Effect of castration and slaughter age on performance, carcass, and meat quality traits of Holstein calves fed a high-concentrate diet

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ABSTRACT: The aim of this study was to evaluate the effect of castration and slaughter age on performance and meat quality of Holstein bulls fed a high-concentrate diet. A total of 132 animals (116 ± 3.7 kg of BW and 97 ± 2.4 d of age) were randomly allocated in 6 pens using a 3 × 3 factorial arrangement of treatments. Three castration ages [bulls, animals castrated at 3 mo (CAS3), and animals castrated at 8 mo of age (CAS8)] and 3 slaughter ages (10, 12, and 14 mo of age) were evaluated. Feed intake was recorded daily using a computerized concentrate feeder, and BW was recorded every 14 d. The 9th to 11th rib section was removed at 24 h postmortem and dissected into lean, fat, and bone, and meat quality was evaluated on the LM. Castration, at 3 or 8 mo of age, reduced (P < 0.001) ADG and muscle pH and impaired (P < 0.01) feed efficiency. As slaughter age increased, concentrate consumption increased linearly (P < 0.001) and feed efficiency was reduced linearly (P < 0.001). Slaughter age also affected (P < 0.001) meat pH. Significant interactions between castration and slaughter ages were also observed in carcass conformation (P < 0.05), fatness (P < 0.001), percentage of subcutaneous fat (P < 0.01), carcass dressing percentage (P < 0.05), and intramuscular fat (P < 0.05) and tended to be significant in intermuscular fat (P = 0.09). In Holstein animals, castration age affects performance and meat pH regardless of slaughter age, and slaughter age affects performance and meat pH independently of castration. However, in Holstein animals, castration affects several characteristics related to fat deposition differently depending on slaughter age, such as carcass fat cover and intramuscular, intermuscular, and subcutaneous fat.

Key words: beef, castration, meat quality


INTRODUCTION

Optimum slaughter age to obtain maximum net return and desired meat quality may differ depending on castration age, gender, nutrition, and genetics, together with economic factors such as feed costs and carcass prices (Mark et al., 2000; Pyatt et al., 2005). Knight et al. (1999a) studied different castration and slaughter ages in grazing crossbred beef animals and proposed postpubertal castration of calves (13 mo of age) followed by a finishing period as an effective management strategy to maximize benefits. This proposed strategy maintains the performance advantages of intact males until 13 mo and the benefits of castration on meat quality characteristics thereafter. In Holstein bulls slaughtered at 12 mo of age, prepubertal ring castration was recently proposed (Marti et al., 2010) as a castration procedure to reduce labor and rates of failure compared with those obtained using Burdizzo castration (Mach et al., 2009). However, ring castration at 3 mo of age reduced feed efficiency and carcass weight compared with bulls (Marti et al., 2011) and postpubertal (8 mo of age) castrated animals (Mach et al., 2009). In the recent years, in Europe feed prices have drastically increased and as a consequence production costs have risen and net returns have decreased. Amer et al. (1994) observed that in some breeds, the reduction of slaughter age could be an alternative to maximize net return. Therefore, reducing slaughter age of these prepubertal castrated steers could be an alterna-
tive to improve feed efficiency without compromising carcass and meat quality. The aim of this study was to provide the necessary understanding about the effects of age of castration and age of slaughter on performance, carcass, and meat quality of Holstein bulls and steers fed high-concentrate diets to determine the optimum castration age and its corresponding optimum slaughter.

**MATERIALS AND METHODS**

**Animals, Housing, and Diets**

One hundred thirty-two weaned Holstein calves (116 ± 3.7 kg of BW and 97 ± 2.4 d of age) were managed using the principles and guidelines of the Animal Care Committee of Institut de Recerca i Tecnologia Agroalimentàries and randomly distributed to 1 of the 9 treatments using a complete randomized design with a 3 × 3 factorial arrangement of treatments: bulls, animals castrated at 3 mo of age (CAS3), and animals castrated at 8 mo of age (CAS8) and slaughtered at 10, 12, and 14 mo of age. Number of replicates for each treatment was 14 or 15. Animals were housed at a commercial farm (Montgai, Spain) in 6 pens (2 pens for each castration age). Animals in the CAS3 group were castrated using ring castration as described elsewhere (Marti et al., 2010) whereas CAS8 were surgically castrated following Ting et al. (2003). In each pen, animals had access to 1 computerized concentrate feeder (GEA Surge-Westfalia, Bönnen, Germany) that recorded individual daily concentrate consumption (Devant et al., 2012), to 1 water source, and also ad libitum access to barley straw [3.5% CP, 1.6% ether extract (EE), 70.9% NDF, 6.1% ash, and 1.45 Mcal ME/kg; DM basis] in a separate feed trough (3 by 1.12 by 0.65 m; 7 feeding spaces). The amount of straw offered to each pen was recorded to estimate the total amount of straw consumed; however, as straw was also used for bedding, these data are only estimates. In the present study, apparent straw intake was around 756 ± 58 g/d (Devant et al., 2012), corresponding to a concentrate to straw ratio of 89 to 11. All animals were fed ad libitum the same concentrate (40% corn, 21% barley, 15% wheat middlings, 14.3% soybean meal, 5% soyhulls, 2.6% palm oil, 1.6% calcium carbonate, 0.3% salt, 0.2% premix; 14.6% CP, 5.4% EE, 16.7% NDF, 4.6% ash, 3.25 Mcal EM/kg, 0.7% Ca, 0.4% P, 0.4% Cl, and 0.1% Na; DM basis) throughout the study. Body weight was recorded every 14 d until animals were transported to the slaughterhouse.

**Chemical Analyses**

Feed samples were analyzed for DM (24 h at 103°C), ash (4 h at 550°C), CP by the Kjeldahl method (AOAC International, 1995), NDF according to Van Soest et al. (1991) using sodium sulfite and α-amylase, and fat by Soxhlet with a previous acid hydrolysis (AOAC International, 1995).

