Beef production potential of Norwegian Red and Holstein-Friesian bulls slaughtered at two ages

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(Received 2 March 2007; Accepted 15 August 2007)

There is a paucity of data on the beef production potential of Norwegian Red (NOR) compared with ‘modern’ Holstein-Friesian (HF) cattle. The present study used a total of 64 bulls in a $2 \times 2$ factorial design study encompassing two breeds (HF and NOR) and two slaughter ages (485; E, and 610; L, days). The mean initial age and live weight of the HF bulls were 179 (s.d. 47.1) days and 203 (s.d. 64.0) kg, while the corresponding data for the NOR bulls were 176 (s.d. 39.7) days and 185 (s.d. 63.6) kg, respectively. Bulls were offered a 50 : 50 mixture (dry matter (DM) basis) of grass silage and concentrates. No breed \times slaughter group interactions were recorded for any parameters evaluated ($P > 0.05$). HF bulls had higher ($P < 0.001$) DM intake and poorer ($P < 0.01$) efficiency of conversion of food to carcass gain than NOR bulls. HF bulls tended ($P = 0.07$) to have a higher rate of live-weight gain and were heavier ($P < 0.001$) at slaughter than NOR bulls, though both carcass weight and rate of carcass gain did not differ between the breeds ($P > 0.05$). NOR bulls had higher ($P < 0.001$) dressing proportion and carcass conformation score than HF bulls, while breed of bull had no influence ($P > 0.05$) on carcass fat classification, depth of subcutaneous fat, marbling score or on the weight of fat in the internal depots. Daily food intakes did not differ ($P > 0.05$) across the two slaughter age groups, though efficiency of conversion of food to carcass gain was poorer ($P < 0.05$) in the L compared with E bulls. Rate of live-weight gain was lower ($P < 0.01$) for L bulls, although rate of carcass gain did not differ ($P > 0.05$) between the E and L bulls. Increasing age at slaughter increased ($P < 0.01$ or greater) dressing proportion and carcass conformation score. Instrumental measures of meat quality indicated that meat from NOR bulls was tougher ($P < 0.01$) than meat from HF bulls, while delaying slaughter increased ($P < 0.001$) a* and $C_{ab}$* and decreased ($P < 0.01$) h0, indicating improved redness. It is concluded that NOR bulls have higher food efficiency and produce more highly conformed carcasses than HF bulls, but HF bulls produce more tender meat.

Keywords: bulls, Holstein-Friesian, meat quality, Norwegian Red, slaughter weight

Introduction

Dairy herds within the United Kingdom are based predominantly on Holstein-Friesian (HF) genetics, a breed which has developed primarily from single-trait selection procedures with little emphasis on other functional traits. However, as the intensity of selection for dairy characteristics has increased, the beef production potential of the male calves has declined, particularly when considered in terms of parameters such as carcass conformation (Keane et al., 2001).

In contrast, Norwegian Red (NOR) dairy cattle have been bred using multi-trait selection procedures, with emphasis not only on milk production but also on parameters including, inter alia, fertility and longevity (Yan et al., 2006). While the study by Yan et al. (2006) evaluated the milk production potential of NOR and HF dairy cows, there is a paucity of scientific data on the beef production potential of the NOR cattle breed when compared with ‘modern’ high genetic merit HF cattle. Such information is essential for dairy producers considering introducing a ‘dual-purpose’-type cow breed to their business and for specialist beef producers rearing and finishing cattle.

It is common practice for many of the male progeny of dairy cows in the UK to be finished as bulls, as these animals are inherently more efficient for beef production...
than similarly reared steers (Kirkland et al., 2006). Furthermore, previous studies have reported that many important beef characteristics, including carcass fatness and food conversion efficiency, are influenced by age or live weight of the animal at slaughter (Andersen and Ingvartsen, 1984a; Kirkland et al., 2006) and it is important to determine the relative differences between breeds in their response to a change in these factors.

Furthermore, the impact on meat quality is an important aspect which should be considered in any evaluation of breeds or production systems, particularly when operating in a market-driven environment for beef production. Factors such as colour and tenderness have been identified as critical components associated with meat quality by consumers (Carpenter et al., 2001; Miller et al., 2001).

The objective of the present study was to evaluate the influence of breed and age at slaughter on food efficiency, animal performance, carcass attributes and meat quality of HF and NOR bulls.

