Factors affecting carcass composition and beef quality have been outlined in this chapter by looking at ways in which the true value of two finished cattle-beasts can differ at the same final live weight, and at the same time and place.

True value is taken to be determined by the quantity of lean saleable beef produced, the quality of that beef, and the value of other products, but only the first two items have been expanded on here.

One animal will yield more beef than another if its dressing-out % is greater, if carcass fat % is lower, or if carcass muscle to bone (M:B) ratio is higher, but superiority in any one of these could be offset by inferiority in one or more of the others. Other composition characteristics of direct or indirect importance include the distribution of muscle over the carcass, the partitioning and distribution of fat, and carcass shape.

Superiority of an animal in terms of beef quality cannot be described so easily because of the multiple components of meat quality, and the wide variation in consumer preferences. It is further complicated by quality differences between muscles within the same carcass, and because of the many ways in which meat quality can change post mortem. The focus here is on those quality characteristics that consumers most frequently find unsatisfactory, including beef tenderness, flavour, meat colour, fat colour, juiciness and fat content.

Ways in which one animal might be superior to another in terms of carcass composition have been considered in terms of breed makeup, genetic merit within a breed, gender, what and how much is fed, whether or not the animal receives growth promotants, and the length of the pre-slaughter holding time. The most common reason for higher yields of beef per unit live weight is a lower carcass fat %, but there are also instances of where higher yields are due primarily to a higher dressing-out % or a higher M:B ratio.

Reasons why beef from one animal might be of better quality than that from another (assuming constant post mortem conditions) have been
discussed in terms of differences in age, breed or breed cross, genetic worth for meat quality within a breed, gender, nutritional background, and treatment during the pre-slaughter period. Making generalisations in this area is hazardous because an on-farm treatment that has a significant effect on quality under one set of post mortem conditions (e.g. ageing times, cooking conditions) may have no discernable effect under another.

It is concluded that there are many opportunities to increase the proportion of cattle with desirable carcass and meat attributes. An important development that will encourage such changes is the continued move towards a more accurate evaluation of the true worth of animals by processors so that this information can be passed back to the producer and can also be used as the basis of a more precise payment system.

Ensure primals are managed appropriately prior to them leaving the farm for slaughter.

Introduction
This chapter discusses some of the factors affecting carcass composition characteristics and meat quality characteristics for beef cattle. Taken together, these two groups of characteristics make a major contribution to the true value of a beef animal at the time of slaughter.

The effects of various factors on this true value through these characteristics are described by comparing two animals of the same weight at the time of slaughter and in the same place at the same time. In this way, fluctuations in values with changes in supply and demand over time and at different places are excluded. Although comparisons will be made here between two individual animals, it is important to appreciate that most of the effects described are based on averages of groups of cattle. So, it can be expected that some individuals within any group will not comply with the generalisations made.

Unfortunately, the true values of any pair of cattle are not always matched by the prices actually received for a number of reasons, not the least of which is the fact that many of the characteristics determining true value (as outlined below) can not be measured satisfactorily at the time the price is decided.

Characteristics to be considered here that make the true value of one animal exceed that of another, include the yield of saleable beef, and/or the quality of that beef. In addition their relative values will depend on the size and quality of non-carcass components such as the hide and the offal (Figure 1), and also of non-meat parts of the carcass (mainly excess fat and bone), but these aspects will not be considered here. Note, however, that there is continuing interest in increasing the value of many of these non-traditional and non-beef sources of income from the beef processing industry (1)
Figure 1: The true value of an animal at the time of slaughter will be determined by the yield of saleable beef, the quality of that beef, and the value of non-beef co-products.

Saleable meat yield
Saleable beef is defined here as the boneless product with no visible fat except intramuscular or marbling fat, although it is recognised that consumers frequently see meat on sale containing some subcutaneous or intermuscular fat. However, the growing trend in most countries is to remove all such fat before placing beef on display. Even when some is present at the time of sale, it is frequently removed before the beef is consumed, either before or after cooking.

Figure 2: Subdivision of the beef-animal body into its component parts of importance to beef production.

The saleable meat yield (SMY%) refers to the weight of saleable meat as a percentage of carcass weight. The dressing-out % (DO%) is carcass weight as a percentage of live weight, so saleable meat weight as a percentage of live weight is SMY% multiplied by DO%. As defined here, SMY% is also equal to lean meat yield (LMY%) (Figure 2).
Although variation in DO% can clearly affect the yield of beef per kg of live weight (Figure 2), values obtained for DO% need to be interpreted with caution because they are heavily dependent on the level of gut-fill at the time the live animal was weighed. Gut contents can make up as much as 12 to 15% of live weight so it is to be expected that DO% will tend to be higher (due to a lower gut-fill) for cattle on a lower level of nutrition, for those on a diet that is highly digestible, or for cattle that have been removed from feed for a longer period. For example, for a group of 40 steers at Massey University averaging 508 kg, the DO% based on their weight less than 2 hours off pasture was 50.6%, while the value provided by the meat plant after being held overnight was 54.6% (17). (Refer Chapter 11, Table 1).

**Figure 3**: This graph shows how the SMY% decreases with increasing carcass fat%, but at any given fat%, it will be higher when the M:B ratio is higher. The equation used to produce these lines is SMY% = (100 − fat %) x (M:B)/ ((M:B) + 1)

![Graph showing the relationship between SMY% and carcass fat%](image)

Beef carcasses are made up of muscle, fat, and bone with fat being the most variable component in most situations. Since the relationship between muscle and bone is less variable, it is commonly expressed as a muscle to bone ratio (M:B) because this will be unaffected by changes in fat%. A useful way of expressing SMY% is as a function of fat% and M:B ratio (Figure 3). This shows that the only ways in which SMY% of one animal can exceed that of another is by having either a lower carcass fat% or a higher M:B ratio.