**Carcass and Meat Quality Measurements**

At 10, 12, and 14 mo of age, animals were randomly selected and transported to a commercial slaughterhouse (Mercabarna, Barcelona, Spain). Animals from different treatments were not mixed in the truck, and the transport distance was fewer than 150 km. Animals were stunned using a captive-bolt pistol and dressed according to commercial practices. The HCW (with tail attached and without kidney, liver, and heart) was recorded, and the degree of carcass conformation and fatness were graded according to the EUROP categories [European Union (EU) regulation number 1208/81 and 1026/91] and into EU classification system into 1.2.3.4.5 (EU regulation number 1208/81), respectively. The conformation class designated by the letter “E” (excellent) describes carcasses with all profiles convex to superconvex and with exceptional muscle development whereas the conformation classified as “U” (very good) present profiles on the whole straight and with good muscle development. Carcasses classified as “R” (good) present profiles on the whole straight and with good muscle development. Carcasses classified as “O” (fair) present profiles straight to concave and with average muscle development, and carcasses classified as “P” (poor) present all profiles concave to very concave with poor muscle development. In addition, the degree of fat cover describes the amount of fat on the outside of the carcass and in the thoracic cavity. The class of fat ranges from 1 to 5, in which the class 1 describes none to low fat cover and no fat in the thoracic area and the class 5 describes an entire carcass covered with fat and important fat deposition in the thoracic area. After 24 h of carcass chilling, a bone-in rib section between the 9th and 11th ribs was removed as outlined by Hankins and Howe (1946) and used to determine physical separable fat, lean, and bone and to predict carcass composition using the equations proposed by Hankins and Howe (1946). In addition, the subcutaneous (s.c.), intermuscular, and remaining fat were removed from the 9th, 10th, and 11th rib section and weighed based on Walstra and Merkus (1995). The LM and remaining lean were also removed from the 9th, 10th, and 11th rib section and weighed. The different rib dissection tissues were expressed as percentage relative rib cut weight as described by Hankins and Howe (1946).

Muscle pH was measured at 24 h postmortem using a portable pH meter (PH 25 DL; Crison, Alella, Spain) equipped with a xerolyt electrode inserted in the LM at the 11th rib level. The LM was removed from each
rib section and cut between the 10th and 11th rib and instrumental color measurements recorded. Lightness \((L^*)\), redness \((a^*)\), and yellowness \((b^*)\) were measured on the exposed cut surface of the LM after 30 min of bloom time using a Minolta colorimeter (CR-400, Minolta Inc., Osaka, Japan) in the CIE-LAB space (CIE, 1976) with illuminant D65 and 2° viewing angle. After measuring color, the LM was cut into 4 steaks (2.5 cm each), which were individually vacuum packaged; 2 of them were immediately frozen \((d = 0)\) and the other 2 were stored at 4°C during 7 d of aging and then frozen for subsequent sensory analysis and Warner-Bratzler shear force (WBSF) measurements. The remaining steak of the LM was vacuum packaged and stored at −20°C until determination of intramuscular \((i.m.)\) fat content as described in Marti et al. (2011) and protein and humidity using near-infrared transmission (FoodScan analyzer, Type 78800; FOSS, Hilleroed, Denmark).

The steaks for WBSF analysis were thawed for 24 h at 2°C, wrapped in aluminum foil, and cooked to an internal temperature of 71°C in an oven preheated to 200°C. Sample internal temperature was monitored with a data logger and a thermocouple probe inserted horizontally at the steak midpoint. Cooked steaks were allowed to come to room temperature during 2 h before 6 cores \((1 \text{ cm}^2 \times 3 \text{ cm})\) were removed per steak, with the fiber direction parallel to the longest dimension of the sample, and shared perpendicular to the direction of the blade. The WBSF was measured using a texture analyzer Alliance RT/5 (MTS Systems Corp., Eden Prairie, MN) equipped with a Warner-Bratzler blade with crosshead speed set at 2 mm/s.

For sensory attributes evaluation, thawing and cooking were accomplished using the same protocol described previously for WBSF determination. After cooking, each sample was cut into subsamples. Each subsample was immediately wrapped in aluminum foil, codified, and kept in a heater to maintain a constant temperature of 60°C until panelist assessment (Serra et al., 2008). Trained panelists evaluated the cooked subsamples in individual booths provided with red light. The subsamples were tasted in a different order in each session to eliminate carryover effects (MacFie and Thompson, 1988). Panelists were required to rate each subsample for beef flavor, initial hardness, overall hardness, and juiciness. Each attribute was rated on a nonstructured 10-point scale, with score 0 equivalents representing the least and 10 the greatest intensity of the attribute.

Statistical Analyses

Animal was the experimental unit. Normally distributed variables (performance and meat quality data) were analyzed using a mixed-effects model (SAS Inst. Inc., Cary, NC) including castration age, slaughter age, and the interactions between these factors as fixed effects and pen as a random effect. The model was also tested for linear and quadratic effects of slaughter age and their interaction with the other fixed effects. To analyze sensory evaluation data, the same model was used and also included panelist and session as random effects was used. Carcass conformation and fatness were analyzed using the \(\chi^2\) test of SAS. Significance was established at \(P < 0.05\) and trends at \(P \leq 0.10\).

RESULTS

Four bulls and 3 CAS8 were removed from the study due to health problems unrelated to treatments (pneumonia, anorexia, and lameness), and their corresponding data were excluded from all analyses. Also, all data from 1 CAS8 that died the day after castration \(\text{the necropsy did not lead to a clear diagnosis were excluded as well.}

To simplify the presentation of results, tables herein show least squares means for the main effects because only a few interactions between castration and slaughter age were significant \((P < 0.10)\) and these are indicated in the tables with least square means being described in the text.

Performance

No interactions between castration age and slaughter age were found for performance data. The final BW of bulls was greater \((P < 0.001)\) than that of CAS8 and CAS3. No differences in final BW were observed between CAS8 and CAS3. Final BW increased linearly \((P < 0.001)\) with slaughter age; final BW of 14 mo was 16.0 and 27.7% greater than final BW at 12 and 10 mo of age, respectively (Table 1). Average daily gain was not affected by slaughter age; however, castration had a detrimental effect \((P < 0.001)\) on ADG. Bulls had a greater ADG than CAS8 and CAS3; CAS8 tended \((P = 0.10)\) to have a greater ADG than CAS3 (Table 1).

No differences were observed in concentrate intake between bulls and castrated animals \(\text{Table 1); the same results were obtained when concentrate intake or nutrient intake were expressed as percentage of metabolic BW (data not shown). As a result of increased ADG in bulls, these animals were more efficient \((P < 0.01)\) than castrated ones. Concentrate intake increased linearly \((P < 0.001)\) with slaughter age, with animals slaughtered at 10 mo consuming 9.5% less than animals slaughtered at 12 mo and animals slaughtered at 12 mo consuming 8.9% less than animals slaughtered at 14 mo of age. A similar slaughter age effect was observed when concentrate intake and nutrient intake were expressed as percentage of metabolic BW (data not shown). Concentrate intake expressed as percentage of metabolic BW increased
When animals were slaughtered at 10 mo of age, dressing percentage was 11.5% ± 1.4 of concentrate intake expressed as percent-ADG but did affect concentrate intake, feed efficiency was greater (P < 0.01) than that of animals slaughtered at 10 mo of age. Because slaughter age did not affect ADG but did affect concentrate intake, feed efficiency decreased linearly (P < 0.001) with slaughter age.