**Material and methods**

**Animals and experimental design**

A total of 64 bulls were used in a $2 \times 2$ factorial design study encompassing two breeds (HF or NOR) and two slaughter ages (target slaughter ages of either 16 (E) or 20 (L) months). The study was undertaken at the Agri-Food and Biosciences Institute (AFBI), Hillsborough, Northern Ireland. Bulls used were obtained from the Institute dairy herd, artificially reared and both breeds were treated similarly prior to initiation of the study. The animals were born to high genetic merit parentage, with HF dams representative of the top 0.5% of those in the UK and NOR dams the top 10% of the breed in Norway. The mean initial age and live weight of the 33 HF bulls were 179 (s.d. 47.1) days and 203 (s.d. 64.0) kg, while the corresponding data for the 31 NOR bulls were 176 (s.d. 63.6) kg, respectively.

Bulls were allocated nominally, within breed, to pens of three animals of similar age and retained in these pens to the point of slaughter. Bulls were blocked into blocks of two animals, within breed, according to similarity of age, and one animal from each block was allocated at random to each slaughter age treatment group (E or L).

**Diet and sample analysis**

The diet consisted of grass silage offered ad libitum, supplemented with sufficient concentrates (once per day) to achieve proportionately 0.50 of the total dry matter (DM) intake. The composition of the concentrate portion of the diet was changed when animals reached 350 kg live weight and comprised (g/kg) rolled barley 550 and 380, soya bean meal 175 and 145, sugar-beet pulp 150 and 150, maize meal 100 and 300, vitamin/mineral pre-mix 25 and 25, for concentrates offered pre- and post-350 kg live weight, respectively.

Silage DM concentration was determined daily by drying at 85°C, and the daily dried samples were bulked weekly for the determination of acid-detergent fibre (ADF), neutral-detergent fibre (NDF) and ash. Further fresh silage samples were taken once weekly throughout the study and analysed for volatile-corrected oven dry-matter (VCODM) concentration, pH, nitrogen (N), NH$_3$N (proportion of total N), lactic acid, volatile fatty acids and alcohol concentrations, and gross energy (GE). A representative sample of forage refusal for each treatment was analysed daily for oven DM concentration. Concentrates were sampled daily and bulked weekly for the determination of DM, N, ash, ADF and NDF concentrations. Chemical analyses were undertaken as described by Keady et al. (1998 and 1999).

**Measurements**

Concentrate and total DM intakes were recorded daily on a per-pen basis throughout the study, and food refusals were discarded twice weekly. All bulls were weighed on 2 consecutive days initially, at intervals throughout the study, and on two consecutive days prior to slaughter. Slaughtering was undertaken at a commercial abattoir located 26 miles from the Institute. Post-slaughter procedures, including the carcass suspension method (tenderstretch hanging technique), cooling rates and ageing were similar for all bulls slaughtered in the study.

Live-weight gain and estimated rate of carcass gain of each animal were determined by difference. Carcass gain was determined after calculation of initial carcass weight using regression equations between live weight and carcass weight for each breed. The regression relationships were developed using data obtained from different animals of each breed slaughtered at a range of live weights encompassing the range of initial live weights of the bulls used in the present study.

All carcasses were graded visually for conformation and fatness using the five-point scales of the European Carcass Classification Scheme (Kempster et al., 1982). The depth of subcutaneous fat over the eye muscle (m. longissimus dorsi) was measured at points 0.25, 0.50 and 0.75 across the width of the cross-section of the eye muscle at the 10th rib on both sides of each carcass, and the mean of these values was subsequently determined for each individual carcass. The amount of marbling fat in the cut surface of the eye muscle was assessed independently by two individuals using the eight-point scale of the United States Department of Agriculture photographic standards (Agricultural Research Council, 1965). A photograph of the cut surface of the eye muscle at the 10th rib on both sides of each carcass was taken and the area of each determined using a Delta-T Devices leaf-area machine. Weights of kidney, cod and channel fat, removed during the carcass dressing procedure, were recorded from each animal. Quantities of omental and mesenteric fat were recorded across slaughter age groups from a total of 21 HF and 23 NOR bulls.

After chilling (10°C for 10 h followed by 1°C for 24 h, before storage at between 2°C and 4°C), the fore-rib joint (6/7 rib to 10/11 rib) was removed from the left side of the
carcass of all bulls as described by Kempster et al. (1980). Instrumental measures of meat quality were undertaken at AFBI, Newforge (Belfast, Northern Ireland), using samples of longissimus dorsi muscle obtained from the fore-rib joint of each animal. For these procedures, the fore-rib was removed 48 h post mortem and two, 50-mm thick, slices of the muscle were vacuum-packed and aged for 7 days post mortem at 2°C. The sample for colour measurement was opened and a 5-mm slice removed from one surface and discarded. The remaining slice was used for colour measurement after allowing to bloom for 1 h. The vacuum pack sample for Warner–Bratzler shear force (WBSF) was opened and a central 25-mm slice taken (perpendicular to the direction of the fibres) for the determination of cooking loss and WBSF. Details of methodology for ultimate pH (pHu), cooking loss, WBSF and CIELAB colour parameters were recorded using the methods detailed by Keady et al. (2007).

