, expected, minimum or maximum amount allowed for compliance to USDA label claim and critical level (99% Confidence level limit for fat:lean tissue ratio).

From the comparison of all products most nutrient levels fell within the compliance levels, but total fat and saturated fat were the closest to the limits. In two cases PX shortloin section and PX 75mm rack frenched 25mm cap on the fat and saturated fat critical levels fell just outside the compliance levels. This however is not a problem as these critical limits are the worst case scenario expected and compliance is performed on a minimum of six products, which are averaged so compliance to the requirements will be easily achieved.

The spreadsheet containing the calculated nutritional levels for varying ratios of fat to lean tissue for each grade and product can be found in the appendix under the titles “PX Grade Nutritional Information” and “YX Grade Nutritional Information”.

5.8.1 Nutritional information to include on label

The following is a list of the nutrients that are recommended for inclusion on any nutritional label of lamb cuts, separated into mandatory and voluntary sections. The recommended (RDI) values and the percentage RDI that 100g contains are included. An example is shown below for tenderloins or boneless loin in table 5.18

Mandatory	Level (g/100g)	RDI Values	%RDI
Protein (g)	20	50	40
Fat (g)	4	65	6.2
Carbohydrate (g)	0	300	0
Sugars (g)	0	-	0
Dietary Fibre (g)	0	25	0
Calcium (mg)	10	1000	1.0
Iron (mg)	1.7	18	9.4
Sodium (mg)	80	2400	3.4
Saturated Fat (g)	1.9	20	9.5
Cholesterol (mg)	80	300	26.7
Vitamin A (IU)	0	5000	0
Vitamin C (mg)	0	60	0

Voluntary	Level (g/100g)	RDI Values	%RDI
Zinc (mg)	2.4	15	16
Phosphorous (mg)	200	1000	20.0
Niacin (mg)	6.9	20	34.5
Thiamine (mg)	0.15	1.5	10
Riboflavin (mg)	0.35	1.7	20.6
Vitamin B6 (mg)	0.15	2.0	7.5
Vitamin B12 (μg)	2.3	6.0	38.3

Table 5.18 Tenderloin or boneless loin nutritional values.

The Recommended Daily Intake levels (RDI) are sourced from the USA Food and Drug Administration (FDA) Website, and are based on a 2000 calorie diet for adults and children 4 years and older. The 2000-calorie diet is the current standard used for labelling purposes in the USA.

5.8.2 Nutritional Values via Proximate Composition

During the course of this nutritional investigation, the question was often asked if the nutritional values of selected cuts could be calculated directly from proximate composition i.e. nutritional values assigned to protein, fat and moisture. Unfortunately this is not possible, as the nutritional values per gram of protein/fat for lean and fat tissue are significantly different, this is shown below in table 5.19.

	Normal Values			Per Gram Protein			Per Gram Fat		
Nutrient	**Lean**	**Fat Cap**	**Intercostal**	**Lean**	**Fat Cap**	**Intercostal**	**Lean**	**Fat Cap**	**Intercostal**
Moisture (g)	76.0000	28.0000	59.0000	3.8000	3.5000	3.2778	19.0000	0.4308	2.3600
Protein (g)	20.0000	8.0000	18.0000	1.0000	1.0000	1.0000	5.0000	0.1231	0.7200
Fat (g)	4.0000	65.0000	25.0000	0.2000	8.1250	1.3889	1.0000	1.0000	1.0000
Carbohydrate (g)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Sugars *g)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dietary Fibre (g)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Calcium (mg)	10.0000	10.0000	10.0000	0.5000	1.2500	0.5556	2.5000	0.1538	0.4000
Iron (mg)	1.7000	1.1500	1.3800	0.0850	0.1438	0.0767	0.4250	0.0177	0.0552
Sodium (mg)	80.0000	120.0000	94.0000	4.0000	15.0000	5.2222	20.0000	1.8462	3.7600
Saturated Fat (mg)	1.9000	32.5000	12.6100	0.0950	4.0625	0.7006	0.4750	0.5000	0.5044
Cholesterol (mg)	80.0000	90.0000	83.5000	4.0000	11.2500	4.6389	20.0000	1.3846	3.3400