### Carcass Quality

Hot carcass weight was affected by castration age (P < 0.001) and describing a linear increase (P < 0.001) with slaughter age. Hot carcass weight of bulls was greater (P < 0.01) than that of castrated animals (Table 2). The HCW of animals slaughtered at 14 mo of age was 16% greater (P < 0.001) than that of animals slaughtered at 12 mo of age, and HCW of the latter was 19.9% greater than that of animals slaughtered at 10 mo of age. In dressing percentage the interaction between castration age × quadratic slaughter age tended to be significant with a nonlinear effect (P = 0.06). When animals were slaughtered at 10 mo of age, dressing percentage was greater (P < 0.01) in bulls (52.8 ± 0.34%) than in CAS8 (51.1 ± 0.34%) and tended to be greater (P = 0.07) in bulls than in CAS3 (51.9 ± 0.34%); however, no differences among castration ages (CAS8 and CAS3) were observed. At 12 mo of age, the lowest dressing percentage (P < 0.01) was observed in CAS8 (52.1 ± 0.34%), and no differences (P = 0.13) in dressing percentage were observed between bulls (53.9 ± 0.34%) and CAS3 (53.2 ± 0.34%). Last, at 14 mo of age no differences in dressing percentages among treatments were observed (52.9, 52.7, and 52.5 ± 0.34% for bulls, CAS8, and CAS3, respectively).

Carcass fat cover and conformation were affected by an interaction (P < 0.05) between castration and slaughter age. Animals slaughtered at 10 mo of age presented 91.7, 53.8, and 85.7% of carcasses classified as “O” for bulls, CAS8, and CAS3, respectively; these proportions increased with slaughter age in all animals; however, the increase was more pronounced for CAS8. At 12 mo of slaughter age, 92.9, 92.3, and 80% of carcasses were classified as “O” for bulls, CAS8, and CAS3, respectively. At 14 mo of slaughter age, 100, 92.9, and 93.3% of carcasses were classified as “O” for bulls, CAS8, and CAS3, respectively. At 10 mo of age, CAS8 had the greatest percentage of carcasses classified as “P” (the lowest carcass classification) compared with bulls and CAS3 (42.6, 8.3, and 14.3% for CAS8, bulls, and CAS3, respectively). However, at 12 mo of age, CAS8 reduced the percentage of carcasses classified as “P” to 7.7% whereas CAS3 increased this percentage to 20%. At 14 mo of age, only CAS3 registered carcasses classified as “P” (6.7%). However, carcasses classified as “R,” which corresponds to the best carcass conformation registered in Holstein animals under the production system described herein, were only registered at 14 mo of age in CAS8 with a percentage of 7.1%. At 10 mo of age, 50% of bulls and above 90% of castrated animals (CAS3 and CAS8) slaughtered were classified as “2” for carcass fat cover, and 50% of bulls and 7.7% of CAS8 were classified as “1” (the lowest carcass fat cover classification). At 12 mo of age and 14 mo of age no carcasses classified as “1” were recorded. At 12 mo of age the carcass fat cover of bulls increased, and 100% of bull carcasses were classified as “3.” For CAS8, no carcasses were classified as “3” at 10 mo of slaughter age, and at 12 mo of age this proportion of carcasses classified as “3” was 38.5%. Animals castrated at 3 mo of age had 7.2% of carcass classified as “3” at 10 mo of age and this proportion was maintained when CAS3 were slaughtered at 12 mo of slaughter age (60%). At 14 mo of slaughter age,
78.6% of bulls, 100% of CAS8, and 86.7% of CAS3 were classified as “3” of carcass fat cover.

**Rib Section Data**

Castration age had no effect on section weight of the 9th, 10th, and 11th ribs (Table 2). However, rib weight increased linearly ($P < 0.001$) with slaughter age (Table 2). Bulls had 31.5% less ($P < 0.001$) proportion of rib-separable fat than CAS3, and the proportion of separable fat of CAS8 was 8.9% less ($P < 0.001$) than that of CAS3. The proportion of rib-separable fat showed a quadratic effect ($P < 0.001$) with slaughter age; between 10 and 12 mo of age rib-separable fat increased ($P < 0.001$), and from 12 to 14 mo of age no further increase in the proportion of rib-separable fat was observed. A nonlinear slaughter age × castration age interaction ($P < 0.01$) was observed in the proportion of rib-separable s.c. fat. At 10 mo of age, the proportion of rib-separable s.c. fat tended ($P = 0.08$) to be greater in CAS3 ($7.6 \pm 0.76$%)

<table>
<thead>
<tr>
<th>Item</th>
<th>Castration age</th>
<th>Slaughter age</th>
<th>SEM</th>
<th>CA</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW before slaughter, kg</td>
<td>Bulls CAS8 CAS3</td>
<td>10 12 14</td>
<td>P-value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCW, kg</td>
<td>494b 478b 464b</td>
<td>405a 475b 555a</td>
<td>5.5</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Dressing percentage, %</td>
<td>53.2a 52.0c 52.5b</td>
<td>51.9b 53.0a 52.7a</td>
<td>0.20</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Carcass fat cover, %</td>
<td>15.0 2.5 0</td>
<td>17.9 0 0</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>57.5 50.0 47.3</td>
<td>79.5 66.7 11.6</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>27.5 47.5 52.7</td>
<td>2.6 33.3 88.4</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Carcass conformation, %</td>
<td>5.0 17.5 13.6</td>
<td>23.1 11.9 2.3</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>95.0 80 86.4</td>
<td>76.9 88.1 95.3</td>
<td>0.25</td>
<td>&lt;0.01</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>0 2.5 0</td>
<td>0 0 2.33</td>
<td>&lt;0.01</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Ninth-tenth-eleventh-rib weight, kg</td>
<td>4.5 4.4 4.3</td>
<td>3.7c 4.2b 5.3a</td>
<td>0.07</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Ninth-tenth-eleventh-rib cut</td>
<td>19.2c 25.7b 28.0a</td>
<td>19.6b 26.3a 27.0a</td>
<td>0.67</td>
<td>&lt;0.001</td>
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</tr>
<tr>
<td>Separable fat, %</td>
<td>6.4b 8.8a 9.5a</td>
<td>5.7c 10.8b 8.1b</td>
<td>0.44</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Separable subcutaneous fat, %</td>
<td>8.3c 11.1b 12.6a</td>
<td>9.0b 9.4b 13.5a</td>
<td>0.40</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Separable intermuscular fat, %</td>
<td>4.5b 5.9a 5.9a</td>
<td>4.9b 6.0a 5.3b</td>
<td>0.21</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Separable remaining fat, %</td>
<td>58.9a 53.0b 50.8c</td>
<td>56.9a 53.0b 52.8b</td>
<td>0.55</td>
<td>&lt;0.001</td>
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<tr>
<td>Separable LM, %</td>
<td>27.0a 24.5b 22.7c</td>
<td>26.0b 27.8a 21.3c</td>
<td>0.35</td>
<td>&lt;0.001</td>
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<tr>
<td>Separable remaining lean, %</td>
<td>31.1a 28.5b 28.1b</td>
<td>30.9a 25.2b 31.5a</td>
<td>0.42</td>
<td>&lt;0.001</td>
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</tr>
<tr>
<td>Separable bone, %</td>
<td>21.9a 20.7b 20.6b</td>
<td>22.9a 20.2b 20.1b</td>
<td>0.27</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Ninth-tenth-eleventh-rib cut (edible portion)</td>
<td>17.3a 15.9b 15.4c</td>
<td>16.8a 15.9b 15.9b</td>
<td>0.13</td>
<td>&lt;0.001</td>
<td></td>
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<tr>
<td>Protein, %</td>
<td>22.7c 28.2b 30.2a</td>
<td>23.1b 28.7a 29.3b</td>
<td>0.57</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