Dressing-out percent and SMY% are the two composition characteristics that most often differ between animals. There are, however, some other aspects of composition that are of commercial importance and that may differ between groups of cattle in some situations. Examples include:
• **Muscle distribution:** This would favour an animal, if it had a higher proportion of total muscle in the high-priced cuts. Evidence suggests, however, that variation in muscle distribution between different types of cattle is very limited (2), so there is little scope for improving this potentially important characteristic.

• **The way in which total fat is partitioned between fat depots, or distributed within a depot:** These characteristics are of commercial importance for several reasons. For example, if one animal had a lower proportion of total fat in the non-carcass depots it would have a higher dressing-out percent (other things being equal). Likewise, if a greater proportion of its carcass fat was in the subcutaneous depot (the fat immediately under the skin), and carcass classification was based on a depth of subcutaneous fat, then this animal’s carcass would be classed as over-fat at a lower total fat% if carcass classification was based on assessments of subcutaneous fat depth, as is commonly the case.

• **Muscularity:** This is a characteristic that is often closely related to M:B ratio. However, whereas M:B is the ratio of the weights of muscle and bone from a carcass or cut, muscularity is the depth of muscle relative to a bone dimension such as a bone length. Usually carcasses with a high muscularity will also have a high M:B ratio, but this is not necessarily the case. For example, if two animals had the same M:B ratio, but the bones of one are longer and finer, then that animal would have a lower muscularity score. As a consequence, if M:B ratio was evaluated from visual assessments of muscularity as is commonly done, then the carcass of that animal may be placed in a lower muscularity class even though its M:B ratio was the same. At present there is limited information on the extent to which the relationship between muscularity and M:B ratio differs between classes of cattle. But, with the availability of objective methods of measuring muscularity, such information should become increasingly available (3). In addition to being a useful indicator of M:B ratio (and therefore SMY%), muscularity also affects the thickness of cuts relative to their weight, which may be commercially important in some situations.

**Meat quality**

Compared with SMY%, meat quality is a more difficult characteristic to tie down and explain because it is ultimately determined by the perceptions of the person who consumes the beef, and it is well known that such perceptions vary from person to person and also for the same person at different times and on different occasions. This “moving-target” problem can be overcome to some extent by splitting the overall concept of meat quality into a number of components that can be measured and studied separately (Table 1). Although
this is commonly done, it is important to remember that it is the overall eating-experience that needs to be maximised and then maintained.

**Table 1:** Characteristics of beef from one animal that may be responsible for it being of higher quality than beef from another. The characteristics are divided into five categories with examples of specific characteristics within each category.

<table>
<thead>
<tr>
<th>Quality Characteristic</th>
<th>Forms of the characteristic that are preferred</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appearance Characteristics:</strong></td>
<td></td>
</tr>
<tr>
<td>Lean meat colour</td>
<td>□ A strong bright red colour is favoured in most markets although lighter colours are preferred for some specialty products such as veal.</td>
</tr>
<tr>
<td></td>
<td>□ Undesirable colours include beef that is too dark (usually due to a high ultimate pH), too brown (due to oxidation), or too light (due to freezer burn).</td>
</tr>
<tr>
<td></td>
<td>□ Both pre-slaughter and post mortem treatments affect lean colour.</td>
</tr>
<tr>
<td>Fat Colour</td>
<td>□ Market preferences vary, but generally yellowness and pinkness are associated with lower quality.</td>
</tr>
<tr>
<td></td>
<td>□ Yellowness of fat is affected by nutrition and also by age and genetic factors.</td>
</tr>
<tr>
<td></td>
<td>□ Pinkness of fat is less common and may be indicative of poor health.</td>
</tr>
<tr>
<td>Meat texture <em>(fineness or coarseness of the cut surface)</em></td>
<td>□ Fine-textured meat is usually favoured but not very strongly.</td>
</tr>
<tr>
<td></td>
<td>□ Coarse texture may be indicative of an older animal or of meat with a higher connective tissue content.</td>
</tr>
<tr>
<td>Firmness <em>(the ability of a cut to maintain shape on display)</em></td>
<td>□ Meat that looks as though it has been freshly cut will usually be favoured.</td>
</tr>
<tr>
<td></td>
<td>□ Firmness is influenced by several intrinsic features including pH, water-holding capacity and fat content.</td>
</tr>
</tbody>
</table>
| Composition  
(mainly in terms of fatness) | □ For most consumers the trend has been to favour lower levels of fat, with levels of marbling fat an exception for some consumers.  
□ Low levels of bone are favoured for those cuts containing some bone.  
□ Composition at retail is determined by pre-slaughter as well as processing factors. |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Palatability Characteristics:</td>
<td></td>
</tr>
</tbody>
</table>
| Tenderness  
(the force required to bite through a piece of beef) | □ More tender meat is usually favoured, provided it is not mushy.  
□ In many surveys tenderness is the feature of beef that consumers are most often dissatisfied with.  
□ Although much is known about characteristics of beef that affect tenderness, it is seldom possible to account for all the measurable variation.  
□ Treatments that can affect tenderness have been identified at many stages within the overall business of beef production and processing. |
| Flavour  
(this includes the separate sensations of taste and colour) | □ Preferences for flavour vary widely and are often influenced by previous experiences and by cultural background.  
□ Differences in odour are generally detected with greater sensitivity than differences in taste.  
□ Flavour is primarily influenced by treatments and events prior to slaughter and during cooking |
| Juiciness  
(the perception of moistness) | □ Juiciness is determined by both the water content after cooking and by factors that increase salivation, such as marbling fat.  
□ An intermediate juiciness is often preferred.  
□ Beef that is more juicy is often, but not invariably, more tender. |
**Nutritive-Value Characteristics:**
Lean beef is generally considered to have a high nutritive value for several reasons, including:

- It has a high protein to energy ratio, and the protein is of high quality.
- Lean meat is highly digestible, but because of this is a poor source of fibre.
- It is an excellent source of iron and zinc, and the iron in meat is particularly well absorbed by humans.
- Beef is a good source of B vitamins, and is one of the few available sources of vitamin B12.
- Lean pasture fed beef usually has a low fat content compared to grain feed beef and only 25-40% of the fatty acids present are saturated. In addition it has high levels of Omega-3 fatty acids compared to grain fed animals. This could be a significant human health benefit.
- Lean beef contains cholesterol, but only in moderate concentrations (about 70-80mg/100g).