Nutrient	Lean	Fat Cap	Intercostal	Lean	Fat Cap	Intercostal	Lean	Fat Cap	Intercostal
Zinc (mg)	2.4000	0.8500	1.8575	0.1200	0.1063	0.1032	0.6000	0.0131	0.0743
Phosphorous (mg)	200.0000	40.0000	144.0000	10.0000	5.0000	8.0000	50.0000	0.6154	5.7600
Niacin (mg)	6.9000	2.5000	5.3600	0.3450	0.3125	0.2978	1.7250	0.0385	0.2144
Thiamine (mg)	0.1500	0.0500	0.1150	0.0075	0.0063	0.0064	0.0375	0.0008	0.0046
Riboflavin (mg)	0.3500	0.1200	0.2695	0.0175	0.0150	0.0150	0.0875	0.0018	0.0108
Vitamin B6 (mg)	0.1500	0.0300	0.1080	0.0075	0.0038	0.0060	0.0375	0.0005	0.0043
Vitamin B12 (□g)	2.3000	1.0000	1.8450	0.1150	0.1250	0.1025	0.5750	0.0154	0.0738

Table 5.19 Comparison of nutrients on protein and fat basis from different tissues.

From table 5.19 it can be seen that there are a number of significant differences between the tissue types (lean, fat and intercostal) when nutrients are compared on a protein or fat basis. Examples are, iron per gram protein from lean tissue is 0.085mg while from fat tissue it's 0.144mg (higher due to less protein in fat tissue). Cholesterol per gram fat from lean tissue is 20mg while from fat tissue its 1.38mg, whereas both tissue types have similar overall values i.e. 80mg per gram lean tissue and 90mg per gram fat tissue.

5.9 Nutritional data for other regions of lamb

After reviewing the available data for other potions of the lamb carcass the following data was compiled for further characterisation of the nutritional properties of other export lamb cuts. The data was mainly gathered from the USDA Food and Nutrition website, but slight changes were made to ensure compliance levels are met. An example of this is for the fore shank sodium levels reported as 50mg/10g and cholesterol as 67mg/100g, suggested levels to use are sodium 80mg/100g and cholesterol 70mg/100g. This is because most sodium levels measured are usually higher than 50mg/100g for other lean meat and the difference of 30mg/100g represents only a 1.25% change in the RDI level. Similarly for cholesterol the difference of 3mg/100g represents a change in RDI levels of 1%. The levels suggested allow a little bit more room for compliance without adversely affecting the %RDI levels for marketing purposes.

Mandatory	Fore shank (g/100g)	Leg (shank and sirloin) (g/100g)	Shoulder (arm and blade) (g/100g)
Protein (g)	20	20	20
Fat (g)	3.4	4.0	5.5
Carbohydrate (g)	0	0	0
Sugars (g)	0	0	0
Dietary Fibre (g)	0	0	0
Calcium (mg)	10	10	15
Iron (mg)	1.57	1.68	1.4
Sodium (mg)	80	80	80
Saturated Fat (g)	1.5	1.7	2.4
Cholesterol (mg)	70	75	75
Vitamin A (IU)	0	0	0
Vitamin C (mg)	0	0	0
Voluntary			
Zinc (mg)	4.00	3.0	3.5
Phosphorous (mg)	190	200	160
Niacin (mg)	6.2	6.9	5.1
Thiamine (mg)	0.15	0.15	0.14
Riboflavin (mg)	0.40	0.4	0.36
Vitamin B6 (mg)	0.13	0.15	0.1
Vitamin B12 (μg)	2.7	2.6	3.5

Table 5.20 Nutritional values for lean tissue from other regions of lamb.

The data in table 5.20 can be used along with data for fat tissue (fat cap) from table 5.11 to characterise additional export lamb cuts (i.e. lamb hindquarter legs). Yielding information will have to be collected for these products to allow the calculation of their nutritional values. Once the yielding information is collected the nutritional characteristics of the various cuts can be calculated.