Statistical analysis
Data on food intake, animal performance and carcass characteristics were analysed using analysis of residual maximum likelihood (REML) using Genstat 5 (Lawes Agricultural Trust, 1998). Live weight and age at the beginning of the study (within breed), and age at slaughter (within slaughter age group), were incorporated into the analyses as covariates. Data on meat quality were similarly analysed using the REML technique both without covariate adjustment and using pHu as a covariate.

Results
There were no major health problems in the animals during the study and the mean age at slaughter of bulls in the E and L slaughter groups was 485 and 610 days, respectively.

Diet
The mean chemical composition of the silage offered throughout the study is presented in Table 1. The silage was of moderate quality as indicated by pH and concentration of NH3-N and fermentation acids.

The mean chemical composition of the concentrate offered pre- and post-350 kg live weight was (respectively): DM 827 and 838 g/kg, crude protein (CP) 182 and 168 g/kg DM, ADF 75 and 77 g/kg DM, NDF 184 and 199 g/kg DM, and ash 68 and 67 g/kg DM.

Food intake, animal performance and carcass data
As no (P > 0.05) breed × slaughter group interactions were recorded, only the effects of the main treatments are presented.

Data on food intake and animal performance are presented in Table 2. HF bulls had higher (P < 0.001) daily DM intake of silage and concentrate, and hence total DM intake, than NOR bulls. Holstein bulls were heavier (P < 0.001) at slaughter than NOR bulls, and tended (P = 0.07) to have a higher rate of live-weight gain. In contrast, both carcass weight and rate

| Table 1 Chemical composition of silage offered |
|-----------------|-----------------|-----------------|-----------------|
| Value           |                | 236.2 | 4.1 | 0.11 |
| DM (g/kg)       | pH              | NH3–N | 131.2 | 12.6 | 3.8 |
| pHu             |                | 26.6 | 6.9 | 3.5 | 0.3 | 62.7 | 86.8 | 344.2 | 579.3 | 19.3 |
|                 |                | 131.2 | 12.6 | 3.8 | 6.9 | 3.5 | 0.3 | 62.7 | 86.8 | 344.2 | 579.3 | 19.3 |
|                 |                | 26.6 | 6.9 | 3.5 | 0.3 | 62.7 | 86.8 | 344.2 | 579.3 | 19.3 |
|                 |                | 6.9 | 3.5 | 0.3 | 62.7 | 86.8 | 344.2 | 579.3 | 19.3 |
|                 |                | 3.5 | 0.3 | 62.7 | 86.8 | 344.2 | 579.3 | 19.3 |
|                 |                | 0.3 | 62.7 | 86.8 | 344.2 | 579.3 | 19.3 |
|                 |                | 62.7 | 86.8 | 344.2 | 579.3 | 19.3 |
|                 |                | 86.8 | 344.2 | 579.3 | 19.3 |
|                 |                | 344.2 | 579.3 | 19.3 |
|                 |                | 579.3 | 19.3 |
|                 |                | 19.3 |
| Abbreviation is: DM = dry matter.

| Table 2 The effect of breed and age at slaughter on food intake and animal performance |
|-----------------|-----------------|-----------------|-----------------|
| Breed           | Slaughter group1 | s.e.d. | Significance | s.e.d. | Significance |
| Food intake (DM, kg/day) |                |                |                |                |                |
| Concentrate     | 4.01 | 3.79 | 0.048 | *** | 3.87 | 3.94 | 0.048 | NS |
| Silage          | 4.21 | 3.75 | 0.097 | *** | 3.97 | 3.99 | 0.096 | NS |
| Total           | 8.23 | 7.54 | 0.117 | *** | 7.84 | 7.92 | 0.115 | NS |
| Animal performance data |                |                |                |                |                |
| Live weight at slaughter (kg) | 617.1 | 583.6 | 9.56 | *** | 545.1 | 655.7 | 9.60 | *** |
| LWG (kg/day)    | 1.13 | 1.08 | 0.026 | P = 0.07 | 1.14 | 1.07 | 0.026 | ** |
| FCR (kg DM per kg LWG) | 7.43 | 6.99 | 0.173 | * | 6.88 | 7.54 | 0.171 | *** |
| Carcass weight (kg) | 314.7 | 308.4 | 5.07 | NS | 278.8 | 344.3 | 5.09 | *** |
| Carcass gain (kg/day) | 0.59 | 0.59 | 0.014 | NS | 0.60 | 0.58 | 0.014 | NS |
| FCR (kg DM per kg carcass gain) | 14.17 | 12.84 | 0.370 | ** | 13.11 | 13.91 | 0.366 | * |

Abbreviations are: HF = Holstein-Friesian; NOR = Norwegian dairy breed; DM = dry matter; LWG = live-weight gain; FCR = food conversion ratio.