**Processing Properties of Beef:**

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-holding capacity</td>
<td>Higher values are generally favoured as they are usually associated with better juiciness and tenderness.</td>
</tr>
<tr>
<td></td>
<td>Mainly of importance in processed products such as hamburgers and sausages.</td>
</tr>
<tr>
<td>Binding capacity</td>
<td>Important for reformed products where pieces of beef are moulded together.</td>
</tr>
</tbody>
</table>

**Safety and Wholesomeness Characteristics:**

Although this topic will not be covered here, it is important that beef products be as safe and as wholesome as practically possible. This means that microorganisms (mainly bacteria) that cause disease or spoilage should be controlled, that residues from medications or dietary components be absent, and that no item that affects the wholesome appearance of the meat (e.g. specks of dirt or rust, bone chips, etc) be present.
A further complication for meat quality characteristics is that they vary widely from muscle to muscle within the same carcass, and factors that have a major effect on the quality of one muscle or cut may have little or no effect on another. This problem does not exist to the same extent for composition-related characteristics.

In considering factors that may be responsible for differences in the quality of beef from two similar animals, the focus will be on the appearance and palatability characteristics outlined in Table 1. Nutritive value characteristics will receive some mention as they are becoming increasingly important to the average consumer, but generally the nutritive value of lean beef is consistently high and much less variable than characteristics such as tenderness or colour.

It is crucial to the meat industry that the safety and wholesomeness of beef is maintained, at the current high levels, by the continuing development of comprehensive inspection and hygiene standards. The requirements in this respect are well known and clearly laid out (4), but will not be considered further here.

The components of beef quality listed in Table 1 are intrinsic properties of meat that can be assessed for any sample of beef given the appropriate facilities. The perception of beef quality by consumers, however, is not determined totally by intrinsic properties. Extrinsic properties that require information about where the meat came from are becoming increasingly important to some consumers. Examples of such extrinsic aspects, that are usually not measurable on a piece of meat, include the type of farming system (e.g. organic farming practices), how the cattle were treated (particularly during the pre-slaughter period, and whether or not the cattle had received hormonal growth promotants (5). A definition of beef quality incorporating these concepts is given in Figure 4.

**Figure 4:** A definition of beef quality.

“The combination of all those intrinsic and extrinsic characteristics of a beef product that determine or affect its level of acceptability for a consumer.”

To conclude this introductory section it can be re-stated that the relative true values of beef animals of the same live weight at a particular time and location will be primarily determined by the relative yields of saleable beef and by the quality of that beef. Each of these aspects can be subdivided into a number of components, so that in considering the factors that may be responsible for one animal having a higher true value than another, any factor that affects any component should ideally be taken into account. The remainder of this chapter considers some of these factors, first for composition characteristics, and then for beef quality characteristics.
Factors affecting saleable beef yield

It is assumed that saleable beef is made up entirely of lean beef with no bone and essentially no visible fat except marbling fat. For the yield of saleable beef from one animal to be greater than that from another of the same final weight it would have to have either a higher dressing-out %, or a lower carcass fat % or a higher carcass M:B ratio or some combination of these. Conversely, changes in any of these three characteristics in the opposite directions will push SMY% down. For a farmer selling on the basis of carcass weight and class or grade, the rewards for a better dressing-out % are direct because there will be more carcass weight per kilogram of live weight. But rewards for lower fat % or better M:B are more problematical, as they are dependent on these characteristics being assessed accurately during carcass classification.

In considering the composition characteristics of importance, it is useful to group them according to when the effect is exerted, as outlined in Figure 5.

**Figure 5:** Points of difference between two beef animals of the same final live weight that may be responsible for differences in the weight of beef produced, and for differences in other composition characteristics of commercial importance.
A number of generalisations will be made in this section with regard to the seven points listed in Figure 5. Generalising about these factors is a risky undertaking, because the results from different trials have not been totally consistent. Often there are no clear reasons for these inconsistencies, but sometimes they can be explained on the basis of interactions between the different factors of Figure 5. Two examples of such interactions are as follows:

1. High levels of nutrition are more likely to lead to higher carcass fat% levels at a set carcass weight for those cattle that have a lower capacity for lean-tissue growth. Thus, late-maturing cattle and bulls are less likely to be affected than early-maturing cattle and heifers, respectively.

2. Increasing the protein to energy ratio in the diet is more likely to lead to a lower carcass fat% at a set carcass weight for cattle early in their life, or at a lighter weight, than for cattle in the finishing phase of growth when protein levels in the diet have little effect.

All the body composition characteristics of interest change markedly as cattle grow and develop. So, to make a valid assessment of whether a treatment or a type of animal has an effect on carcass fat% or any other composition characteristic, the comparison between the two groups of interest should be made at the same carcass weight. Otherwise it is difficult to determine whether any differences in composition are due to the weight differences or to treatment effects. The principal ways in which composition changes with increasing weight for cattle can be summarised in general terms as:

- Dressing-out % increases gradually with increasing weight.
- Carcass fat % increases markedly with increasing weight.
- Carcass M:B ratio increases slowly with increasing weight.
- Changes in carcass SMY% (shown as carcass lean % in Figure 6) with increasing weight are difficult to predict because they will be the net outcome of increases in M:B ratio, which will push SMY% up, and increases in fat%, which will pull SMY% down.
- With increasing weight there is an increase in the proportion of total fat in the subcutaneous depot.
- A number of changes in muscle distribution occur as weight increases, with, for example, decreases in the proportion of total muscle in the distal limb muscles and an increase in the proportion as abdominal muscles (2). The proportion of muscle in the high-priced cuts declines gradually.
- Muscularity and other measures of carcass shape show that carcasses become more “blocky” with growth.
**Figure 6:** Changes in three key carcass composition characteristics of Simmental bulls and steers as live weight increased from about 200 to 650 kg (6).