4 For each factor studied (castration age or slaughter age) means within rows not bearing a common superscript letter differ ($P < 0.05$).
1 Bulls, CAS3 = bulls castrated at 3 mo of age, CAS8 = bulls castrated at 8 mo of age.
2 10 = animals slaughtered at 10 mo of age; 12 = animals slaughtered at 12 mo of age; 14 = animals slaughtered at 14 mo of age.
3 CA = effect of castration age; SA = effect of slaughter age.
4 P-value corresponding to the linear (L) effect ($P < 0.001$) and to the quadratic effect ($P = 0.10$) of slaughter age.
5 Interaction between castration age and slaughter age (dressing percentage, $P < 0.05$; carcass fat cover, $P < 0.001$; carcass conformation, $P < 0.05$; separable subcutaneous fat, $P = 0.05$; and separable intermuscular fat, $P = 0.07$).
6 P-value corresponding to the linear (L) effect ($P < 0.001$) of castration age, and the interaction of the linear (L) of slaughter age by castration age ($P = 0.09$), the quadratic (Q) effect ($P < 0.01$) of slaughter age, and the interaction of the quadratic (Q) effect of slaughter age by castration age ($P = 0.06$).
7 P-value corresponding to the linear (L) effect ($P = 0.02$); and to the quadratic (Q) effect ($P = 0.74$) of slaughter age.
9 P-value corresponding to the linear effect ($P < 0.001$) and to the quadratic effect ($P < 0.001$) of slaughter age.
10 P-value corresponding to the linear effect ($P < 0.001$) of castration age and the interaction between the linear of slaughter age and castration age ($P = 0.06$), the quadratic effect ($P < 0.001$) of slaughter age, and the interaction between the quadratic effect of slaughter age and castration age ($P < 0.01$).
11 P-value corresponding to the linear effect ($P < 0.01$) of castration age and the interaction between the linear of slaughter age and castration age ($P = 0.17$), the quadratic effect ($P < 0.001$) of slaughter age, and the interaction between the quadratic effect of slaughter age and castration age ($P = 0.09$).
compared with CAS8 (5.7 ± 0.76%) and bulls (3.8 ± 0.76%). At 12 mo of age, this proportion was also greater (P < 0.05) in CAS3 (13.2 ± 0.76%) than CAS8 (10.9 ± 0.76%) and bulls (8.3 ± 0.76%). From 12 to 14 mo of age a pronounced decrease (P < 0.01) in the proportion of rib-separable s.c. fat was observed in CAS3, and at 14 mo of age this proportion did not differ among bulls (7.0 ± 0.76%), CAS8 (9.7 ± 0.76%), and CAS3 (7.5 ± 0.76%). In the proportion of rib-separable intermuscular fat a nonlinear slaughter age × castration age interaction tended to be significant (P = 0.09). The proportion of rib-separable intermuscular fat tended (P = 0.10) to decrease from 10 (8.8 ± 0.69%) to 12 mo (7.4 ± 0.69%) of age in CAS8 whereas in bulls (7.2 and 7.4 ± 0.69% for 10 and 12 mo of age, respectively) and CAS3 (10.9 and 10.4 ± 0.69% for 10 and 12 mo of age, respectively) it did not change. From 12 to 14 mo of slaughter age this proportion increased in all treatments, with CAS3 showing the greatest (P < 0.05) rib-separable i.m. fat (16.5 ± 0.69%) compared with bulls (10.1 ± 0.69%) and CAS8 (13.9 ± 0.69%).

Castration age affected the proportion of total separable lean (P < 0.001). Bulls had a 16.0% greater (P < 0.001) separable lean than CAS3, and the proportion of total rib-separable lean of CAS8 was 4.7% greater (P < 0.001) than that observed in CAS3. The proportion of total separable lean decreased quadratically (P < 0.001) with slaughter age. The proportion of LM in the rib was affected by castration age (P < 0.001) and a quadratic effect of slaughter age (P < 0.001) was observed. The proportion of LM in the rib was greater (P < 0.001) in bulls compared with castrated animals, and in CAS8 this proportion was greater (P < 0.001) than CAS3. Also, the proportion of remaining lean after LM removal was greater (P < 0.001) in bulls compared with castrated animals, and no differences were observed between CAS8 and CAS3 (Table 2). The rib-separable bone proportion was affected by castration age (P < 0.01) and quadratically by slaughter age (P < 0.001; Table 2), with bulls having a greater (P < 0.01) proportion of rib-separable bone compared with CAS8 and CAS3. The proportion of rib-separable bone was greater (P < 0.001) in animals slaughtered at 10 mo compared with animals slaughtered at 12 and 14 mo of age. As expected, the carcass content of protein and ether extract estimated by equations described by Hankins and Howe (1946) followed the same pattern of the proportions of separable rib lean and fat, respectively.

**Meat Quality**

Meat pH was greater (P < 0.001) in bulls than in castrated animals independently of castration age (Table 3). Slaughter age had a quadratic effect (P < 0.001) on meat pH, with the greatest values being obtained at 12 mo of slaughter age.