1Animals slaughtered at 485 (E) or 610 (L) days.
of carcass gain did not differ between the breeds ($P > 0.05$). The efficiency of conversion of food to gain differed between the breeds, with HF having a poorer food conversion ratio (FCR) when assessed on both a live weight ($P < 0.05$) and carcass basis ($P < 0.01$).

Mean daily DM intakes did not differ ($P > 0.05$) between the two slaughter age groups. Increasing age at slaughter (L) resulted in bulls achieving higher ($P < 0.001$) final live weights and carcass weights than bulls slaughtered at an earlier age (E), while rate of live-weight gain was reduced ($P < 0.01$) by delaying age at slaughter. In contrast, rate of carcass gain did not differ ($P > 0.05$) between E and L bulls.

Mean daily DM intakes did not differ ($P > 0.05$) between the two slaughter age groups. Increasing age at slaughter (L) resulted in bulls achieving higher ($P < 0.001$) final live weights and carcass weights than bulls slaughtered at an earlier age (E), while rate of live-weight gain was reduced ($P < 0.01$) by delaying age at slaughter. In contrast, rate of carcass gain did not differ ($P > 0.05$) between E and L bulls. FCR was poorer for L than E bulls when expressed either on a live- ($P < 0.001$) or carcass- ($P < 0.05$) weight basis.

The increase in slaughter age had a marked effect on efficiency of food conversion, with bulls slaughtered in the L group having poorer FCR than bulls slaughtered in the E treatment group when assessed on either a live weight ($P < 0.001$) or carcass basis ($P < 0.05$).

Data on carcass characteristics are presented in Table 3. Holstein bulls had lower ($P < 0.001$) dressing proportion and carcass conformation score than NOR bulls. In contrast, breed had no ($P > 0.05$) influence on carcass fat class score, depth of subcutaneous fat, marbling score, eye muscle area or on the weight of fat in the internal depots.

Increasing age at slaughter increased dressing proportion, carcass fat class, depth of subcutaneous fat, marbling score, weights of internal fat depots and eye muscle area ($P < 0.01$ or greater), but had no effect on carcass conformation score ($P > 0.05$).

Meat quality

Data on measures of instrumental meat quality are presented in Table 4. HF bulls had higher ($P < 0.05$) pHu than NOR bulls. The average pHu of both breeds was above the normal accepted range, with 19 of the HF carcasses and 8 of the NOR carcasses having longissimus dorsi muscles with pHu greater than 5.8. Given the breed differences in pHu values recorded, means presented in Table 4 have been adjusted using pHu as a covariate. There were no differences in CIELAB values or cooking loss between breeds when adjusted for pHu, though WBSF values were lower ($P < 0.001$) in the HF than NOR bulls. Bulls in the L group had higher ($P < 0.001$) a* and metric chroma ($C_{ab}^{*}$) values, but lower hue angle ($h^{0}$) ($P < 0.01$) and cooking loss ($P < 0.001$) than those in the E group.

Table 3 The effect of breed and age at slaughter on carcass characteristics

<table>
<thead>
<tr>
<th>Breed</th>
<th>Slaughter group</th>
<th>HF</th>
<th>NOR</th>
<th>s.e.d.</th>
<th>Significance</th>
<th>E</th>
<th>L</th>
<th>s.e.d.</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dressing proportion (g carcass per kg live weight)</td>
<td></td>
<td>509</td>
<td>527</td>
<td>2.8</td>
<td>***</td>
<td>511</td>
<td>526</td>
<td>2.8</td>
<td>***</td>
</tr>
<tr>
<td>Carcass fat class</td>
<td></td>
<td>2.85</td>
<td>2.96</td>
<td>0.095</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carcass conformation</td>
<td></td>
<td>1.56</td>
<td>2.20</td>
<td>0.096</td>
<td>***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth of subcutaneous fat (mm)</td>
<td></td>
<td>3.7</td>
<td>3.1</td>
<td>0.32</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marbling score</td>
<td></td>
<td>2.6</td>
<td>2.2</td>
<td>0.18</td>
<td>P = 0.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kidney, cod and channel fat (kg)</td>
<td></td>
<td>17.4</td>
<td>15.9</td>
<td>1.35</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omental and mesenteric fat (kg)</td>
<td></td>
<td>28.9</td>
<td>28.4</td>
<td>1.91</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye muscle area (cm²)</td>
<td></td>
<td>58.9</td>
<td>58.3</td>
<td>2.24</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations are: HF = Holstein-Friesian; NOR = Norwegian dairy breed.