**Breed and breed-cross effects on composition**
An animal from a later maturing breed such as Charolais, Simmental or Maine Anjou will generally yield more beef at the same live weight than another animal of the same weight of an early maturing breed such as Hereford, Angus, Shorthorn or Murray Grey. This is because the later maturing breed is at a lower proportion of its mature weight, and hence has a lower carcass fat % (7,8,9). The same would apply to a lesser extent to crossbred progeny sired by bulls from these same breeds.
Alternatively, a double boost to SMY% may be provided if the animal was from a late maturing breed that also excelled in M:B ratio, such as the Limousin or Blonde Aquataine, \(^8,^9\).

A more extreme difference in terms of a low fat% and high M:B would be expected if the beef animal was from a breed with a high incidence of the “double-muscling” condition (the muscular hypertrophy or myostatin-deficient gene) such as the Belgian Blue or Piedmontese \(^10,^{11}\).

Breed differences in dressing-out% generally arise from positive associations between dressing-out % and both carcass fat% and carcass M:B. In some cases these two effects will cancel each other out, but in the case of double-muscled cattle the M:B effect dominates so that dressing-out % values are significantly elevated, despite the low levels of carcass fat \(^10\).

For dairy breeds (most work has been done in this area with the Friesian), the yield of beef at the same final live weight as a beef-breed animal will often be lower because of a lower dressing-out % (due in part to a higher proportion of fat in the non-carcass depots), and a lower carcass M:B ratio. However, it is also likely to have a lower carcass fat%, so it may yield more beef if the comparison with the beef-type animal is made at heavier weights \(^7,^{19}\). Some of these points are illustrated by the results from France shown in Table 2 \(^12\).

**Table 2:** Breed differences in composition characteristics for steers of a similar weight (adapted from \(^12\)). In the first row the yield of lean meat is expressed as a percentage of the empty body (EB) weight. The dressing-out % values are also based on EB weight.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Holstein</th>
<th>Angus</th>
<th>Limousin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lean meat (% of EB)</td>
<td>39</td>
<td>35</td>
<td>50.5</td>
</tr>
<tr>
<td>Dressing-out %</td>
<td>63.1</td>
<td>66.7</td>
<td>67</td>
</tr>
<tr>
<td>Carcass muscle % (SMY%)</td>
<td>63.2</td>
<td>52</td>
<td>72.5</td>
</tr>
<tr>
<td>Carcass fat %</td>
<td>21.4</td>
<td>20</td>
<td>14.6</td>
</tr>
<tr>
<td>Carcass bone %</td>
<td>15.4</td>
<td>11.8</td>
<td>12.9</td>
</tr>
<tr>
<td>M:B ratio</td>
<td>4.11</td>
<td>5.00</td>
<td>5.61</td>
</tr>
</tbody>
</table>

The data in Table 2 show that the Holstein and Angus groups had similar yields of lean meat at the same EB weight, which indicates that the poorer dressing-out% and M:B ratio for the Holstein group were compensated for by a lower carcass fat%. The Limousin group, on the other hand, had an
appreciably higher yield of lean meat at the same EB weight than either of the other groups because they had the highest dressing-out %, the lowest fat %, as well as the highest M:B ratio. That is, all three of the determinants of meat yield from whole body weight favoured this breed.

Within-breed genetic effects on composition
Whether or not changes in composition can be made within a breed by genetic selection will depend mainly on the heritabilities of the composition characteristics in question, the ease with which they can be measured on the live animal, and the amount of genetic variability in the population of interest. For beef cattle the biggest problem is with measuring relevant characteristics in live cattle. The main options are the use of ultrasound to measure fat depths (as an indicator of carcass fat %) and eye-muscle areas (as measures of M:B ratio or muscularity). Unfortunately the accuracy with which these measures reflect SMY% is not particularly high, with one study involving 1602 steers showing, for example, that eye-muscle area accounted for only 19% of the variation in SMY%, while fat depth accounted for a somewhat more respectable 58% of the variation in the same trait \(^{(13)}\). Heritability estimates for these characteristics, however, are generally moderate (e.g. 0.56 and 0.65 for fat depth and eye-muscle area, respectively, in one study involving 888 steers \(^{(14)}\)). Improvement in carcass composition through genetic selection is discussed in more detail in Chapter 8.

Composition differences between the sex/castration classes
The only sex/castration classes to be considered here are bulls, steers and heifers, although in some situations there may also be interest in cryptorchid males (where the composition is generally very similar to bulls), short-scrotum males (very similar to cryptorchids), spayed females (similar to heifers, but often slightly fatter at a similar weight), and once-bred heifers (not greatly different from comparable heifers \(^{(15)}\)).

Consistent patterns are sometimes difficult to pick out from the results of many studies comparing carcass characteristics of bulls, steers and heifers, because differences are often small and in many cases it is not possible to determine whether differences are due to the different genders or to different carcass weights. Generally, however, it is clear that at a set weight, heifers will be fatter than steers, and steers will be fatter than bulls. Differences in dressing-out % are less clear, but bulls usually have slightly higher values, and heifers may have higher values than steers if they are appreciably fatter.

Comparisons between bulls and heifers in muscularity and M:B ratio provides an interesting example of where these characteristics are not tightly linked. Thus, in a comparison of a bull and a heifer at the same weight, the bull will tend to be superior in muscularity, but the heifer is likely to have a higher
M:B ratio, possibly due to a finer bone structure (3). This could lead to a bias against heifers when their M:B ratio is assessed from a measure of carcass shape such as muscularity.