The WBSF on d 0 of aging was affected by castration age (P = 0.05) and linearly decreased with slaughter age (P < 0.001; Table 3). On d 0, WBSF values for bulls were greater (P < 0.05) than those for CAS8 and CAS3, but these differences were not observed on d 7 of aging. At d 0 of aging, meat from animals slaughtered at 10 or 12 mo of age was less (P < 0.001) tender (greater WBSF values) compared with that from animals slaughtered at 14 mo of age. However, the effect of slaughter age on WBSF was not observed after 7 d of aging.

Meat from CAS3 did not differ in lightness and redness from that of CAS8 (Table 3). However, meat from bulls was darker, less red, and less yellow (P < 0.001) compared with the meat from castrated animals. Lightness and redness were nonlinearly affected by slaughter age (P < 0.001). Meat from animals slaughtered at 10 mo of age was less dark than meat from animals slaughtered at 12 or 14 mo of age, and meat from animals slaughtered at 12 mo of age was more red than meat from animals slaughtered at 10 or 14 mo of age (Table 3). No significant slaughter age effect was observed for b* values.

The percentage of LM i.m. fat was affected by a nonlinear slaughter age × castration age interaction (P < 0.05). In bulls and CAS8, the i.m. fat content increased linearly whereas in CAS3 it increased quadratically with age. At 10 mo of age, CAS3 (2.1 ± 0.23%) had a 55.1% greater (P < 0.01) i.m. than bulls (1.4 ± 0.23%) and CAS8 (1.4 ± 0.23%), and no differences were observed between bulls and CAS8. At 12 mo of age, CAS3 (2.7 ± 0.23%) had 19.1 and 65.0% more i.m. fat than CAS8 (2.3 ± 0.23%) and bulls (1.7 ± 0.23%), respectively. At 14 mo of age the difference in percentage of i.m. fat between CAS3 (3.9 ± 0.23%) and CAS8 (3.2 ± 0.23%) was 18.2% (similar to the differences between CAS3 and CAS8 observed at 12 mo of age); however, the difference between CAS3 and bulls (1.9 ± 0.23%) increased to 98.5%. In LM no interaction in protein percentage between slaughter age and castration age were observed. However, animals castrated at 8 mo of age had greater (P < 0.05) LM protein percentage than bulls and animals castrated at 3 mo of age (Table 3). Moreover, the proportion of LM humidity was affected by a nonlinear slaughter age × castration age interaction (P < 0.01). The humidity percentage followed the opposite pattern of i.m. fat; in bulls and CAS8 it decreased linearly whereas in CAS3 it decreased quadratically with age. At 10 mo of age, CAS3 (71.8 ± 0.20%) and CAS8 (73.9 ± 0.20%) had less (P < 0.05) LM humidity content than bulls (74.5 ± 0.20%) and these differences increased at 12 mo of age. However, at 14 mo of slaughter age, CAS3 had less (P < 0.01) LM humidity percentage than CAS8, and CAS8 had lesser (P = 0.05) LM humidity percent-
Table 3. Meat quality of LM of Holstein bulls, animals castrated at 8 mo of age (CAS8), or animals castrated at 3 mo of age (CAS3) and slaughtered at 10, 12, and 14 mo of age fed a high-concentrate diet

<table>
<thead>
<tr>
<th>Item</th>
<th>Castration age1</th>
<th>Slaughter age2</th>
<th>P-value3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bulls CAS8 CAS3</td>
<td>10 12 14 SEM CA SA</td>
<td></td>
</tr>
<tr>
<td>pH4</td>
<td>5.7a 5.5b 5.5b</td>
<td>5.5c 5.7a 5.6b 0.03 &lt;0.001 &lt;0.001</td>
<td></td>
</tr>
<tr>
<td>WBSF d 0.5,6 kg</td>
<td>6.6a 6.3ab 5.7b</td>
<td>7.0a 6.4a 5.2b 0.28 0.05 &lt;0.001</td>
<td></td>
</tr>
<tr>
<td>WBSF d 7,5 kg</td>
<td>5.0 5.2 5.3</td>
<td>4.8 5.3 5.3 0.27 0.76 0.41</td>
<td></td>
</tr>
<tr>
<td>Instrumental color7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>32.0b 33.7a 34.0a</td>
<td>36.1a 24.3c 29.3b 0.34 &lt;0.001 &lt;0.001</td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td>14.5b 15.9a 15.6a</td>
<td>15.2b 16.7a 14.1b 0.26 &lt;0.001 &lt;0.001</td>
<td></td>
</tr>
<tr>
<td>b*</td>
<td>1.6c 2.3b 2.7a</td>
<td>2.2 2.4 2.4 0.15 &lt;0.001 0.46</td>
<td></td>
</tr>
<tr>
<td>Intramuscular fat,10,11 %</td>
<td>1.6c 2.3b 2.9a</td>
<td>1.6a 2.2b 3.0a 0.13 &lt;0.001 &lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Protein, %</td>
<td>24.3b 24.6a 24.5b</td>
<td>24.5 24.4 24.5 0.09 0.05 0.67</td>
<td></td>
</tr>
<tr>
<td>Humidity,10,12 %</td>
<td>74.2c 73.2a 72.8b</td>
<td>74.1a 73.5b 72.7c 0.12 &lt;0.001 &lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

*For each factor studied (castration age or slaughter age) means within rows not bearing a common superscript letter differ (P < 0.05).
1 Bulls, CAS3 = bulls castrated at 3 mo of age, CAS8 = bulls castrated at 8 mo of age.
2 10 = animals slaughtered at 10 mo of age; 12 = animals slaughtered at 12 mo of age; 14 = animals slaughtered at 14 mo of age.
3CA = effect of castration age; SA = effect of slaughter age.
4P-value corresponding to the linear effect (P < 0.01) and to the quadratic effect (P < 0.001) of slaughter age.
5WBSF = Warner-Bratzler shear force.
6P-value corresponding to the linear effect (P < 0.001) and to the quadratic effect (P = 0.42) of slaughter age.
7L* = lightness; a* = redness; b* = yellowness.
8P-value corresponding to the linear effect (P = 0.08) and to the quadratic effect (P < 0.001) of slaughter age.
9P-value corresponding to the linear effect (P < 0.001) and to the quadratic effect (P < 0.001) of slaughter age.
10Interaction between castration age and slaughter age (intramuscular fat P = 0.06; humidity P = 0.04).
11P-value corresponding to the linear effect (P = 0.60) of castration age and the interaction of the linear of slaughter age × castration age (P = 0.01), the quadratic effect (P = 0.58) of slaughter age, and the interaction of the quadratic effect of slaughter age × castration age (P < 0.05).
12P-value corresponding to the linear effect (P = 0.62) of castration age and the interaction between the linear of slaughter age × castration age (P < 0.001), the quadratic effect (P = 0.51) of slaughter age, and the interaction between the quadratic effect of slaughter age and castration age (P < 0.01).

