Lucerne grazing compared with concentrate-feeding slightly modifies carcass and meat quality of young bulls

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A B S T R A C T
Carcase and meat quality of young bulls raised on one of three fattening strategies from 224 to 450 kg were compared. One group was fed concentrates (CON), another group grazed on lucerne plus 1.8 kg DM barley/day (LUC) and the last group had the same management as LUC young bulls for 3 months and was then finished on concentrates for 2 months. Among carcase traits, only tissue composition differed, with LUC young bulls having more muscle and less subcutaneous and intermuscular fat than their counterparts. Concerning meat quality, most attributes did not differ among fattening strategies but LUC young bulls had the lowest intramuscular fat, which presented greatest n–3 PUFA content. It can be concluded that lucerne grazing can be a good alternative to concentrates for young bulls, with similar carcase and meat quality but with lower fat content and healthier fatty acid composition than young bulls fed concentrates during the finishing period.

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1. Introduction

Forage-feeding could confer specific physical, chemical and sensory characteristics to meat (Coulon & Priolo, 2002) as well as a positive image for consumers, who associate extensive production systems with natural products (Dieguez Cameroni, Hornick, Cabarrux, Istatse, & Dufrasne, 2006). Moreover, this feeding system could be a cost-effective alternative to finishing on high concentrate diets (Kerth, Braden, Cox, Kerth, & Rankins, 2007). However, literature regarding the effect of forage and concentrate-feeding on carcase and meat quality is difficult to interpret because many factors are involved. Age, live weight, fatness degree, plane of nutrition, concentrate:roughage ratio, and developmental traits are the most important (French et al., 2001; Muir, Deaker, & Bown, 1998a). Among these factors, nutrition plays a major role due to its regulatory effect on biological processes in muscle and on fat deposition (Coulon & Priolo, 2002; Hocquette, Tesseraud, Cassar-Malek, Chilliard, & Ortigues-Marty, 2007; Priolo, Micol, & Agabriel, 2001).

Carcasses from pasture-fed cattle may be lighter at a given age than those from concentrate-fed cattle and have lower fat content (Bidner, Schupp, Montgomery, & Carpenter, 1981). The low fat content can affect negatively some aspects of meat quality due to the shortening of the fibres during cooling. When forage-fed cattle are fed grain for short periods before slaughtering, an improvement of shortening of the fibres during cooling. When forage-fed cattle are fed grain for short periods before slaughtering, an improvement of toughness and sensory attributes compared with that from concentrate-fed cattle (Larick et al., 1987; Muir et al., 1998b; Priolo et al., 2001), while other studies reported no differences (French et al., 2001).

The fatty acid (FA) composition of beef may be altered by the nutritional background. Pasture-finished cattle may produce beef with a more desirable fatty acid composition in terms of its effect on human health, especially in relation to n–3 fatty acids, than concentrate-fed cattle (Steen, Lavery, Kilpatrick, & Porter, 2003). Besides n–3 PUFA, ruminant meat and milk and their products are the main sources of CLA in the human diet. However, beef with increased PUFA could be more prone to oxidation (Yang, Lanari, Brewster, & Tume, 2002) and colour deterioration.

Thus, the aim of this study was to compare carcase and meat quality of yearling bulls of three fattening strategies: concentrate-feeding, grazing lucerne plus grain supplementation, or grazing lucerne plus supplementation and 2 months of concentrate-feeding and slaughtered at a fixed live weight.

2. Material and methods

Three fattening strategies were tested in 21 Parda de Montaña young bulls from 224 kg (aged 188 ± 20.6 d) to 450 kg (aged 338 ± 22.2 d). On the day after arrival at CITA research centre (41° 43’ N, 0° 48’ W; altitude 225 m), young bulls were weighed,
blocked by body weight (BW) and randomly assigned to one of three fattening management systems. The first group of young bulls was fed concentrates and straw (5.02 MJ ME/kg DM, 3.5% CP) on ad libitum basis until slaughter (CON, n = 7). From the arrival to 350 kg BW, young bulls were fed a growing concentrate (11.47 MJ ME/kg DM, 14.9% CP) and thereafter a finishing concentrate (11.65 MJ ME/kg DM, 13.7% CP). These young bulls were placed in a straw-bedded pen with 5 m² allowance per young bull. The second group of young bulls rotationally grazed in 0.3-ha lucerne paddocks supplemented with 1.8 kg DM/d barley (11.93 MJ ME/kg DM, 11.3% CP) until slaughter (LUC, n = 7). Young bulls were changed to a new paddock fortnightly to ensure that lucerne stubble height was above 10 cm. Lucerne pre-grazing mass was on average 2818 kg DM/ha with 22.3% crude protein content. The third group of young bulls had the same management as LUC young bulls for 3 months (Period 1) and for the last 2 months (Period 2) was fed the finishing concentrate and straw on ad libitum basis (LUC + CON, n = 7). The paddocks had access to a shed to provide shade during the summer. Water, barley straw and minerals were offered on an ad libitum basis. Calf performance according to the fattening strategy is detailed in Table 1.