*Animals slaughtered at 485 (E) or 610 (L) days.

Fat classes: five-point scale: 1 = leanest; 5 = fattest. Carcass conformation classes: five-point scale: 1 = worst; 5 = best. Marbling scores: eight-point scale: 1 = low marbling; 8 = high marbling.

Table 4 The effect of breed and age at slaughter on meat quality parameters (using pHu as a covariate)

<table>
<thead>
<tr>
<th>Breed</th>
<th>Slaughter group</th>
<th>HF</th>
<th>NOR</th>
<th>s.e.d.</th>
<th>Significance</th>
<th>E</th>
<th>L</th>
<th>s.e.d.</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>pHu</td>
<td></td>
<td>6.04</td>
<td>5.80</td>
<td>0.108</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Colour</td>
<td></td>
<td>34.9</td>
<td>36.7</td>
<td>1.09</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td></td>
<td>19.0</td>
<td>18.6</td>
<td>0.79</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b*</td>
<td></td>
<td>12.8</td>
<td>12.7</td>
<td>0.73</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hue angle ($h^{0}$)</td>
<td></td>
<td>34.0</td>
<td>33.7</td>
<td>0.96</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metric chroma ($C_{ab}^{*}$)</td>
<td></td>
<td>22.9</td>
<td>22.6</td>
<td>1.02</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooking loss (%)</td>
<td></td>
<td>22.0</td>
<td>21.6</td>
<td>1.06</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WBSF (kg/cm²)</td>
<td></td>
<td>2.46</td>
<td>2.95</td>
<td>0.170</td>
<td>**</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Abbreviations are: HF = Holstein-Friesian; NOR = Norwegian dairy breed; WBSF = Warner–Bratzler shear force.

*Animals slaughtered at 485 (E) or 610 (L) days.
Discussion

Effect of breed

Total daily DM intake of the HF bulls was 9.2% higher than that of the NOR bulls. Previous studies have reported Holstein- and/or Friesian-type beef animals to have higher DM intakes than beef × Friesian genotypes (Steen, 1995; Keane et al., 2001), probably reflecting differences in the relative size of the gastro-intestinal tract between the dairy breeds (given that the HF breed have been selected for increased feed intake; Simm (1998)) and that of the beef breeds.

Rate of live-weight gain tended \((P = 0.07)\) to be higher with HF compared with NOR bulls and at the point of slaughter HF bulls were 33.5 kg heavier than NOR bulls when slaughtered at the same age. Keane et al. (2001) reported numerically higher rates of gain for Charolais × Friesian compared with HF cattle, while Belgian Blue × HF cattle grew significantly faster than HF cattle in the study reported by Keane, 2003. Hence, the tendency for the NOR bulls to have a lower rate of live-weight gain than the HF bulls in the present study indicates that the growth potential of the NOR bulls is below that of the more traditional continental × Friesian cattle breeds typical of the UK.

Despite the greater slaughter live weight of the HF bulls, carcass weights of the HF and NOR bulls were similar, reflecting the similar rate of carcass gain between the breeds and the higher killing-out (dressing) proportion of the NOR bulls. The major (18 g/kg) improvement in killing-out proportion recorded with NOR bulls compared with HF bulls is similar to the difference reported by Keane et al. (2001) with Friesian-type compared with HF-type male cattle. However, the difference in killing-out proportion is well below that typically observed between HF and the higher values recorded with beef breed × Friesian-type animals (Keane et al., 2001; Keane, 2003). Previous studies (Steen, 1995; Keane et al., 2001; Keane, 2003) have reported dairy beef cattle to have higher quantities of internal fat than beef breed × Friesian cattle, which would have contributed to the differences in killing-out proportions recorded between the breeds in those studies. This was not a factor in the present study as weight of internal fat was similar between the breeds. Hence, the higher killing-out proportion of the NOR bulls probably reflects two main factors; firstly, the lower DM intake of the NOR bulls would have resulted in a reduced gut fill, and secondly, the higher conformation score of the NOR breed, which indicates greater flesh cover, would also have contributed to the higher killing-out proportion of the NOR compared with HF bulls. The relationship between good conformation and high killing-out proportion has been reported previously (Kauffmann, 1978).