Age than bulls (71.8 ± 0.20% for CAS3, 72.5 ± 0.20% for CAS8, and 73.8 ± 0.20% for bulls).

Initial hardness was affected (P < 0.05) by a nonlinear castration age effect (Table 4). Initial hardness was greatest at 10 and 12 mo of slaughter age whereas meat from animals slaughtered at 14 mo had the less initial hardness. Meat from bulls and CAS8 had a greater (P < 0.001) initial hardness than that from CAS3. An interaction between castration age and slaughter age tended (P = 0.06) to affect overall hardness. In bulls and CAS8, overall hardness decreased linearly with slaughter age whereas in CAS3 slaughter age did not affect overall hardness. At 10 and 12 mo of slaughter age meat from bulls (6.1 and 6.1 ± 0.09, respectively) and CAS8 (6.1 and 6.1 ± 0.09, respectively) had greater (P < 0.05) hardness values than that from CAS3 (5.8 and 5.6 ± 0.09, respectively). At 14 mo of age, meat from castrated animals, independently of castration age, was less (P < 0.05) hard (5.6 and 5.5 ± 0.09 for CAS8 and CAS3, respectively) than meat from bulls (5.8 ± 0.09). Juiciness was affected by a quadratic interaction between slaughter age and castration age (P = 0.05). Meat from bulls and CAS3 had 6.7 and 5.0% greater (P < 0.05) juiciness than that from CAS8. No differences in meat juiciness were observed between 10 and 12 mo of slaughter age; however, meat from animals slaughtered at 14 mo of age had greater (P < 0.01) meat juiciness than meat from animals slaughtered at younger ages (Table 4). Meat from CAS3 tended (P = 0.09) to have less flavor compared with meat from bulls and CAS8.

**DISCUSSION**

**Effect of Castration Age**

In the present study, castration decreased ADG and feed efficiency. Different authors (Martin and Stob, 1978; Fisher et al., 2001; Earley and Crowe, 2002) have reported that bulls gain BW more rapidly and efficiently than steers. The greater ADG observed in bulls compared with steers could be attributed to the anabolic property of androgens, especially testosterone (Galbraith et al., 1978; Katz, 2007; Mach et al., 2009). Previous studies (Brännäng, 1966; Hedrick et al., 1969; Field, 1971) indicated that bulls grow on average 14 to 17% more than steers; however, in the present study castration only reduced ADG a 7.5% compared with bulls.

It was expected that bulls castrated after puberty would have a greater ADG and final BW than bulls castrated at 3 mo of age because when castration is per-
formed after puberty the advantages of bulls on performance could be maintained for a longer period of time throughout the growing phase (Knight et al., 1999a). However, surgical castration has an important detrimental effect on performance during 2 wk after castration (Devant et al., 2012) and this slump probably offsets the expected advantages of delaying age of castration on performance. In agreement to the present study, different studies conducted with different breeds (precocious and late maturing) and feeding systems compared with the present study did not report an effect of castration age on performance. In agreement to the present study, different authors observed that meat from castrated animals had more lightness, redness, and yellowness than meat from bulls. In addition, bulls may be stressed more easily (Field, 1971; Katz, 2007) and perform more mounting activity (Katz, 2007; Mach et al., 2009) than steers. These 2 factors may explain the greater meat pH and the darkness observed in bulls compared with the meat from steers (Jago et al., 1996; Price et al., 2003; Katz, 2007). In accordance to the results presented herein, several authors observed that meat of castrated animals at prepubertal ages (Purchas et al., 2002; Marti et al., 2011) or at postpubertal ages (Mach et al., 2009) has less WBSF values and consequently lesser hardness compared with meat from bulls. These authors associated the increase of tenderness with a slightly lower ultimate pH, greater myofibrilar fragmentation index, greater i.m. fat content, and possibly a smaller contribution of connective tissue. However, after 7 d of aging, differences in WBSF values disappeared as also reported by Cahill (1964). The small juiciness differences observed between castrated animals and bulls in the present study have also been previously reported (Purchas et al., 2002; Mach et al., 2009; Marti et al., 2011).

Castration, independently of slaughter age, increased rib separable fat content and decreased rib separable lean content. In addition, in the present study, it was also observed that castration age affected carcass-separable fat and lean and estimated carcass protein and ether extract content. The younger the animals were castrated, independently of slaughter age, the greater the rib-separable fat percentage (carcass ether extract) and the lesser rib-separable lean percentage (carcass protein) were deposited. Also, the amount and location of fat is important because remaining, intermuscular, and s.c. fats are of low economic value, and only i.m. fat is appreciated by consumers (Aldai et al., 2007). Intermuscular separable fat was greater in castrated animals compared with bulls as described by Keane (2003), and

Table 4. Sensory quality of the LM from Holstein bulls, animals castrated at 8 mo of age (CAS8), or animals castrated at 3 mo of age (CAS3) and slaughtered at 10, 12, and 14 mo of age fed a high-concentrate diet

<table>
<thead>
<tr>
<th>Item</th>
<th>Castration age1</th>
<th>Slaughter age2</th>
<th>P-value3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bulls</td>
<td>CAS8</td>
<td>CAS3</td>
</tr>
<tr>
<td>Initial hardness4</td>
<td>5.9a</td>
<td>5.8a</td>
<td>5.5b</td>
</tr>
<tr>
<td>Overall hardness5,6</td>
<td>6.0b</td>
<td>5.9a</td>
<td>5.6b</td>
</tr>
<tr>
<td>Juiciness7</td>
<td>2.7a</td>
<td>2.5b</td>
<td>2.6a</td>
</tr>
<tr>
<td>Flavor</td>
<td>2.6</td>
<td>2.5</td>
<td>2.4</td>
</tr>
</tbody>
</table>

a,b For each factor studied (castration age or slaughter age) means within rows not bearing a common superscript letter differ (P < 0.05).
1 Bulls, CAS = bulls castrated at 3 mo of age, CAS8 = bulls castrated at 8 mo of age.
210 = animals slaughtered at 10 mo of age; 12 = animals slaughtered at 12 mo of age; 14 = animals slaughtered at 14 mo of age.
3CA = effect of castration age; SA = effect of slaughter age.
4P-value corresponding to the linear effect (P = 0.11) and to the quadratic effect (P < 0.05) of slaughter age.
5Interaction between castration age and slaughter age (overall hardness P = 0.06)
6P-value corresponding to the linear effect (P = 0.19) and to the quadratic effect (P = 0.05) of slaughter age.
7P-value corresponding to the linear effect (P = 0.22) and to the quadratic effect (P = 0.05) of slaughter age.