Clear sex effects on muscle distribution are apparent, with bulls having a higher proportion of total muscle in the not particularly valuable neck region (2). Several of the differences between sex/castration classes are illustrated by the data in Table 3 from an Irish trial (16). This is one of a relatively small number of trials that has included bulls, steers and heifers and that has made comparisons at a common final weight.

**Table 3:** Carcass composition characteristics of bulls, steers, and heifers at a final live weight of 560 kg (16). Because of the constant final weight, the carcass weights are indicative of differences in dressing-out %. EMA is the eye-muscle area per kg of carcass.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Feeding level</th>
<th>Bull</th>
<th>Steer</th>
<th>Heifer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcass weight (kg)</td>
<td><em>Ad lib</em></td>
<td>316</td>
<td>307</td>
<td>307</td>
</tr>
<tr>
<td></td>
<td>80% <em>ad lib</em></td>
<td>317</td>
<td>307</td>
<td>305</td>
</tr>
<tr>
<td>Fat depth (mm)</td>
<td><em>Ad lib</em></td>
<td>5.4</td>
<td>7.9</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>80% <em>ad lib</em></td>
<td>4.0</td>
<td>6.9</td>
<td>4</td>
</tr>
<tr>
<td>Carcass fat %</td>
<td><em>Ad lib</em></td>
<td>14</td>
<td>23.4</td>
<td>25.2</td>
</tr>
<tr>
<td></td>
<td>80% <em>ad lib</em></td>
<td>16.8</td>
<td>21.9</td>
<td>22.8</td>
</tr>
<tr>
<td>M:B ratio</td>
<td><em>Ad lib</em></td>
<td>4.38</td>
<td>4.28</td>
<td>4.45</td>
</tr>
<tr>
<td></td>
<td>80% <em>ad lib</em></td>
<td>4.35</td>
<td>4.26</td>
<td>4.47</td>
</tr>
<tr>
<td>Carcass SMY%</td>
<td><em>Ad lib</em></td>
<td>74.1</td>
<td>70.4</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>80% <em>ad lib</em></td>
<td>74.2</td>
<td>70.4</td>
<td>67</td>
</tr>
<tr>
<td>EMA (mm²/kg)</td>
<td><em>Ad lib</em></td>
<td>24.8</td>
<td>22.0</td>
<td>23.4</td>
</tr>
<tr>
<td></td>
<td>80% <em>ad lib</em></td>
<td>24.7</td>
<td>21.6</td>
<td>23.4</td>
</tr>
</tbody>
</table>

The results in Table 3 show that bulls had the highest SMY %, indicating that their lower carcass fat % more than compensated for the slightly lower M:B ratio. The yield of saleable meat per kg of final live weight would have
favoured the bulls even more because their dressing-out % was slightly higher (as shown by the higher carcass weights at 560kg live weight). It is noteworthy that even though the M:B ratio of the bulls was lower than that for the heifers, their EMA was higher suggesting a better muscularity. Subjective assessments of carcass conformation also favoured the bull carcasses in this study.

**Nutritional effects on beef cattle composition at a set weight**

Both the level and quality of feeding (Figure 5) can affect the yield of saleable beef per kg of final live weight. For two animals of the same live weight, breed and gender, the three most likely nutritional explanations of why one might yield more saleable beef are:

1. Because its diet was more digestible so that there was a lower level of gut-fill and as a consequence a higher dressing-out %.
2. Because it was fatter as a result of being on a sufficiently higher level of nutrition to allow fat synthesis.
3. Because it received a diet with a higher P/E (protein to energy) ratio that resulted in greater muscle growth at the expense of fat growth. Note, however, that such an effect has been demonstrated mainly with calves at an age when the capacity to use extra protein is greater. Extra protein in finishing diets for cattle has sometimes had the opposite effect because it is treated as an extra source of energy and therefore becomes effectively a higher level of nutrition.

The term “overflow” is used because it is envisaged that the protein synthesising capacity of the body becomes saturated at a certain level of nutrition so that additional nutrients “overflow” into fat tissue growth. The level of nutrition at which this takes place will tend to be higher when the protein-synthesising capacity of the animals is higher, so it might be expected to be at higher levels of nutrition for bulls, for cattle at an earlier stage of development, and for later or heavier-maturing animals. Very often the effect is quite small, as indicated by the results in Table 3 where the groups on 80% ad lib feeding for each gender group (except bull) were less fat at the same weight, but the differences were not large enough to be reflected in SMY% values.

The results of studies into the extent to which higher levels of nutrition lead to fatter animals at the same weight vary widely, which is not surprising as the response will depend on the levels of nutrition involved, the nature of the diet, and the type of cattle. In the New Zealand context, there have been several studies indicating that cattle finished before their second winter (at 15-18 months) are fatter and have shorter, more compact carcasses than cattle of the same weight that are 8-12 months older (24-30 months). In such comparisons, a level-of-nutrition effect is probably operating, but there may also be effects of diet quality and season of the year (17).
Effects of growth promotants on beef cattle composition

A growth promotant is taken here to be a non-nutritional and non-medicinal substance, which, when administered to an animal, will enhance some aspect of its growth. Most growth promotants that have been used with cattle in New Zealand have their main effect on growth rate, but there are some other substances that show potential as means of enhancing the efficiency of growth and/or the composition of growth.

Based on what is known about the ways in which they exert their enhancing effects, it might be expected that growth promotants such as oestradiol-17β (the active ingredient of Compudose®) would lead to carcasses with less fat and more muscle at the same weight, but trials have shown that such effects are small and have often not been detectable even when administration has been over an extended period (18).