Young bulls were transported to a commercial abattoir (Merca-Zaragoza, Zaragoza, Spain) 6 km from the Research Centre when they individually reached the target weight. Slaughtering took place immediately upon arrival to minimize pre-slaughter stress. Young bulls were stunned by captive bolt pistol and dressed place immediately upon arrival to minimize pre-slaughter stress. Carcase weight divided by slaughter live weight, which was obtained at the Veterinary Station in Zaragoza, Zaragoza, Spain) 6 km from the Research Centre when the carcase was hung, hot carcase weight was recorded. After 24 h chilling at 4°C, the ultimate pH (24 h) with a Crison pHmeter (Crison Instruments, SA, Barcelona, Spain). Drip loss was measured in the other half. Each sample was placed in a net, to prevent contact, and then suspended in a bag. Drip loss was estimated by dividing the steak weight before and after 24 h at 4°C (Honikel, 1998).

Two steaks per calf were placed in polystyrene trays, wrapped with an oxygen permeable film and kept in the dark at 4°C for colour determination with a Minolta CM-2600d spectrophotometer (Konica Minolta Holdings, Inc, Osaka, Japan). Meat colour (CIE L* (lightness), a* (redness) and b* (yellowness)) was measured after blooming 4 h, 1, 2, 5, 7 and 14 days of air exposure. These data were used to calculate Hue angle value (H* = arctg a*/b* × 57.29) and Chroma (C* = (a*² + b*²)0.5).

For instrumental texture analysis, 3 steaks per calf were vacuum-packaged and stored at 4°C for 1, 7 and 14 days for subsequent Warner–Bratzler shear force determination. Steaks were heated in a water bath (75°C) to an internal temperature of 70°C and after cooling at least ten probes were cut with 10 × 10 mm² cross section with the fibre direction parallel to the long dimension of at least 30 mm (Honikel, 1998). Samples were sheared perpendicular to the long axis of the core using an Instron (Model 5543, Instron Limited, Barcelona, Spain) provided with a Warner–Bratzler device and with a cross-head speed of 150 mm/min. Values for toughness (energy needed per unit of volume to shear the sample below the shear blade until the point of maximum load) and maximum stress (maximum load per unit of cross section) were recorded.

One steak per calf was halved perpendicularly to the surface and randomly assigned to either chemical or fatty acid composition determination. Half steak was minced and freeze-dried to determine the chemical composition. Meat was weighed before and after freeze-drying to calculate dry matter content. The minced samples were ground before protein, ether extract and ash contents determination. Protein was determined following the Dumas procedure (AOAC, 1995) using a Nitrogen and Protein analyser (Model NA 2100, CE Instruments, Thermostar SA, Barcelona, Spain). Fat content was quantified using the Ankom Procedure (AOCS Am 5-04) with an Ankom extractor (Model XT10, Ankom Technology, Madrid, Spain). Ash content was determined by dividing the weight before and after ignition in a muffle for 8 h (AOAC, 1995). Analyses were run in duplicate.

The remaining half steak per calf was minced for fatty acid determination. The fatty acids were extracted (Bligh & Dyer, 1959), methylated, and analyzed with a gas chromatograph (Auto- system XL Agilent Technologies 7890 Net Work GC System, Perkin Elmer, Boston, USA) equipped with a flame ionization detector, a Hamilton injector, and an Omegawax 320 capillary column (30 m × 0.32 mm with a film thickness of 0.25 μm; Supelco, Belle-

Table 1

<table>
<thead>
<tr>
<th></th>
<th>LUC</th>
<th>LUC + CON</th>
<th>CON</th>
<th>s.e.m.</th>
<th>Sign.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily gain (kg/d)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period 1</td>
<td>1.332</td>
<td>1.325</td>
<td>1.524</td>
<td>0.1211</td>
<td>+</td>
</tr>
<tr>
<td>Period 2</td>
<td>1.308</td>
<td>2.017²</td>
<td>1.529³</td>
<td>0.1414</td>
<td>++</td>
</tr>
<tr>
<td>Age at slaughter</td>
<td>350</td>
<td>335</td>
<td>329</td>
<td>14.2</td>
<td>NS</td>
</tr>
</tbody>
</table>

s.e.m.: standard error of the mean; Sign: significance; NS: non significant

*² Means within a row with different superscript differ at P < 0.05.

Fig. 1. Slicing pattern of L. thoracis muscle for the different determinations.

KP-82; Koizumi Inc., Tokyo, Japan). Then, the rib joint was weighed and dissected into muscle, fat (subcutaneous and intermuscular), bone and others (tendons and noticeable blood vessels).

One steak per calf was split and one half was used to measure ultimate pH (24 h) with a Crison pHmeter (Crison Instruments, SA, Barcelona, Spain). Drip loss was measured in the other half. Each sample was placed in a net, to prevent contact, and then suspended in a bag. Drip loss was estimated by dividing the steak weight before and after 24 h at 4°C (Honikel, 1998).

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Fig. 1. Slicing pattern of L. thoracis muscle for the different determinations.
fonte, USA) with He as the carrier gas at 30 cm/s. The temperature of the inlet detector was 260 °C and the internal temperature of the oven was 190 °C for 2 min, increasing to 205 °C at 5 °C/min for 3 min. Fatty acids were quantified using the internal standard (C21:0) after adjusting for response determined using the Sigma–Aldrich standard mixtures. Proportions of polyunsaturated (PUFA), monounsaturated (MUFA), saturated (SFA) fatty acids, n–6 and n–3 and the PUFA:SFA and n–6:n–3 ratios were obtained from individual fatty acid percentages.