The WBSF values at d 0 and d 7 observed in the present study are close to the observed in Holstein bulls and steers fed high-concentrate diets (Mach et al., 2009; Marti et al., 2011). As expected, castration improved meat tenderness and meat pH (lower values). Also, meat of castrated animals had more lightness, redness, and yellowness than meat from bulls. In addition, bulls may be stressed more easily (Field, 1971; Katz, 2007) and perform more mounting activity (Katz, 2007; Mach et al., 2009) than steers. These 2 factors may explain the greater meat pH and the darkness observed in bulls compared with the meat from steers (Jago et al., 1996; Price et al., 2003; Katz, 2007). In accordance to the results presented herein, several authors observed that meat of castrated animals at prepubertal ages (Purchas et al., 2002; Marti et al., 2011) or at postpubertal ages (Mach et al., 2009) has less WBSF values and consequently lesser hardness compared with meat from bulls. These authors associated the increase of tenderness with a slightly lower ultimate pH, greater myofibrilar fragmentation index, greater i.m. fat content, and possibly a smaller contribution of connective tissue. However, after 7 d of aging, differences in WBSF values disappeared as also reported by Cahill (1964). The small juiciness differences observed between castrated animals and bulls in the present study have also been previously reported (Purchas et al., 2002; Mach et al., 2009; Marti et al., 2011). Castration, independently of slaughter age, increased rib separable fat content and decreased rib separable lean content. In addition, in the present study, it was also observed that castration age affected carcass-separable fat and lean and estimated carcass protein and ether extract content. The younger the animals were castrated, independently of slaughter age, the greater the rib-separable fat percentage (carcass ether extract) and the lesser rib-separable lean percentage (carcass protein) were deposited. Also, the amount and location of fat is important because remaining, intermuscular, and s.c. fats are of low economic value, and only i.m. fat is appreciated by consumers (Aldai et al., 2007). Intermuscular separable fat was greater in castrated animals compared with bulls as described by Keane (2003), and...
when Holstein bulls were castrated at 3 mo of age this t.m. percentage was greater than when castration was delayed at 8 mo of age. In addition, remaining separable fat increased in castrated animals compared with bulls independently of castration age. Remaining fat during carcass manipulation usually is removed, and in consequence carcass dressing percentage may be impaired, as observed with castrated animals in the present study.

Effect of Slaughter Age

As described by May et al. (1992), final BW and carcass weight improved as slaughter age increased. Berg and Butterfield (1968) observed, in both beef and milk type breeds, that BW at slaughter has an important influence on carcass composition; the point of inflection of carcass fat deposition is approximately between 12 and 18 mo of age. In the present study, rib section data evolution, which reflects carcass composition evolution (Hankins and Howe, 1946), was in accordance to several studies (Berg and Butterfield, 1968; Jenkins et al., 1981; Andersen and Ingvartsen, 1984). As rib weight increased with slaughter age, muscle and bone percentages decreased and fat percentage increased. However, in the present study, this evolution was only observed from 10 to 12 mo of age, and no differences between 12 and 14 mo of slaughter age were observed, so in Holstein animals fed high-concentrate diets the inflection of carcass fat deposition would be around 10 and 12 mo of age. Differences among studies could be related to breed and/or feeding systems.

On the other hand, as reported by Van Koevering et al. (1995) concentrate intake increased linearly with slaughter age. Decreasing slaughter age, independently of castration, may be a good strategy to reduce production costs when feed prices are high; however, the quantification of the detrimental effects of reducing slaughter age on carcass weight is necessary to decide whether this strategy has negative effects on net returns. In addition, performing the slaughter at 10 mo of age may improve meat pH. Meat with pH above 6.0 at 24 h after slaughter represents a meat quality problem and is undesirable for consumption (Viljoen et al., 2002; Wulf et al., 2002; Pipek et al., 2003). Mellor et al. (1991) observed that temperament and stress level increased with age, and as a consequence animals slaughtered at older ages have increased meat pH and lower L* values.

As described by Hedrick et al. (1969), it was expected that age would have an adverse effect on tenderness. The negative effect of age on tenderness is mainly attributed to an increase in intermuscular collagen, which becomes progressively tougher, more rigid and resistant, and less easily denatured as age increases (Nishimura et al., 1999). In the present study tenderness improves by age and 1 possible explanation for these unexpected results could be that Hedrick et al. (1969) used animals that grazed for a long period and/or because animals were slaughtered at older ages (between 15 and 18 mo) whereas in contrast in the present study these Holstein bulls and steers were fed concentrate and straw throughout the study and were slaughtered at the maximum of 14 mo of age.

Castration Age and Slaughter Age Interactions

In the present study, most of the interactions between castration age and slaughter age were observed in carcass classification, carcass dressing percentage, and some rib fat distribution characteristics. Nutrient intake can affect the effect of castration age on carcass composition (Muller et al., 1991); however, in the present study nutrient intake, daily consumption or expressed as percentage of metabolic BW, was not affected by the castration age, discarding the possible confounding effect between nutrient intake and castration on carcass composition. When castration was performed in the prepubertal period, carcass conformation was poor independently of slaughter age, probably because anabolic effects of testosterone were suppressed at an early stage when most of muscle growth takes place. Marti et al. (2011) also found greater conformation grades in bulls compared with prepubertal castrated animals. However, Andersen and Ingvartsen (1984) did not find differences between animals castrated at 3 to 4 mo of age and bulls. As in the present study, Mach et al. (2009) did not find a castration effect on carcass conformation when castration was performed at postpuberty ages and animals were slaughtered at 12 mo of age. The improvement of carcass conformation in CAS8 Holstein animals between 10 and 12 mo of slaughter age was greater than in the other treatments because at 10 mo of age these animals did not recover completely from surgical castration. Delaying slaughter age is a good strategy to improve carcass conformation when Holstein animals are castrated at 8 mo of age but does not seem to be an effective strategy when Holstein animals are castrated at 3 mo of age.