Composition changes during pre-slaughter handling

Composition changes after animals are last removed from feed should be minimal with respect to levels of carcass fatness or M:B ratio provided this period is not excessively long. The main area of concern is whether there will be some loss of carcass weight as this will commonly represent a direct monetary loss. Most of the loss in live weight for the initial period following removal from feed is in the form of decreased gut-fill with no carcass weight loss. At what stage live-weight losses start to include some loss of carcass weight is the key question. The answer probably depends to some extent on how well the animals had been fed, and on the type of animals. But, on the basis of the results of one trial involving Angus and Angus-cross bulls and steers (19), at a final live weight of 550kg, an animal held off feed pre-slaughter for 6 hours would have yielded 6.9kg more carcass weight than another animal held off feed pre-slaughter for 30 hours.

Factors affecting beef quality characteristics

Comparing the quality of beef from two animals at the time of slaughter is difficult. This is because the beef will not be consumed until some time later and there are numerous ways in which the various quality characteristics can be influenced by the way it is treated during this time. Some of the periods following slaughter when quality changes may arise are listed in Figure 7. This would not be a problem if the effects of post mortem factors were reasonably consistent and predictable, but unfortunately this is not the case as the nature of the beef immediately post mortem can have a major effect on the way in which it responds to subsequent treatments. An example that would be familiar to most is the way in which beef from a high quality cut from a young animal will be most tender if it is cooked quickly at high temperatures, while a cut with a high content of connective tissue from an older animal will require long slow cooking
to achieve maximum tenderness. Thus, the extent of the difference in tenderness between two such samples will depend on the cooking method used.

**Figure 7:** Points of difference between the beef from two animals that may be responsible for differences in beef quality characteristics. This list of points needs to be considered as continuing on from the list in Figure 5. The extended list here shows that beef quality can be influenced in many more ways than composition.

The period for the first 24 hours **post mortem**, or up until the time the muscle sets in **rigor mortis** (commonly referred to as the pre-rigor period) is particularly important to meat quality because many changes are taking place during this conversion of muscle to meat. Predominant amongst these is a fall in pH (a measure of acidity) from a value around neutrality (just over pH 7) in living muscle to an ultimate pH of about 5.5. The extent of this drop, as measured by the ultimate pH, as well as the rate at which it drops, both influence several quality characteristics including tenderness and flavour.
particular concern over this period, while the muscle can still contract, is to avoid cold temperatures of below about 8°C, which can induce a muscle to contract and toughen (the so-called cold-shortening and cold-toughening effect). Once the muscle has set in **rigor mortis** it is no longer capable of contracting, so methods have been developed to hasten the onset of **rigor mortis** so that beef can be cooled sooner without needing to be concerned about this toughening. Electrically stimulating the muscles (also termed accelerated conditioning) is widely practised in the industry for this purpose.

Beef is treated in a wide variety of ways during storage (the 4th box in Figure 7), with the two most common options for New Zealand beef being freezing, or chilling at temperatures close to 0°C. Freezing has the advantage of permitting much longer storage periods before the beef is consumed, but frozen beef products are discounted on most markets relative to the comparable chilled product. Storage of meat in the chilled form has the advantage that the tenderness improves over time due to the activity of proteolytic enzymes, but this has to be balanced against the increased chances of spoilage (due to the growth of bacteria) and colour deterioration.

The conditions during the cooking of beef (the final box in Figure 7) can influence all the main quality characteristics (Table 1), with final internal temperature and time being the main cooking variables that affect final quality.

From this brief introduction it can be seen that our goal of comparing two animals at the same weight for beef quality is not straightforward. The best that can be done is to assume that the conditions during the pre-rigor period, the storage period and during cooking are representative of good commercial practise and are the same for beef from both animals. This also has its problems because the best way to treat beef will differ for different cuts of beef and for beef from different classes of animal.

A related question here is whether the demonstration of superior quality characteristics for one muscle or cut from a carcass can be taken to indicate that other muscles will show a similar superiority. For large differences in quality this will probably be the case, but there is also good evidence that relationships between muscles are far from perfect (20).

The factors beyond pre-slaughter handling in Figure 7 will not be considered here, but will be alluded to in some examples where they are relevant to the way in which factors on the farm can have an effect on beef quality. The first on-farm factors to be considered will be animal age and weight, and then the other factors will be covered as they are listed in Figure 5. All the beef quality characteristics listed in Table 1 will not be given equal emphasis however. Beef tenderness will be given priority because surveys have indicated that this is a particularly variable characteristic (20) and it is one that is very important to consumers. Some mention will also be made of other beef palatability and appearance characteristics, particularly the colour of the muscle and the fat.
Changes in quality characteristics with increasing age and weight
The age and weight of cattle under reasonable conditions will increase in parallel, but this does not necessarily mean that two beef animals of the same weight will also be the same age. Their ages could be quite different if they had been on different levels of nutrition, which indicates why it is often difficult to clearly separate the effects of age, weight, and nutrition on quality characteristics.

Over wide ranges of age and weight from, say, 120kg vealer carcasses to 350kg prime carcasses from 3-year old cattle, expected differences would include a decrease in beef tenderness (due mainly to the collagen in the muscle becoming less soluble), an increase in the redness of the beef (due to higher concentrations of the pigment myoglobin), an increased likelihood of yellow fat (due to an accumulation of carotenoid pigments), and an increased flavour and juiciness (due to higher levels of intramuscular marbling fat).

For the more relevant comparison of where two animals are both 500kg live weight, but different in age (e.g. 30 months vs. 20 months), the differences are more difficult to predict. In some cases clear tenderness differences have been shown in favour of the younger animal \(^{(17)}\), but this has not always been the case. Colour differences are unlikely for either the meat or the fat (provided their diets have been similar), but intramuscular fat levels may be sufficiently higher at the lower age, to produce detectable improvements in juiciness and flavour.