For the sensory panel, the steaks were vacuum-packed and aged at 4 °C for 7 days before freezing and kept at −18 °C until analysis. The day of analysis, samples were thawed inside their vacuum bags (4 h) in tap water until the internal temperature reached 15–17 °C. After the vacuum was broken, the samples were wrapped in aluminium foil and cooked at 200 °C in a double plate grill (Sannmic P8D2) until the internal temperature, which was monitored using an internal thermocouple (Jenway, Bibby Scientific Ltd., Essex, England), reached 70 °C. Each cooked steak was trimmed of fat and external connective tissue, cut into 2 × 2 cm² samples, wrapped in codified aluminium foil, and stored at 60 °C until they were served to the sensory panel. The sensory test was performed during two sessions in a standardised tasting room equipped with individual booths and, to mask any differences in meat colour, under red lighting. In a comparative multi-sample test using a completely balanced design, the samples were served randomly to a trained eight-member sensory panel (ISO 8586-1:1993). To avoid the possible effects of the order of presentation, and first-order and carry-over effects, the samples were presented to panellists in different orders (Macfie, Bratchell, Greenhoff, & Vallis, 1989). Panellists used 10-point scales to quantify beef odour intensity, abnormal odour intensity, tenderness, juiciness, beef flavour intensity and abnormal flavour intensity.

2.1. Statistical analyses

Statistical analyses were performed with SAS v.9.1. (SAS Inst. Inc., Cary, USA). Meat instrumental colour and texture variables were analysed using mixed models based on Kenward–Roger’s adjusted degrees of freedom solution for repeated measures including fattening strategy, time and their interaction as fixed effects, and animal as the random effect. A first-order autoregressive structure with heterogeneous variances for each date was used to model justed degrees of freedom solution for repeated measures. The t-test, Pearson’s correlation coefficient and abnormal flavour intensity.

3. Results

3.1. Carcass traits

The fattening strategy did not affect carcase weight, dressing percentage, conformation score, degree of fat cover or LMA (\(P > 0.05\)) but affected the tissue composition of the 10th rib (\(P < 0.05\); Table 2). Subcutaneous and intermuscular fat percentages were lower and muscle percentage greater in LUC young bulls than in their counterparts (\(P < 0.05\)), which presented similar tissue composition regardless of the duration of the concentrate-feeding period. Bone percentage tended to be greater in LUC than in CON young bulls (\(P = 0.08\)).

3.2. Meat quality

Fattening strategy had no effect on ultimate pH, which ranged between 5.5 and 5.6 (s.e.m. = 0.05, \(P > 0.05\)), and drip loss (0.7, 0.9 and 0.8 for LUC, LUC + CON and CON young bulls respectively; s.e.m. = 0.17, \(P > 0.05\)). Meat lightness (\(L^*\)), redness (\(a^*\)), yellowness and Hue angle (\(H^*\)) were not affected by the fattening strategy but were affected by time of air exposure (\(P < 0.01\) (Fig. 2). From blooming, lightness, redness and yellowness increased until day 2 of air exposure, but thereafter they decreased to similar values to those measured at blooming time. From day 7 to day 14 of air exposure \(H^*\) decreased in LUC young bulls (\(P < 0.05\)) while it increased in LUC + CON (\(P < 0.05\)) and CON young bulls (\(P < 0.10\)).

Maximum stress and toughness did not differ among fattening strategies but were affected by ageing time (\(P < 0.001\) (Fig. 3). Maximum stress decreased almost linearly with ageing time whereas toughness decreased 60% in the first 7 days of ageing. The fattening strategy affected the dry matter and intramuscular fat content (\(P < 0.01\)) but did not affect protein and ash contents (Table 3). Dry matter content was greater in LUC + CON young bulls, intermediate in CON young bulls and lower in LUC young bulls (\(P < 0.01\)). Beef from LUC young bulls had less intramuscular fat than that of their counterparts (\(P < 0.01\)), which had similar contents. Intramuscular fat content was correlated with subcutaneous fat content (\(r = 0.64, P < 0.01\)). Concerning intramuscular fat content and colour traits, the former was correlated only with \(L^*\) after 4 h (\(r = 0.54, P < 0.05\)) and 24 h of air exposure (\(r = 0.61, P < 0.01\)).

Fatty acid composition differed between LUC young bulls and concentrate-fed young bulls, which had similar fatty acid profiles regardless the duration of concentrate-feeding period (Table 4). Total SFA was similar among fattening strategies (\(P > 0.05\)) but CON and LUC + CON young bulls had greater MUFA (\(P < 0.01\)), mainly due to greater oleic acid content, and less PUFA (\(P < 0.05\)) than LUC young bulls. Thus, the ratio PUFA:SFA was lower in LUC + CON and CON than in LUC young bulls (\(P < 0.05\)). On the other hand, the fattening strategy did not affect n–6 fatty acids (\(P > 0.05\)) whereas

### Table 2

Carcass traits according to fattening strategy.\(^\text{a}\)