5.10 Conclusion

As the collected data and literature data are very similar it is recommended that literature values be used for subsequent calculations. The main cause of variation in final product nutritional levels arises from yielding differences. The variation associated with the yielding greatly outweighs any variation from the nutritional data values used. The critical factor is the lean tissue to adipose tissue (fat tissue) ratio, which means that there will be significant differences between grades for nutritional values for cuts comprising both lean and adipose tissue (i.e. saddle chops). It might be worth Richmond Ltd getting an independent analysis of one or two lamb cuts from a known grade (YX or PX) to test predictions for risk management purposes.

The matrix approach of collecting nutritional information for constituent components and combining this with yield data to calculate the nutritional properties of a selected cut can be used for other species (i.e. beef and venison). Currently no data for New Zealand beef or venison can be found, therefore nutritional data may have to be collected if the nutritional properties of meat cuts from these species are wanted for labelling purposes. However by using the matrix approach the amount of analysis that has to be done is reduced to a minimum.

Chapter 6
Conclusions and Recommendations

6.1 Introduction

The objective of adding value to several products has been accomplished as the project set out to do. Those muscles within the beef forequarter which have the best potential for added value via further processing have been identified. Recommendations have also been made on the cooking regimes to use to optimise the functional properties of further processed products. Along with the functional property added value aspect an inexpensive and easy method has been developed (matrix method), which allows the nutritional characterisation of any export lamb product originating from the saddle region (shortloin and rack section). Further recommendations are made on how this matrix method can be further utilized for other lamb products originating from the hindquarter and forequarter, as well as how it could be adapted to other species.

6.2 Beef forequarter functionality

6.2.1 Tenderness

It can be concluded that for the beef forequarter muscles tested that there are distinct differences in tenderness. The Infraspinatus is the most tender of the muscles tested, followed by the Triceps Brachi Longhead and the Supraspinatus. These are the muscles that are identified as having the best potential for adding value in further processing applications were whole cuts of meat are used such as ready meals.

The other muscles tested Triceps Brachi Medialhead, Latissimus dorsi, Serratus Ventralis and Pectorialis Profundus were found not to have as good a tenderness profiles as the other muscles. Therefore their application in further processing applications such as ready meals would be very limited. This is compounded for the Latissimus dorsi and Triceps Brachi Medialhead as these muscles are quite small so would yield very little product per muscle (animal). Also the Pectorialis Profundus is a large flat muscle so the range of cuts able to be fabricated from it would be minimal.

6.2.2 Cook loss

There was no significant difference between the muscles tested, for cook loss. This was because the variation in cook loss for the muscles was the same order of magnitude as the range of cook losses over all the muscles. Another reason that no differences were observed may be due to the long cooking time, which meant cook losses had adequate time to diffuse out of the meat compared to some other studies which heat up to an internal temperature then stop cooking (variation in cooking times can occur). The cook loss for the muscles ranged from 29% to 34% but the amount of variation meant that no significant differences could be detected. This also emphasises the fact that cooking losses are more dependent on cooking temperature than muscle type.

6.2.3 Shrinkage

No significant difference in shrinkage could be detected between the different muscles. This was not unexpected due to the fact that there was a large amount of variation encountered with the shrinkage measurements. The shrinkage values ranged from 30% to 48% but the variation was at least 12% for each muscle (i.e. 31%+-12% or range of 19% to 43%).

6.3 Functionality as effected by cooking regime

6.3.1 Tenderness

The tenderness was markedly affected by the cooking regime employed. The main factor being the cooking temperature the meat is subjected too. The best tenderness is achieved when the meat is cooked at a temperature of 60°C to 65°C. This has been linked back to the fact that this is the temperature at which the collagen fraction of meat denatures. Due to the variation encountered the tenderness at temperatures above 65°C could not be said to be less tender, but meat cooked at temperatures above 65°C was firmer to touch. This would be due to increased cook loss and actomyosin denaturation. One problem with the current tenderness measurements is that they only take into account the force needed to cut through the meat, whereas tenderness as judged by consumers is more a combination of force needed to cut the meat and juiciness (i.e. a

pieces of meat needing the same force to cut through but different juiciness' will probably be judged differently for tenderness).