Decreases in tenderness with increasing age and weight are more apparent for muscles with a higher connective tissue content because the main causes of toughening with age appear to be changes within the collagen in this part of the muscle as illustrated in Figure 8.

**Figure 8:** Changes in beef tenderness with increasing animal age showing that the effect was less for a muscle with a low connective tissue content (psoas major from the tenderloin cut) than for one with a moderate to high level (biceps femoris from the silverside). For this study, care was taken to avoid cold-shortening. (Adapted from \(^{21}\)).
In some cases beef quality characteristics including tenderness will improve with increasing weight, probably because for larger carcasses with a greater fat cover, muscles will cool down more slowly (thereby increasing the ageing effects and minimising cold-shortening) and also because of higher marbling levels within the muscle. The fact that increased fatness is involved to some extent in such quality improvements is supported by indications that tenderness improvements with finishing are less apparent for beef from bulls than steers.

Breed and breed-cross effects on beef quality
Consistent differences in quality characteristics between the main breeds of cattle used in New Zealand are rare, partly because between-breed differences are generally swamped by the amount of variation found between animals within a breed, especially for beef tenderness (14). Examples of breeds or their crosses that have shown some superiority in beef tenderness in some studies include the following:

• Beef from an animal of a *Bos indicus* breed (e.g. Brahman, Sahiwal, and Nellore), has been shown in a number of studies to be more likely to be tough than beef from an animal of a *Bos taurus* breed (e.g. British and Continental breeds)(17, 20). The reason for this is not totally clear, but it appears to be attributable in part to higher concentrations of calpastatin in muscle from the *Bos indicus* breed. This leads to tougher beef because calpastatin inhibits the calpain enzymes that are responsible for tenderising beef by protein breakdown during ageing. This, and other possible explanations for tenderness differences in beef, have been reviewed by Oddy et al. (22).

• If an animal has the “double-muscling” gene, then beef from it is more likely to be tender than that from animals without the gene (10, 11). In this case the better tenderness appears to be associated with a lower concentration of collagen in the muscle due to larger muscle fibres, but this may not be the only explanation as sometimes the effect is not apparent.

• Several, but not all studies have suggested that slightly more tender meat may be obtained from cattle of the Jersey breed (23). There is no clear indication of why this may be so, but Jersey beef is characterised by having more intramuscular fat than beef from most other breeds.

• Based on some studies, an animal of the Japanese Waygu breed may also be expected to produce more palatable beef from the point of view of tenderness, flavour and juiciness (24).

Within-breed genetic effects on beef quality
There is considerable interest in this topic because cattle breeders are keen to improve traits, such as tenderness in their cattle, by genetic selection, having
been told repeatedly that they should take more account of what the consumer favours. The heritability of beef palatability characteristics appears to be low to moderate with tenderness being slightly more heritable than juiciness and flavour (this topic was comprehensively reviewed by Australian scientist Heather Burrow (25)), but the main difficulty is with measuring these characteristics in live cattle. Many alternative approaches have been discussed over the years, including progeny testing, performance testing of bulls by slaughtering the animals after saving semen, and more recently through the use of genetic markers such as the calpastatin gene (25). This aspect is covered in more detail in Chapter 8.

**Beef quality differences between sex/castration classes**

Results of comparisons of meat quality characteristics between the sex/castration classes have been notoriously inconsistent in the many trials that have been conducted. This provides a good example of where differences will depend on a number of other factors that have their effect on the farm, during the pre-slaughter period or post mortem (Figures 5 and 7). Some of these can be illustrated by considering the following specific situations where the quality of beef differs for animals of different genders:

- If beef from a heifer is compared with that from a steer or bull, and post mortem conditions are such that cold-shortening and toughening is possible (e.g. due to fast chilling rates and no electrical stimulation), then the quality of beef from the heifer may be better because the greater levels of subcutaneous fat and intramuscular fat of heifers will mean cooling rates within the muscles are slower. This will often be offset by the fact that heifer carcasses are smaller, but in our comparisons of the two animals it is assumed that the final live weights are the same so heifer carcasses may be slightly heavier due to greater fatness being associated with a higher dressing-out %. A similar difference might be expected between beef from a steer and a bull under the same conditions.

- If pre-slaughter conditions are particularly stressful and involve a lot of activity, beef from a bull may be more tender than that from a steer or heifer, because bulls are more likely to produce high-pH beef under these conditions, and beef with an ultimate pH above about 6.5 is characterised by being very tender. This is not a good way to achieve tender beef, however, because it clearly has negative welfare implications and the good tenderness is usually more than out-weighed by a dark colour, a less desirable flavour, and poorer keeping quality.

- Having pre-slaughter conditions as stress-free as possible can result in beef from a steer being of better quality than beef from a bull. This is because the differences in the incidence of high-pH beef will be minimal.
and differences between beef from bulls and steers in the activity of the calpain system and possibly in the nature of the connective tissue tend to favour steers for tenderness in particular. The higher level of intramuscular (marbling) fat may also favour steer beef. Results of a trial run at Massey University with Angus and Angus-cross bulls and steers (Figure 9) are shown here as an example of differences obtained in one trial where care was taken to avoid cold-shortening conditions (26). It should be noted, however, that much smaller differences have been shown in some other comparisons.

**Figure 9:** Results showing greater toughness of beef from bulls (expressed relative to steers at 100) based on a sensory panel (toughness) as well as two mechanical measures of toughness (WB peak force and MIRINZ) for samples from 117 animals.

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**Nutritional effects on beef quality**

Nutritional effects can again be divided into the effects of the level of nutrition and the effects of the composition of the diet. In both cases there will often be an effect on growth rate, so that in order to compare two animals at the same weight they will be at different ages. It is quite possible that even at the same weight they will have a different level of fatness (as discussed above) so it is often difficult to distinguish between indirect effects of a nutritional treatment through differences in age and/or fatness, and direct effects (e.g. of specific nutrients).