<table>
<thead>
<tr>
<th></th>
<th>LUC</th>
<th>LUC + CON</th>
<th>CON</th>
<th>s.e.m.</th>
<th>Sign.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot carcass weight (kg)</td>
<td>256</td>
<td>263</td>
<td>260</td>
<td>4.7</td>
<td>NS</td>
</tr>
<tr>
<td>Dressing percentage (%)</td>
<td>57.53</td>
<td>57.50</td>
<td>57.18</td>
<td>0.94</td>
<td>NS</td>
</tr>
<tr>
<td>Conformation score (1–18)</td>
<td>10.9</td>
<td>11.1</td>
<td>10.3</td>
<td>0.71</td>
<td>NS</td>
</tr>
<tr>
<td>Degree of fat cover (–15)</td>
<td>4.7</td>
<td>5.0</td>
<td>5.4</td>
<td>0.43</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Tissue composition of the 10th rib (%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muscle</td>
<td>71.1(^b)</td>
<td>66.8(^a)</td>
<td>67.3(^b)</td>
<td>1.48</td>
<td>**</td>
</tr>
<tr>
<td>Subcutaneous fat</td>
<td>1.4(^b)</td>
<td>3.3(^a)</td>
<td>2.7(^a)</td>
<td>0.37</td>
<td>**</td>
</tr>
<tr>
<td>Intermuscular fat</td>
<td>8.5(^b)</td>
<td>11.7(^a)</td>
<td>12.8(^b)</td>
<td>1.09</td>
<td>**</td>
</tr>
<tr>
<td>Bone</td>
<td>19.0</td>
<td>18.2</td>
<td>17.2</td>
<td>0.90 (^t)</td>
<td></td>
</tr>
<tr>
<td>M. Longissimus thoracis area, (cm²)</td>
<td>78.5</td>
<td>79.0</td>
<td>83.0</td>
<td>7.63</td>
<td>NS</td>
</tr>
</tbody>
</table>

s.e.m.: standard error of the mean; Sign.: significance; NS: non significant.

\(^a\) CON: concentrate-feeding; LUC: lucerne grazing + 1.8 kg DM barley/day; LUC + CON: lucerne grazing + 1.8 kg DM barley/day for 3 months and finishing on concentrates for 2 months.

\(^b\) \(P < 0.01\).

\(^\text{**}\) \(P < 0.001\).

\(^\text{***}\) \(P < 0.01\).

\(^\text{****}\) \(P < 0.001\).

\(^t\) \(P < 0.10\).

\(^b\) Means within a row with different superscript differ at \(P < 0.05\).
LUC young bulls had the greatest percentage of \(n-3\) fatty acids, LUC + CON young bulls intermediate and CON young bulls the lowest \((P < 0.001)\). Consequently, LUC young bulls had the most favourable \(n-6:n-3\) ratio, LUC + CON intermediate and CON young bulls the least \((P < 0.001)\).

Despite the differences in the fatty acid profile, the sensory assessment did not differ in any of the variables studied among fattening strategies (Table 5). Tenderness and juiciness were positively correlated with SFA \((r = 0.55, P < 0.01\) and \(r = 0.55, P < 0.01\), respectively) and MUFA \((r = 0.49, P < 0.05\) and \(r = 0.50 P < 0.05\), respectively) and negatively with PUFA \((r = -0.61, P < 0.01\) and \(r = -0.59, P < 0.01\)) whereas beef flavour was correlated negatively with PUFA \((r = -0.48, P < 0.05)\).

4. Discussion

4.1. Carcase traits

In the present study young bulls slaughtered at a given live weight had similar carcase dressing percent, conformation score and fat cover. Bulls and steers fed concentrates, forage on ad libitum basis or finished on concentrates after grazing slaughtered at a similar weight had similar dressing percentage and degree of fat cover (Dieguez Cameroni et al., 2006; French et al., 2000a; Steen et al., 2003). There were no differences in age at slaughter. Severe restriction may delay sexual maturity as Renaville et al. (2000) reported. However, young bulls in the current study were not severely restricted according to energy intake, thus the sexual stage would be expected to be similar.

Concerning tissue composition, young bulls finished on concentrates (CON and LUC + CON young bulls) had greater subcutaneous
could increase lipogenesis (Davis, 1977). Thus, the low fat deposi-
tion could be related to the nature of the diet, the lower feeding level,
greater mobility and lower growth rate prior to slaughter (Table 1).
Among these factors, the nature of the diet and mobility are
the most relevant (Juries, Ortigues-Marty, Picard, Micol, & Hoc-
quette, 2006). Bowling et al. (1978) and Steen et al. (2003) reported
no differences in carcass composition of steers either fed concentra-
tes or forages, when carcass weight was adjusted. However, car-
cass composition might have responded differently to diet as
steers from the aforementioned studies were heavier (above 500 kg)
and older at slaughter (yearlings) compared with the young bulls in the current study. Breeds used in the abovementioned studies also differed and the effect of diet on tissue lipid deposition can be amplified by breed (Geay, Bauchat, Hocquette, & Cutuli, 2001).

Differences in carcass composition between animals fed differ-
ent diets can be attributed either to a direct effect of diet composi-
tion or an indirect effect on growth rate (Davis, 1977). In the
present study, the indirect effect on growth rate was not evident.
LUC + CON showed compensatory growth during Period 2 and
reached the target slaughter weight at the same age as CON young
bulls, that had grown continuously (Table 1) but carcasses from both
fattening strategies had similar composition, which agrees with
the results found by Laborde, Mandell, Tosh, Buchanan-Smith,
and Wilton (2002); and Ryan, Williams, and Moir (1993). Contrary,
others (Hornick, Van Eenaeme, Gérard, Dufrasne, & Istasse, 2000)
report that cattle under compensatory growth could be fatter
depending on the duration of the refeeding period, because at the
initial stages of compensatory growth the deposited tissue is
mostly muscle but afterwards fat deposition takes over. This con-
troversy can be related to the different influence of compensatory
growth on tissue composition, which depends on the length and
severity of the restriction and level and quality of feed during the
realimentation period, as well as the age during restriction (Hoch,
LUC + CON young bulls had only a mild restriction during Period
1 on lucerne, according to their weight gains (Table 1), and after
two months of realimentation differences in tissue composition,
if they had ever existed, had disappeared.