The similar carcass fat measures recorded indicate that, at the slaughter ages pertaining in this study, HF and NOR bulls were at a relatively similar stage on the established sigmoidal animal growth curve (Brody, 1945). However, carcass conformation was significantly higher with the NOR compared with HF bulls. The latter observation is of major commercial importance as conformation is correlated with muscle size and distribution (Kempster et al., 1988) and suggests that carcasses of NOR bulls would yield a greater mass of lean meat per unit of carcass weight than HF bulls slaughtered at a comparable age. Furthermore, the higher carcass conformation score recorded with NOR compared with HF bulls is in line with previous studies which have reported higher carcass conformation scores with animals containing a proportion of beef genes compared with those bred solely for dairy characteristics (Kempster et al., 1988; Keane et al., 2001).

Despite their higher live weight at slaughter, food efficiency assessed on a live-weight basis was poorer (6.3% poorer) for the HF than for the NOR bulls. Similarly, when assessed on a carcass weight basis, food efficiency was some 10.4% poorer for the HF bulls, reflecting the similar rates of carcass gain recorded between the breeds despite the higher daily DM intake of the HF bulls. A proportion of the lower efficiency of HF bulls can be attributed to increased maintenance requirements relative to NOR bulls due to the greater live weight of the HF bulls. Using the equation of Dawson and Steen (1998) indicates that at the point of slaughter (point of maximum difference in live weight), metabolisable energy requirements for maintenance would differ by just over 3 MJ/day between the breeds. Furthermore, the higher DM intake and lower killing-out proportion of the HF bulls indicates that this breed had a higher proportion of internal organs, which are highly metabolically active (Huntington and Reynolds, 1987), and would have contributed to a higher maintenance requirement of the HF compared with NOR bulls and depressed overall food efficiency for carcass gain.

Ultimate pH is an important indicator of meat quality with higher pHu values resulting in meat of darker colour and lower microbiological shelf life (Silva et al., 1999). In relation to tenderness, Silva et al. (1999) reported shear force values to decrease linearly with pHu, while in contrast Purchas and Aungsupakorn, 1993, reported a quadratic relationship between shear force and pHu with highest shear force values recorded between pHu values of 5.8 and 6.2. The high mean pHu values recorded in the present study (6.04 and 5.80 for HF and NOR bulls, respectively) indicate considerable muscle glycogen depletion prior to slaughter. Since both breeds were finished under the same husbandry conditions, the higher pHu of the HF bulls is most likely related to effects of pre-slaughter handling. This may be due to greater stress sensitivity such that, for the same stressor, more glycogen was mobilised in the HF than NOR. Increased fighting and mounting leads to higher pHu values (Mohan Raj et al., 1992), thus the higher pHu of the HF may also reflect greater aggression and mounting by bulls of this breed in the pre-slaughter period, from loading at the farm, through transport and lairage to slaughter.

At constant pHu, colour characteristics were similar between the breeds. However, the effect of pHu on appearance was evident from data unadjusted for covariance using pHu, in which the \(L^*\) value was significantly lower in the HF.
(34.5) compared with NOR (37.3) bulls. This represents a decrease in $L^*$ of 2.5 units due to an increase in pH, of 0.25, which is of a similar order of difference as reported by Wulf and Wise (1999).

Tenderness is considered to be a major factor of importance in meat quality by consumers (Miller et al., 2001). In the present study, WBSF was lower for HF bulls, representing a real breed difference, which was apparent despite correction of data to constant pH. It is well established that chilling rate, particularly the temperature at which carcasses go into rigor, is a major factor influencing eating quality (Thompson et al., 2006). However, the similar carcass fat parameters recorded indicate that temperature decline within muscles would be expected to be similar between the breeds in the present study.

Marbling in the *longissimus dorsi* has been associated with improved tenderness (Pringle et al., 1997; Lively et al., 2005). In the present study, there was a tendency ($P = 0.06$) for HF bulls to have higher marbling score in the *longissimus dorsi* than NOR bulls (2.6 and 2.2, respectively), and this may contribute to breed differences in WBSF. However, this difference in marbling score was considerably less than that reported by Lively et al. (2005), recorded between HF and Charolais steers (2.9 and 1.6, respectively), in which significant differences were recorded between breeds in both marbling and WBSF values.