Not surprisingly, many trials have been conducted in this area and it is not possible to do justice to all the results that have been published, because for just about every significant effect that has been reported it is possible to find another similar trial where the effect did not occur. The discussion here is confined to a brief outline of a limited number of effects that have arisen with reasonable consistency, that would lead to beef from one animal being superior in one or more ways to that from another because of the amount of feed it received or because of the nature of that feed:
• If one animal is fed in such a way that growth rates for the few months before slaughter are higher than those for another, some evidence suggests that the beef from the former animal is likely to be more tender (22, 26). If the higher growth rates are the result of a high-grain ration (as is usual on a feedlot) the flavour of the beef will differ as well, but whether or not one is preferred will depend on the consumer involved (27). The greater tenderness may be due to several factors, but higher levels of marbling, and slightly more soluble collagen have both been suggested as possible causes (22).

• The effects of specific nutrients on beef flavour are less common than for meat from monogastric animals such as the pig because of the neutralising effects of rumen metabolism, but some flavour effects have been reported, such as that associated with grain feeding (22). Technologies to encapsulate flavour compounds so they are protected from breakdown in the rumen are also now available.

• Fat from an animal is less likely to be yellow if its diet contains lower levels of carotenoid pigments (particularly ßcarotene and lutein). These pigments are in high concentrations in fresh spring and autumn pastures and yellow fat is more likely to result if, in addition, the animal is a Jersey or Jersey-cross, and if it is older. Inclusion of vitamin E in the diet for a period of a few weeks prior to slaughter will increase the shelf life of the beef produced if levels of this vitamin in the diet are low. This is through its anti-oxidant properties which inhibit the conversion of the red myoglobin pigment of beef to a brown colour, and slows the formation of rancid flavours from some meat lipids (22, 28). Vitamin E levels in fresh pasture are moderately high, which means that supplements are unlikely to have much effect.

• There is evidence that the levels of some desirable lipids in beef can be manipulated to some extent by diet. Of particular interest are certain members of the conjugated linoleic acid (CLA) family that have anti-cancer properties, and certain omega-3 polyunsaturated fatty acids that can help combat heart disease (28).

• If an animal is fed very poorly during the period leading up to slaughter, its muscle glycogen levels may be depleted to the extent that beef ultimate pH is above normal. This can affect a number of quality characteristics as explained in the section below on pre-slaughter handling. High growth rates over the 2-3 weeks before slaughter will ensure that on average the muscle glycogen levels are adequate, thereby reducing the potential effects of pre-slaughter handling (see below) on ultimate pH. This in turn will result in a higher proportion of cattle having a desirable low ultimate pH and good lean colour.
Effects of growth promotants on beef quality
The growth promotants available for use with cattle in New Zealand can be classified as either hormonal growth promotants (HGPs) or non-hormonal growth promotants such as rumen modifiers (e.g. monensin sodium) and appetite stimulators. The latter group do not appear to influence meat quality, and effects of the HGPs are also generally small, although where effects have been shown, they indicate that tenderness and sometimes juiciness is less acceptable following HGP use. This is particularly the case when repeat implants of HGPs are used, possibly because of the reduced levels of marbling \(^{18,28}\).

Pre-Slaughter handling effects on beef quality
Handling during the pre-slaughter period (that period after the animal is last removed from feed) is thought to have an effect on beef quality mainly through an effect on the ultimate pH of the beef (Figure 10) by means of glycogen-depleting events during this period.

Figure 10: A flow diagram showing that whether or not glycogen-depleting events affect ultimate muscle pH (pHul).
that started the pre-slaughter period with a muscle glycogen at only 1%, would have a muscle glycogen of 0.4% following a 0.6% glycogen-depleting event, while an animal that started with 1.8% glycogen would have a muscle glycogen level of 1.2% following the same event. This means that the same event has no effect on the ultimate pH of the latter animal but results in the former animal having a significantly elevated ultimate pH. If, however, the latter animal was exposed to an additional 0.8% glycogen-depleting event following the initial event, then it would have only 0.4% of glycogen at slaughter and would also have a significantly elevated ultimate pH.

For most purposes an elevated ultimate pH results in beef of lower overall quality although some of the individual quality characteristics may be improved for certain purposes. Relative to beef with a normal rested ultimate pH of about 5.5, beef with an elevated ultimate pH will be characterised by:

- A darker colour, especially when the ultimate pH is above about 6.2. This effect has given rise to the term “dark-cutting beef”.
- A blander and usually less acceptable flavour. If foreign flavours are present, these become more apparent when the basic beef flavour is weaker.
- A shorter shelf life because some spoilage bacteria grow better at the higher pH and because fewer bacteria are needed to produce off-flavours when the pH is higher.
- A higher water-holding capacity, which may be an advantage for beef to be used for manufacturing purposes.
- Being tougher if the ultimate pH is in the intermediate range (pH of 5.8 to 6.2), but as tender or more tender than an animal with a pH of around 5.5, if a high pH exists (pH of 6.5 to 7.0). This relationship between toughness and ultimate pH, with an intermediate maximum, is not as clear-cut as for other characteristics and has not been apparent in some studies.

Overall, the aim during the pre-slaughter period, apart from maximising the welfare of the animals, should be to minimise the likelihood of elevated ultimate pH values. This can be done by a combination of having cattle accustomed to being handled, by avoiding excessively long holding times, by minimising potentially stressful situations (strange noises and sights, frantic activity, and mixing with strange animals), and by feeding animals well prior to this period so that muscle glycogen levels are not depleted or marginal. Bring cattle off pasture 4 hours or more before transport so they are easier to handle. However, minimise the fasting period to less than 8 hours to avoid carcass weight losses. Alternatively, provide hay, haylage or silage to avoid weight loss and improve behaviour. Keep yards, gates and loading ramps in good order and have water available. Make sure stock are collected on time (29).
References