Concerning LMA, concentrate-fed steers had greater area than
forage-fed steers when the former were heavier than the latter at
slaughter (Kerth et al., 2007; McCaughey & Cliplef, 1996; Neel
et al., 2007). In the current study, no differences were found
among fattening strategies as previous studies with similar
slaughter weight reported (Bidner et al., 1981; Kerth et al.,
2007). On the other hand, Laborde et al. (2002) found that re-
stricted-realimented steers had smaller LMA than continuously
grown steers slaughtered with similar weight and degree of fat
cover, because metabolic energy intake was not enough to in-
crease muscle mass to attain LMA comparable to steers always
fed a grain diet. However, the weight gains of the forage-fed
steers in the abovementioned study were lower than 0.5 kg/d,
while in the current study LUC + CON young bulls had weight
gains above 1.3 kg during lucerne grazing.

4.2. Meat pH and colour

Ultimate pH did not differ among fattening strategies and all
were within the normal range, without incidence of dark cutting
beef or pre-slaughter stress. In the current study, all young bulls
were managed weekly by the same stockmen, being habituated
to human presence and handling, and were identically managed
during transport until slaughter in order to minimise adverse ef-
facts of stress on meat quality.

Beef colour is dependent on myoglobin content and oxidation
state of the pigment, and both are affected by diet (Priolo et
al., 2001). Pasteur supplies antioxidants such as α-tocopherol and β-

Table 4

<table>
<thead>
<tr>
<th>Fatty acid profile (g/100 g fat) of M. Longissimus thoracis according to the fattening strategy.</th>
<th>LUC</th>
<th>LUC + CON</th>
<th>CON</th>
<th>s.e.m.</th>
<th>Sign.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capric (C10:0)</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.000</td>
<td>NS</td>
</tr>
<tr>
<td>Lauric (C12:0)</td>
<td>0.05</td>
<td>0.05</td>
<td>0.04</td>
<td>0.005</td>
<td>NS</td>
</tr>
<tr>
<td>Myristoleic (C14:0)</td>
<td>1.27*</td>
<td>1.73*</td>
<td>1.28</td>
<td>0.08 *</td>
<td>**</td>
</tr>
<tr>
<td>Myristic (C14:1)</td>
<td>0.27</td>
<td>0.37</td>
<td>0.27</td>
<td>0.01</td>
<td>NS</td>
</tr>
<tr>
<td>Palmitoleic (C16:0)</td>
<td>20.91</td>
<td>22.56*</td>
<td>23.22</td>
<td>0.882</td>
<td>NS</td>
</tr>
<tr>
<td>Palmitic (C16:1)</td>
<td>2.16</td>
<td>2.19</td>
<td>2.51</td>
<td>0.191</td>
<td>+</td>
</tr>
<tr>
<td>Heptadecanoic (C17:0)</td>
<td>1.06</td>
<td>1.00</td>
<td>0.94</td>
<td>0.105</td>
<td>NS</td>
</tr>
<tr>
<td>Heptadecenoic (C17:1)</td>
<td>0.57</td>
<td>0.59</td>
<td>0.57</td>
<td>0.064</td>
<td>NS</td>
</tr>
<tr>
<td>Stearic (C18:0)</td>
<td>18.26</td>
<td>17.22</td>
<td>17.56</td>
<td>1.105</td>
<td>NS</td>
</tr>
<tr>
<td>Oleic (C18:1 n-9)</td>
<td>26.03b</td>
<td>34.23d</td>
<td>34.29</td>
<td>2.316</td>
<td>NS</td>
</tr>
<tr>
<td>Vaccenic (C18:1 n-7)</td>
<td>2.88ab</td>
<td>2.43ab</td>
<td>3.73a</td>
<td>0.503</td>
<td>+</td>
</tr>
<tr>
<td>Linoleic (C18:2 n-6)</td>
<td>14.45</td>
<td>12.77</td>
<td>11.13</td>
<td>2.315</td>
<td>NS</td>
</tr>
<tr>
<td>Linolenic (C18:3 n-3)</td>
<td>4.11**</td>
<td>1.02b</td>
<td>0.25a</td>
<td>0.531</td>
<td>**</td>
</tr>
<tr>
<td>CLA, cis, trans (C18:2 n-7)</td>
<td>0.32b</td>
<td>0.32a</td>
<td>0.63a</td>
<td>0.085</td>
<td>**</td>
</tr>
<tr>
<td>Arachidic (C20:0)</td>
<td>0.15*</td>
<td>0.12b</td>
<td>0.12b</td>
<td>0.009</td>
<td>NS</td>
</tr>
<tr>
<td>Gadoleic (C20:1)</td>
<td>0.31**</td>
<td>0.25b</td>
<td>0.24a</td>
<td>0.016</td>
<td>**</td>
</tr>
<tr>
<td>Arachidonic (C20:4 n-6)</td>
<td>3.93</td>
<td>2.90</td>
<td>2.94</td>
<td>0.058</td>
<td>NS</td>
</tr>
<tr>
<td>Eicosapentanoic (C20:5 n-3)</td>
<td>1.16b</td>
<td>0.68b</td>
<td>0.12a</td>
<td>0.203</td>
<td>**</td>
</tr>
<tr>
<td>Docosatetraenoic (C22:4 n-6)</td>
<td>0.22b</td>
<td>0.22b</td>
<td>0.46a</td>
<td>0.045</td>
<td>**</td>
</tr>
<tr>
<td>Clupadonic (C22:5 n-3)</td>
<td>2.02**</td>
<td>1.15**</td>
<td>0.44b</td>
<td>0.289</td>
<td>**</td>
</tr>
<tr>
<td>SFA</td>
<td>42.06</td>
<td>43.13</td>
<td>44.17</td>
<td>1.787</td>
<td>NS</td>
</tr>
<tr>
<td>MUFA</td>
<td>32.22b</td>
<td>38.22a</td>
<td>39.85b</td>
<td>2.416</td>
<td>**</td>
</tr>
<tr>
<td>PUFA</td>
<td>25.71a</td>
<td>18.65b</td>
<td>15.98a</td>
<td>3.581</td>
<td>**</td>
</tr>
<tr>
<td>PUFA:SFA</td>
<td>0.63a</td>
<td>0.44b</td>
<td>0.36a</td>
<td>0.107</td>
<td>NS</td>
</tr>
<tr>
<td>n-6 PUFA</td>
<td>18.10</td>
<td>15.48</td>
<td>14.53</td>
<td>2.763</td>
<td>NS</td>
</tr>
<tr>
<td>n-3 PUFA</td>
<td>7.29a</td>
<td>2.86b</td>
<td>0.82a</td>
<td>0.956</td>
<td>**</td>
</tr>
<tr>
<td>n-6:n-3</td>
<td>2.50b</td>
<td>6.20b</td>
<td>17.88b</td>
<td>1.133</td>
<td>+</td>
</tr>
</tbody>
</table>