Shackelford et al., 1995, using trained sensory panels reported that WBSF values of 3.9 kg (3.0 kg/cm$^2$) would have a 68% chance of being rated as acceptable, while using consumer evaluations, Miller et al. (2001) suggested shear force values less than 3 kg (2.37 kg/cm$^2$) would guarantee tenderness. The tenderness of meat from bulls has been reported to be lower than that of steers and to be more variable (Peachey et al., 2002; Maher et al., 2004). However, on the basis of the relationship published by Platter et al. (2003), the WBSF values of bulls of both breeds in the present study would indicate relatively high acceptability in relation to tenderness.

Most studies on breed differences in meat quality have compared beef breeds (Chambaz et al., 2003; Monsón et al., 2004; Cuvelier et al., 2006) or beef breeds with dairy breeds (Sinclair et al., 2001). When evaluating published data on breed differences it is important to consider the post-slaughter processing operations. Lively et al. (2005) showed that magnitude of the WBSF difference between Charolais and HF steers depended both on the method of carcass suspension post-slaughter and on the ageing period, and reported that in general breed differences decreased with hip suspension and with longer ageing period. Thus, the breed differences in tenderness reported in the present study may be less if studied at longer ageing periods of 21 days.

Maltin et al. (2001) showed that some of the breed differences in meat quality might be explained by muscle fibre type distribution, and that an increase in slow oxidative fibres was positively correlated with overall sensory acceptability of the meat. If we consider that fibre type distribution might contribute to the breed differences observed in the present study (i.e. HF being more tender may have more slow oxidative fibres), then this may also partly explain the higher pH in the HF since slow oxidative fibres have fewer glyogen granules than other fibre types (Lieber, 1992). Further work needs to be done to identify breed differences in meat quality in relation to the relative contribution of intrinsic muscle biochemistry and of the behavioural response to stress.

**Effect of age at slaughter**

Increasing age at slaughter had no significant effect on the DM intake of bulls in the present study, despite the major difference in live weight at slaughter between the E and L groups. This observation contrasts with data from previous studies involving serial slaughter where food intake has increased at progressively higher slaughter age/weight (Keane and Drennan, 1980; Andersen and Ingvarsen, 1984a; Kirkland et al., 2006). The absence of such an effect in the present study probably reflects the type of diet offered and the relative maturity of the bulls at slaughter. Intake of mixed forage/concentrate diets by cattle of increasing live weight has been shown to increase at a lower rate than that of high concentrate diets offered in some other studies (Keane and Drennan, 1980), and indicates that physical and/or metabolic factors (Allen, 2000) were regulating intake at live weights above 545 kg (the mean live weight at slaughter of E group bulls). It has also been suggested (National Research Council, 1987) that intake is related to body composition, particularly percentage body fat, and hence the higher measures of body fat recorded with L group bulls may have reduced the intake potential of bulls slaughtered at higher live weight.

Slaughtering bulls at 610 compared with 485 days (L v. E) increased live weight at slaughter by 111 kg, but was accompanied by a reduction in rate of live-weight gain of over 6% for the L compared with E bulls across the total finishing period. However, the marginal rate of growth of bulls between the E and L slaughter ages, 0.88 kg/day, was 30% lower than the growth rate of the bulls recorded between the start of the study and slaughter at 485 days (1.14 kg/day). A reduction in rate of gain with increasing weight has been observed in many studies involving serial slaughter (Andersen and Ingvarsen, 1984a; Bailey et al., 1985; Patterson et al., 1994), reflecting the stage of maturity of the animals in these studies and their relative position on the established animal growth curve, which is known to be sigmoidal until mature body weight is reached (Brody, 1945). Hence, the reduced rate of gain of L compared with E bulls reflects the higher maintenance costs and increased fat deposition of L bulls. Furthermore, the reduction in rate of gain and increased body fat deposition of bulls at higher slaughter age, and the absence of interactions between breed and slaughter age recorded with these parameters, indicates that the point of inflexion of the growth curve of the HF and NOR bulls lies, similarly, at slaughter weights below 656 kg (L). This observation supports the conclusion of Kirkland et al. (2006) that
HF bulls were not beyond, or were close to, the point of inflexion at live weights up to 550 kg.