6.3.2 Cooking losses

Cooking losses were found to be very temperature dependent as expected. This temperature dependency is related to the temperatures at which the three major protein fractions of meat denature at. The first stage of cooking losses occur at a temperature of around 50°C at which temperature the myosin fraction is known to denature which results in a significant reduction in the water holding capacity of the myosin. The second stage of cooking losses occurs at around 60°C were the collagen fraction of the meat proteins denature. As the collagen denatures is loses its ability to hold it own structure and collapses, causing significant shrinkage of the meat, which causes the expulsion of meat from the meat by compresses forces. The third stage of cook loss occurs at around 70°C and corresponds to the denaturation of actomyosin, which significantly reduces its ability to bind water.

The cook losses were found to not be very time dependent. The cook losses increase rapidly within the first five minutes of cooking as the meat is heated up to temperature and it takes a few minutes for the cook loss too diffuse out. After ten minutes cooking about 80% of the total cook loss occurs (for one hour cooking). As any protein denaturation that is going to occur at a given temperature occurs quite rapidly. Any slight increases in cooking losses after ten minutes are believed to be due to diffusion limiting processes slowing the release of any cook loss.

6.4 Optimal cooking

It has been shown that about 69% of the total cook loss (when cooked at 75°C or higher) is associated with the denaturation of myosin (and collagen shrinkage) and the other 31% due to actomyosin. As myosin denatures at the relatively low temperature of 50°C (relative to usual cooking temperature for meat), this cook loss associated with myosin and collagen denaturation is inevitable. However it is possible to minimise the further cooking loss caused by actomyosin denaturation. If the temperature of the meat

is kept significantly below 70°C the amount of actomyosin denatured will be minimal hence the cook loss can be reduced (i.e. cook at a temperature of 60°C to 65°C).

The tenderness of meat is optimal also at a temperature of around 60°C, which is high enough to cause collagen denaturation and also corresponds to the temperature at which cook loss from actomyosin denaturation is minimised. Therefore meat cooked at this temperatures will have optimal tenderness and yield.

For health and safety concerns a 7D bacterial death has to be achieved for cooked meat products. Cooking at 60°C requires cooking for 12 minutes, while cooking at 65°C requires cooking for 1.45 minutes. Bacterial death is also temperature dependent but it must be remembered that the functional properties change very significantly with temperature. A high cooking temperature will achieve the desired bacterial death in a short period of time, but will be at the detriment of the functional properties. Where possible a cooking temperature of 65°C should not be exceeded to prevent excessive detrimental effects to the functional properties of tenderness and cook yield.

6.5 Nutritional properties of export lamb

By breaking down the products produced from the lamb saddle into their constituent components, collecting product yield data and nutritional data enabled the nutritional easy characterisation of many export lamb products. By combining the yield data (how much of a constituent component is contained within a selected cut) and the nutritional properties of the constituent component the nutritional properties of the saddle cut in interest can be calculated.

It has been found that the major source of variation is the ratio of lean tissue to fat tissue. The different types of lean tissue within the saddle region (loin eye from shortloin and rack section and tenderloin) are very similar in terms of nutritional properties and carcass grade doesn’t make any significant difference. The main difference of concern between grades as regards nutritional properties is the fat tissue to lean tissue ratio, which is different for different carcass grades.

This method of breaking down selected cuts into their constituent components should also work for other portions of export lamb i.e. hindquarter and forequarter sections. Adequate nutritional information for lean and fat tissue from the hindquarter region is already available from the USDA food composition database. Yielding information would have to be collected for these sections to be characterised and to assess the effect of grade on these sections.

The method should also work for other species such as beef, venison and pork. Unfortunately no literature for New Zealand products of these species could be found. Some cuts from other species like beef also contain a significant amount of intermuscular fatty tissue (i.e. fat between muscle seams). This intramuscular fat would have to be yielded out to see how much it varies and consequentially how much it effects the nutritional characteristics of these cuts.