s.e.m.: standard error of the mean; Sign: significance; NS: non significant.

A CON: concentrate-feeding; LUC: lucerne grazing + 1.8 kg DM barley/day; LUC + CON: lucerne grazing + 1.8 kg DM barley/day for 3 months and finishing on concentrates for 2 months.
B SFA: Saturated Fatty Acids; MUFA: Monounsaturated Fatty Acids; PUFA: Polyunsaturated Fatty Acids.

** P < 0.05.
* P < 0.01.
*** P < 0.001.
† P < 0.10.
abc Means within a row with different superscript differ at P < 0.05.

Table 5

<table>
<thead>
<tr>
<th>Sensory panel test evaluation according to fattening strategy.</th>
<th>LUC</th>
<th>LUC + CON</th>
<th>CON</th>
<th>s.e.m.</th>
<th>Sign.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef odour</td>
<td>4.7</td>
<td>4.8</td>
<td>4.3</td>
<td>0.43</td>
<td>NS</td>
</tr>
<tr>
<td>Abnormal odour</td>
<td>3.1</td>
<td>2.6</td>
<td>3.2</td>
<td>0.64</td>
<td>NS</td>
</tr>
<tr>
<td>Tenderness</td>
<td>5.4</td>
<td>5.7</td>
<td>5.8</td>
<td>0.42</td>
<td>NS</td>
</tr>
<tr>
<td>Juiciness</td>
<td>4.1</td>
<td>4.4</td>
<td>4.6</td>
<td>0.43</td>
<td>NS</td>
</tr>
<tr>
<td>Beef flavour</td>
<td>5.0</td>
<td>5.1</td>
<td>5.0</td>
<td>0.44</td>
<td>NS</td>
</tr>
<tr>
<td>Abnormal flavour</td>
<td>4.1</td>
<td>3.2</td>
<td>4.1</td>
<td>0.68</td>
<td>NS</td>
</tr>
</tbody>
</table>

s.e.m.: standard error of the mean; Sign: significance; NS: non significant.

A CON: concentrate-feeding; LUC: lucerne grazing + 1.8 kg DM barley/day; LUC + CON: lucerne grazing + 1.8 kg DM barley/day for 3 months and finishing on concentrates for 2 months.

** P < 0.05.
carotenoids to beef that improve the antioxidant status and colour shelf life (Scollan et al., 2006).

In a review compiling several studies, Priolo et al. (2001) concluded that L* is 5% lower in pasture- than in concentrate-fed cattle. Several studies reported differences in L* and a* between forage- and concentrate-fed steers (Muir et al., 1998b; Yang et al., 2002), however, carcase weight was also different, which led to different cooling rates that affected meat colour (Yang et al., 2002). Other studies (Dieguez Camerón et al., 2006) reported differences in L* and/or a* between forage- and concentrate-fed cattle slaughtered at similar weight, but in this case forage-fed animals were older at slaughter, and myoglobin increases with age (Renerre, 1986). Some authors argued that differences in lightness could be partially explained by differences in the intramuscular fat content (Coulon & Priolo, 2002). Conversely, confirming the results of the current study, others (Cerdeño et al., 2006; French et al., 2001) reported that forage- and concentrate-fed cattle slaughtered at similar live weight had similar L* and a*, despite the different IMF fat content.