In contrast to the live-weight gain data, slaughter age had no significant effect on rate of carcass gain. The higher carcass weights of L bulls were derived primarily from the compounded effects of higher live weight and improved killing-out proportion of these bulls compared with E slaughter group bulls. The relative improvement in killing-out proportion with increasing live weight at slaughter recorded in the present study (13.6 g/100 kg) concurs with findings of other studies with bulls (Andersen and Ingvarsten, 1984b; Bailey et al., 1985). However, in absolute terms, the killing-out proportions of the bulls in the present study are lower than those reported in other studies. Using the equation of Kirkland et al. (2006), developed using data from HF bulls slaughtered at live weights up to 550 kg, indicates that the killing-out proportion of bulls slaughtered at 545 kg (E group) would be 526 g/kg, some 15 g/kg higher than the actual value recorded presently. This discrepancy probably reflects the more fibrous diet offered in the present study compared with the ad libitum concentrate diet offered by Kirkland et al. (2006), which would be expected to increase ‘gut-fill’ as well as carcass fat parameters (Steen and Robson, 1995), and much of the additional fat would be trimmed off post slaughter.

The absence of improvement in conformation at the higher slaughter age (L compared with E bulls) is in contrast with other data from serial slaughter studies (Andersen and Ingvarsten, 1984b; Kirkland et al., 2006). This observation probably reflects the reduction in lean growth potential due to the increased stage of maturity of the bulls with increasing slaughter age as discussed previously. Nevertheless, the increased fat deposition at the higher slaughter age would have been expected to produce some improvement in carcass conformation, given that conformation is a visual assessment of the thickness of both muscle and fat in relation to the size of the skeleton (Kempster et al., 1988).

The efficiency of conversion of food to live weight and carcass weight was reduced by 9.6% and 6.1%, respectively, in the L compared with E slaughter groups. These differences largely reflect the greater maintenance requirements (+15%; Dawson and Steen, 1998) of bulls slaughtered at the higher live weight, and the major differences in the energy content of the gain with increasing slaughter weight, as reflected by the higher measures of carcass fatness and fat in the internal depots. A deterioration in efficiency of food conversion with increasing slaughter weight has been observed in many studies with continental breed (Patterson et al., 1994), Friesian-type (Andersen and Ingvarsten, 1984a; Bailey et al., 1985) and HF bulls (Kirkland et al., 2006).

Increasing age at slaughter had positive effects on several meat colour characteristics, which indicated that meat from the late slaughter group was redder (higher a*, lower b*) and more saturated (higher C*ab). The decrease in \( b^* \) and increase in \( C^*_{ab} \) are predominantly due to the increase in a* value, since this changed much more than b* value in response to age at slaughter. This is an important observation given the preference of many consumers for bright, attractive-coloured meat (Carpenter et al., 2001). Similarly, redness of meat increased linearly when slaughter weight of HF bulls was increased from 300 kg (247 days at slaughter) to 550 kg (434 days at slaughter) live weight (Kirkland et al., 2005; Kirkland et al., 2006), but contrasts with that of Keane and Allen (1998) who reported that increasing live weight at slaughter from 640 to 720 kg had no effect on a* value. Meat colour depends on the amount and type of pigment present and the light-scattering properties of the meat. Increased pigment content with age of animals (Lawrie, 1998) would be expected to increase a* values and decrease \( L^* \) values according to MacDougall (1983) and this may partly explain the increase in redness attributes with slaughter age. However, \( L^* \) values are mainly influenced by changes in the scattering coefficient of the meat and light-scattering properties are influenced by both rate of pH decline and \( \mbox{pH}_u \) (MacDougall, 1983). In the present study, it is most likely that the high \( \mbox{pH}_u \) values were the dominant factor determining lightness values.

Although cooking loss was lower in the late slaughter group, there was no difference in WBSF values between E and L groups when compared at the same \( \mbox{pH}_u \). Lively et al. (2005) reported both cooking loss and WBSF to decrease with age in HF steers. However, the lack of effect of age on WBSF in the present study concurs with data from other studies involving serial slaughter (Keane and Allen, 1998; Sinclair et al., 1998; Kirkland et al., 2005).

Conclusions
When slaughtered at the same age, HF bulls were heavier but had a poorer killing-out proportion than NOR bulls. Carcass weights were similar between breeds but NOR bulls had higher conformation as well as improved food conversion efficiency compared with HF bulls. Delaying slaughter from 485 to 610 days (E v. L) reduced rate of live-weight gain and efficiency of food conversion, and increased body fat deposition. Meat from both breeds was acceptably tender, but delaying slaughter age improved colour characteristics.

Acknowledgements
The authors wish to thank the technical staff of the Beef Unit for their assistance throughout the course of this study and acknowledge the Department of Agriculture and Rural Development for Northern Ireland who provided funding for this project.

References


Keady TWJ, Lively FO, Kilpatrick DJ and Moss BM 2007. Effects of replacing grass silage with either maize or whole-crop wheat silages on the performance and meat quality of beef cattle offered two levels of concentrates. Animal 61, 613–623.