It would be worth investigating all the lamb grades for the products that are to be sold, as it may be found that even though there are differences for lean to fat ratios for grades, they might not be large enough to warrant separate labels. This means that it may be possible to use one label for each type of product, instead of different labels for each product from different grades. An example of this is for lamb racks, for PX grade racks the fat level was 33g/100g whereas for YX grade lamb it was 31g/100g. This difference is minimal, similar comparisons arise when comparing other nutrients for the two grades as can be seen in table 6.1.

Nutrient	**YX Rack Section**	**PX Rack Section**
Mandatory	Per 100g	Per 100g
Protein (g)	15.00	14.55
Fat (g)	31.02	33.07
Carbohydrate (g)	0.00	0.00
Sugars (g)	0.00	0.00
Dietary Fibre (g)	0.00	0.00
Calcium (mg)	10.00	10.00
Iron (mg)	1.44	1.42

Sodium (mg)	97.75	99.09
Saturated Fat (g)	15.48	16.51
Cholesterol (mg)	84.44	84.77
Calories	339.17	355.86
Voluntary		
Zinc (mg)	1.71	1.66
Phosphorous (mg)	128.99	123.63
Niacin (mg)	4.95	4.80
Thiamine (mg)	0.11	0.10
Riboflavin (mg)	0.25	0.24
Vitamin B6 (mg)	0.10	0.09
Vitamin B12 (μg)	1.72	1.68

Table 6.**1** Nutritional properties of YX and PX grade rack section.

Due to the differences in nutritional properties being minimal it may be better to use one label for both grades which complies for both (i.e. if a label assigned for a PX grade product was placed on a YX grade product compliance would still be met). This would reduce the number of different types of label that would need to be used/produced and would allow easier implementation into a processing plant. This would be because all products processed to the same specifications would use the same label and grade differences wouldn't have to be worried about, which means less chance of erroneous labeling in a production/processing environment.

Chapter 7
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Chapter 8
Appendix

Nutritional properties of selected products from the saddle and rack section of New Zealand export lamb, for PX and YX grade lambs can be found on the attached cdrom.

8.1 List of Products:

Shortloin Section 75mm

Rack Section 75mm

75mm Rack frenched 25mm (for both cap on and off)

Tenderloin and Boneless loin

8.2 List of attached files

All peak

All peak data contains the data that was collected for yield and peak force, cook loss, shrinkage. It was the data that was used to remove the effect of animal variation from the functional properties of the selected muscles using the SAS statistical package.

Animal Functional Data

Contains graph of the averages for the muscle functional properties for all ten animals i.e. peak force, shortening e.t.c. Also compares average functional properties for the muscles to the compositional properties on other graphs. Also contains graphs for each separate muscle functional properties for the ten different animals tested.

Average data SAS models and predictions

Contains comparisons between the experimentally measured data and the model predictions for peak force and cook loss.

Bacterial Death

Contains the bacterial death kinetic data, table and graph form.

Functionality with carcass variation removed

Show's graphs of averages and standard deviations with animal variation removed.

Heat transfer models

Models the heat transfer in meat strips.

INF parallel to fiber length

Functional properties of INF cooked at temperatures with fiber direction parallel to strip length.

INF perpendicular to fiber length

Functional properties of INF cooked at temperatures with fiber direction perpendicular to strip length.

Process Ranking and added value

Shows process ranking parameters for each muscle and subsequent potential to add value score.

PX Grade Nutritional Information

Shows nutritional properties of various PX grade export lamb cuts.

YX Grade Nutritional Information

Shows nutritional properties of various YX grade export lamb cuts.

rdi compare

Compares the nutritional value of lamb loin lean tissue from various studies on a recommended daily intake basis.

TBL parallel to fiber length

Functional properties of TBL cooked at temperatures with fiber direction parallel to strip length.

TBL perpendicular to fiber length

Functional properties of TBL cooked at temperatures with fiber direction perpendicular to strip length.

Nutrient data for lamb saddle constituent components

Contains nutritional information for the constituent components from export lamb saddle region.

8.3 Document statistics

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