When carcass fat cover is the main carcass quality trait to be improved, as it is the case in some European markets, castration at young ages is a good strategy to slaughter Holstein animals at young ages because the desired carcass fat cover of “3” could be achieved at 10 mo of age. However, as mentioned before, if Holstein animals are castrated at prepubertal ages and slaughtered at young ages, carcass conformation will be impaired. These statements are valid for Holstein bulls fed high-concentrate diets slaughtered around 1 yr of age; however, breeds such as Charolais cattle need longer to deposit enough adipose tissue and reach their optimal slaughter stage than cattle from a precocious breed. These characteristics might ap-
pears to be in conflict with the shortening of the production cycle. However, Micol et al. (2009) studied if the castration of Charolais bulls at a young age (2 mo of age) rather than at 10 mo could enable the fattening of the steers to be speeded up and also allow slaughtering at a younger age (28 mo of age versus 36 mo of age). These authors (Micol et al., 2009) did not observe any detrimental effect in Charolais bulls of reducing castration age from 10 to 2 mo of age on performance and carcass characteristics when animals were slaughtered at 26 to 28 mo of age. Champagne et al. (1969) in yearling Herefords observed that the animals castrated at 9 mo of age and slaughtered 9 mo later had a decreased carcass conformation score compared with those castrated at birth or at 2 mo of age. So breed, feeding system, and interval between castration and animal marketing are crucial factors to evaluate the optimum age of castration on performance and carcass characteristics (Muller et al., 1991).

Dressing percentage improved as days on feed increased, as it has also been previously reported (Schroeder et al., 1980; Tatum et al., 1980; May et al., 1992). Dressing percentage of CAS8 slaughtered at 10 mo of age was low because they probably did not fully recover from castration. In CAS3, dressing percentage was less than that of bulls at 10 mo of age because their carcasses were fatter (as indicated by the greater level of carcass fat cover and rib dissection data) and had probably more fat removal during carcass manipulation (excess of KPH) than carcasses of bulls. Field (1971) summarized different studies that evaluated the effect of castration on performance and carcass quality, and they observed no clear effect of castration on dressing percentage. However, in most studies (Field, 1971) where fat depth was increased due to castration, dressing percentage was greater in bulls than steers, supporting the hypothesis that carcasses with great fat cover could have more fat retails during carcass manipulation. Moreover, in accordance to the present study, other authors (Champagne et al., 1969; Adams and Adams, 1992; Huxsoll et al., 1998) have also reported reduced dressing percentages of steers compared with bulls.

Several authors (Berg and Butterfield, 1968; Jenkins et al., 1981; Andersen and Ingvartsen, 1984) have indicated the percentage s.c. fat increases with slaughter age. However, in the present study, at 14 mo of age the proportion of rib-separable s.c. fat decreased and the proportion of rib-separable i.m. fat increased, and this effect was most pronounced in CAS3 Holstein animals. In prepubertal castrated Holstein animals, the age of slaughter should be reduced to 10 mo of age because older ages produced an undesirable increase in the percentage of i.m. fat depots, and consequently meat from these animals could be refused by consumers. As mentioned before, reducing slaughter age to 10 mo in prepubertal castrated Holstein animals has advantages such as improving carcass fat cover and reducing total feed cost and disadvantages because carcass conformation is impaired.

The increase of i.m. fat is desired as it may improve meat tenderness by reducing bulk density and decreasing the effect of the strength of the connective tissue (Savell and Cross, 1988); also, large amounts of i.m. fat can increase meat lightness (Boucqué et al., 1982; Fiems et al., 2000) as observed in castrated animals. However, the i.m. fat in CAS8 did not increase until 12 mo of age, probably as a consequence of the stress produced by surgical castration (Knight et al., 1999b; Bretschneider, 2005; Devant et al., 2012). In addition, bulls should be slaughtered at 14 mo of age to achieve similar i.m. fat levels compared with CAS3 slaughtered at 10 mo of age. The percentage of i.m. fat was greater when animals were castrated at young ages at all slaughter ages as also reported by Champagne et al. (1969) and Andersen and Ingvartsen (1984). Therefore, when marbling is an important meat quality attribute, as in the North American market, Holstein animals castrated before puberty could be slaughtered at younger ages (less than 1 yr old) compared with postpuberty castrated animals and bulls without impairing meat marbling, and consequently feed and production costs could be potentially reduced. This method of castrating steers at a young age is commonly used in Anglo-Saxon countries, with breeds such as Angus and Hereford. In agreement with the present study, Worrell et al. (1987) observed in Angus × Hereford steers slaughtered at 470 kg that castration at 70 or 230 kg of BW improved marbling score compared with castration at 320 or 410 kg of BW. However, Destefanis et al. (2003) observed in Piemontese animals slaughtered at 19 mo of age an improvement in i.m. fat when they were castrated at 13 mo of age compared with animals castrated at 5 mo of age. So, the positive effect of castrating animals at young ages to improve marbling seems a good strategy in precocious breeds.

In the present study, early-castrated animals had a reduced overall hardness independently of slaughter age compared with bulls or animals castrated around puberty. In agreement with the present results, Worrell et al. (1987) observed in Angus × Hereford steers slaughtered at 15 mo of age and 470 kg of BW that meat of the early-castrated steers (70 kg of BW) was more tender than meat of those castrated later (230, 320, and 410 kg of BW). However, Destefanis et al. (2003) observed no positive effect of castration age in Piemontese animals or Micol et al. (2009) with Charolais animals slaughtered at 19 mo of age or 26 mo of age, respectively, on meat tenderness or sensory attributes. So, early castration of precocious breeds and slaughtering them young could have an interesting meat tenderness improvement reducing production costs.
In summary, Holstein animals castrated at prepuberty ages could be slaughtered at younger ages as i.m. fat and carcass fat cover improved. In consequence, the days on feed and the production costs could be reduced. However, prepuberty castration impairs carcass conformation of Holstein animals if slaughter age is not delayed until 14 mo of age. Surgical castration of Holstein animals performed at 8 mo of age is not a good strategy when combined with reduced slaughter ages, as carcass and meat quality at 10 mo of age are impaired because animals have not fully recovered from castration sequels. In Holstein bulls, to improve meat and carcass quality, slaughter age cannot be reduced to 10 mo of age, as carcass fat cover, i.m. fat, and proportion of intermuscular fat in the rib are excessively low. Moreover, Holstein bulls have to be slaughtered at 14 mo of age if the same i.m. fat of the LM than animals castrated at 3 mo of age and slaughtered at 10 mo of age is to be achieved.

Castration of Holstein bulls, regardless of castration age and slaughter age, impairs animal growth and feed efficiency, reduces meat pH and WBSF at d 0 of aging, and increases rib-separable i.m. fat. Meat from animals castrated at 3 mo of age has less overall and initial hardness than meat of animals castrated at 8 mo of age and bulls. Moreover, when Holstein animals are castrated before puberty, independently of slaughter age, rib-separable fat percentage increased and rib-separable lean percentage decreased. In Holstein animals, slaughter age, independently of castration, enhances feed consumption and impairs feed efficiency. However, in Holstein animals slaughter age depending on castration age differently affects variables related to fat deposition such as dressing percentage, carcass fat cover, and rib fat distribution.

LITERATURE CITED