Most of the studies cited above measured meat colour after only 1 or 2 days of air exposure, and Daly, Young, Graafhuis, and Moorhead (1999) suggested that if their measuring time had been extended differences might have appeared between forage- and concentrate-fed steers, as the former had greater tocochromanol content in their meat. Accordingly, Hue angle value, which is related to the state of pigments (Renerre, 1986), of LUC young bulls at day 14 of air exposure was similar to the value on day 1, whereas in LUC + CON and CON young bulls it was higher, which implies that shelf life of the former would be greater.

4.3. Drip loss and instrumental texture variables

The lack of effect of fattening strategy on drip loss is in agreement with several studies (French et al., 2000a; French et al., 2001; Hornick et al., 2000).

Tenderness is affected by carcase weight, fatness and chronological age (Muir et al., 1998a), and is improved with ageing (French et al., 2001). In the current study, all these factors were similar among fattening strategies and texture traits did not differ (Davis, 1977; McCaughey & Cleif, 1996). Other authors reported that forage- and concentrate-fed cattle slaughtered at similar weight had different tenderness related to differences in fatness degree (French et al., 2000a) or age at slaughter (Nuernberg et al., 2005). However, when ageing time was increased to 7 or 14 days differences in tenderness between forage- and concentrate-fed cattle disappeared (French et al., 2000a). In the current study, LUC + CON and CON calves had similar tenderness despite the differences in weight gains prior to slaughter. Conversely, Geay et al. (2001) and Hoch et al. (2003) suggested that compensatory growth might improve tenderness, which is affected by the calpain system. However, relationships among growth rates, tenderness and the calpain proteolytic system are not clear (Sazili et al., 2003; Therkildsen, Houbak, & Byrne, 2008).

4.4. Chemical composition

When intramuscular fat contents of concentrate- and forage-fed cattle are compared, different results have been reported. In the current study, concentrate-fed (LUC + CON and CON) young bulls had greater intramuscular fat content than forage-fed (LUC) young bulls. Similarly, others reported that concentrate-fed cattle had greater intramuscular fat content than forage-fed cattle slaughtered at similar live weights (Nuernberg et al., 2005; Vestergaard et al., 2000). Most of the studies that reported differences in intramuscular fat content also reported differences in subcutaneous fat thickness (French et al., 2001; Moreno et al., 2007), which is consistent with the current study, where both subcutaneous fat content measured in the 10 rib and intramuscular fat content were different between concentrate-fed (LUC + CON and CON) and forage-fed (LUC) young bulls. The differences in intramuscular fat content could be related to the different feed type and feeding level but also to the different housing system (Vestergaard et al., 2000), due to different exercise levels (Jurie, Picard, & Geay, 1998). According to Pethick et al. (2004), the greatest potential for increasing intramuscular fat deposition during fattening is via an increase in the net energy of the ration. On the other hand, Moloney, Fallon, Mooney, and Troy (2004) reported differences in intramuscular fat content between bulls fed concentrates indoors or at pasture and suggested that this difference was related to the greater energy expenditure on exercise and/or partitioning of absorbed energy towards muscle as a result of exercise and greater energy expenditure to maintain core body temperature. However, there were differences in carcase weight and fatness, and these parameters are correlated with intramuscular fat content (Muir et al., 1998a). In the current study, the level of exercise differed only slightly among fattening strategies. Exercise affects meat colour and tenderness (Jurie et al., 2006), and NEFA concentrations in blood (Hocquette, Ortigues-Marty, Pethick, Herpin, & Fernandez, 1998), and all of these parameters were similar among fattening strategies (unpublished data).

In the present study, short-term concentrate-feeding increased intramuscular fat content compared with forage feeding. Several studies reported that cattle finished on concentrates for a minimum of 45 days after grazing had similar intramuscular fat contents as cattle continuously-fed concentrates (Dieguez Camerón et al., 2006; Duke, Wagner, Yates, Dolezal, & May, 1993; Moreno et al., 2007). On the contrary, others described that after 75–98 days on concentrates intramuscular fat content was not increased (McCaughey & Cleif, 1996; Muir et al., 1998b). Differences among studies in breed, sex status, and the severity of restriction during forage feeding in cattle can be responsible for differences in fat deposition.

Fat deposition might be confined to some body compartments, and cattle under compensatory growth might have less intramuscular fat than continuously grown cattle due to fast muscle growth (Hornick et al., 2000). In contrast, our results show that LUC + CON and CON young bulls presented similar fat contents, which is in accordance with other studies reporting that chemical composition did not differ among continuously grown and restricted-realmimented cattle (Ryan et al., 1993).

4.5. Fatty acid composition

Total SFA were similar between LUC and CON young bulls but MUFA was lower in the former, as previous comparisons between concentrate- and forage-fed cattle reported (French et al., 2000b; Scollan et al., 2006; Steen et al., 2003). Total MUFA increased mainly due to an increase in oleic acid content, which is increased with grain feeding because of decreased ruminal biohydrogenation of the fatty acids (Duckett et al., 1993).

The dominant PUFA in beef are linoleic acid, which is at high levels in concentrates, and linolenic acid, a major dietary fatty acid for ruminants because it constitutes over 50% of total fatty acids in forage and its products (Scollan et al., 2006). However, cautious comparison with other studies should be made as forage species and conservation method may affect both acid contents (Boufaied et al., 2003).

Linoleic acid did not differ among feeding strategies, which contradicts previous research that reported that concentrate-feeding increased this fatty acid compared with forage feeding (French et al., 2000b; Mandell, Buchanan-Smith, & Campbell, 1998). On the one hand, beef from LUC young bulls might present greater
linoleic acid content than expected because legumes have more linoleic than grasses (Boufaied et al., 2003), which were mainly used in the above studies. On the other hand, LUC young bulls received a grain supplement, which increases linoleic acid content compared with unsupplemented cattle (French et al., 2000b). Since part of dietary linolenic acid escapes from ruminal hydrogenation, meat from forage-fed cattle has greater linolenic acid than that from concentrate-fed cattle (Mandell et al., 1998; Scollan et al., 2006), as seen in the current study.

The reason for the lower CLA cis-9, trans-11 content in both lucerne strategies (LUC and LUC + CON) than in CON young bulls remains unclear. Other authors (French et al., 2000b; Scollan et al., 2006) reported greater CLA in forage- than in concentrate-fed cattle. In the current study, both vaccinated and linoleic acid contents were similar in LUC and CON young bulls. The primary source of CLA found in beef is endogenous synthesis from vaccenic acid, confirmed by the linear relationship between vaccenic and CLA content (Enser et al., 1999), which was also observed in the current study ($r = 0.87$, $P < 0.001$). But CLA is also formed during biodegeneration of linoleic acid in the rumen and the proportion of CLA deposited depends upon the basal diet, breed, age and sex of the animals (Scollan et al., 2006). The type of forage might also influence CLA deposition. In that sense, legumes had greater linoleic and lower linolenic acids than grasses (Boufaied et al., 2003), and the ratio between these two fatty acids might affect the quantity of CLA deposited (Clapham, Foster, Neel, & Fedders, 2005). Moreover, grain supplementation decreases CLA content in relation to unsupplemented forage-fed cattle (French et al., 2000b).

After absorption in the rumen, dietary linoleic and linolenic acids elongate and desaturate leading to an enhanced synthesis of $n$–3 long chain PUFA (Nuernberg et al., 2005). Consequently, total PUFA were greater due to increased PUFA $n$–3, and $n$–6:$n$–3 ratio more favourable in LUC than in CON young bulls since the nutritional advice is a ratio below 4 (Scollan et al., 2006). These results are in accordance with other comparisons between forage- and concentrate-fed cattle (French et al., 2000b; Scollan et al., 2006; Steen et al., 2003). However, absolute values may be affected by diet (type of forage and supplementation), breed, slaughter weight and intramuscular fat content, because as cattle deposit more fat, an increasing proportion of it is deposited as MUFA (Duckett et al., 1993). In all fattening strategies, the ratio PUFA:SFA is in the recommended range, which is 0.4 or above (Scollan et al., 2006). However, LUC young bulls had greater PUFA:SFA ratios than CON young bulls. The short concentrate-feeding of LUC + CON young bulls reduced PUFA:SFA ratios, which was still above the recommended value, and increased $n$–6:$n$–3 compared to LUC young bulls as previously reported by others (Moreno et al., 2007; Nuernberg et al., 2005).

4.6. Sensory panel

The evaluation of CON calves agrees with previous studies in concentrate-fed young bulls from Brown Swiss and Bruna dels Pirineus breeds (Campo, Sañudo, Panea, Alberti, & Santolaria, 1999; Serra et al., 2008), Parda de Montaña and Bruna dels Pirineus breeds derive from the former Brown Swiss and were both selected for meat production.

Several studies reported that beef from concentrate-fed cattle had greater tenderness and better flavour than that from forage-fed cattle (Kerth et al., 2007; Mandell et al., 1998). However in the above studies, slaughter weight and degree of fat cover differed, and dietary differences are often confounded with fatness (Melton, 1983). Increased tenderness might be an indirect effect of increased intramuscular fat, decreased rate of carcass chilling or younger age (Moloney, Mooney, Kerry, & Tory, 2001), as collagen reticulation increases with age (Coulon & Priolo, 2002). Similarly, studies that compared restricted-realimented and continuously grown cattle reported differences in sensory attributes when slaughter weight (Kerth et al., 2007) or age (Laborde et al., 2002) differed. However, in the current study no differences were found in tenderness and flavour between forage- and concentrate-fed young bulls, as other studies with cattle slaughtered at a common weight had reported (Muir et al., 1998a; Nuernberg et al., 2005). Off-flavours have been related with concentrations of linolenic acid and its derivatives (Melton, 1983; Priolo et al., 2001), which in turn depend on the forage species. Melton (1983) listed a variety of forages that appear to cause beef to have a less desirable flavour than that produced by grain-based diets but lucerne was not included. On the other hand, barley supplementation of LUC calves might have diluted the off-flavours as it has been recommended to supply grain to cattle grazing on pasture to reduce or remove the effect of pasture on flavour (Melton, 1983). Furthermore, Muir et al. (1998a) reported that panellists were unable to detected differences in beef flavour despite the differences in fatty acid profile and flavour volatiles among fattening strategies.

In conclusion, grazing young bulls on lucerne could be interesting because of the desirable fatty acid profile and intramuscular fat content compared with concentrate-fed young bulls, without negative effects on the rest of carcass and meat quality characteristics. Two months of concentrate-feeding did not improve carcass quality compared to lucerne grazing, and gave similar tissue and chemical compositions to those of long term concentrate-feeding.

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