Administration of dexamethasone per os in finishing bulls. I. Effects on productive traits, meat quality and cattle behaviour as indicator of welfare

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The study investigated the effects of prolonged oral administration of dexamethasone at a low daily dosage of 0.75 mg/head per day (Dexa) on beef cattle productive traits, behaviour and meat quality. In all, 14 finishing Marchigiana bulls were used in a trial that began 56 days prior to slaughter, of which six bulls received treatment from day 5 to day 53, whereas the remaining animals were used for Control. The animals treated showed an increased average daily gain (1515 v. 1177 g/head per day; P < 0.05; s.e.d. = 48.54) and improved warm carcass dressing percentage (60.8% v. 59.7%; P < 0.05; s.e.d. = 0.32). Behavioural observation did not permit a clear distinction between treated and Control animals since feeding and social behaviour were similar in both groups. The bulls treated spent less time lying (16.5% v. 34.6%; P < 0.05; s.e.d. = 4.38) and grooming (6.7% v. 11.9%; P < 0.05; s.e.d. = 1.23), and this may indicate poorer welfare. No evidence of treatment was observed in other carcass traits, and redness was the only meat quality parameter slightly affected by corticosteroid administration.

Keywords: beef cattle, behaviour, dexamethasone, growth performance, meat quality

Introduction

In addition to anti-inflammatory and immunosuppressive activities, synthetic glucocorticoids such as dexamethasone affect gluconeogenesis, glycogen deposition, protein and calcium metabolism (Courttheyn et al., 2002). The effect of these substances on carbohydrate metabolism led to their use as growth promoters in beef cattle fattening, and in the United States they are still used to increase carcass fatness and meat marbling (Corah et al., 1995). Although the use of corticosteroids as growth promoters is banned in Europe, illegal administration (Courttheyn et al., 2002) in order to increase feed intake, water retention and live weight gain (Istasse et al., 1989) is highly suspected. Beef farmers first began administering dexamethasone in combination with other substances such as β-agonists, at low dosages, in order to exploit additional or synergic growth effects and perhaps conceal its use from public service veterinarians conducting checks at the slaughterhouse (Courttheyn et al., 2002). Dexamethasone and other corticosteroids are now becoming the most commonly used growth promoters, however, because their detection in organic matrices does not necessarily testify the use for non-therapeutic reasons. Dexamethasone alone has also been administered recently in low dosages because field experience and scientific results showed that high dosage inhibits growth and leads to muscle atrophy (Istasse et al., 1989; Corah et al., 1995; Courttheyn et al., 2002).

Various studies have been performed to assess the effects of non-therapeutic dexamethasone use on beef cattle growth and slaughter performance (Brethour, 1972; Dicke et al., 1974), while others (Renaville et al., 1994; Corah et al., 1995) also considered metabolic parameters and nutrient partitioning hormones. None of the above-mentioned works considered cattle welfare, however, which is currently one of the most important issues for the consumer (McGlone, 2001). Precisely because behaviour is a good indicator of welfare, in addition to assessing growth and slaughter performance, this study also evaluated the effect of prolonged daily oral administration of a low dosage of dexamethasone on beef cattle behaviour.

Material and methods

In accordance with Decreto Legislativo n. 116/1992, the Italian Ministry of Health authorized this study following the submission of a detailed description of the experimental plan by the project’s scientific coordinator.

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Animals, housing and management
The study was conducted in a commercial farm in Brugine (Padova, Italy). At the outset, 15 Marchigiana breed finishing bulls were considered, nine of which served as the Control group and six bulls as the dexamethasone per os (Dexa)-treated group. At day 30, one of the Control bulls was excluded from the experiment due to an ocular trauma, and therefore the total number of animals considered was 14. The Dexa per os-treated bulls received orally 0.75 mg of dexamethasone (Desashock®; Fort Dodge Animal Health SpA, Bologna, Italy) every day. Prior to the distribution of the feed each morning, the animals in both groups were caught at the feeding trough, where two trained technicians using a drenching gun gave one capsule containing the compound to the treated animals and an empty capsule to the Control bulls.

The experimental phase in vivo lasted 56 days starting with the weighing of the bulls. The animals were allotted to pens in the Control group or to the Dexamethasone group according to initial body weight (BW) (487 ± 14.9 kg). The treatment was administered for 49 days, from day 5 to day 53 of the experimental period.

The bulls were housed in five contiguous straw-bedded pens of three animals each with 4 m²/head space allowance and 100 cm²/head manger space. Drinking water was available ad libitum and supplied by two waterers per pen. Bulls were fed ad libitum the same diet provided as total mixed ration once a day at 0830 h. Feed composition of the diet is reported in Table 1. Samples of the diet were collected weekly and analysed for dry matter (DM), crude protein (CP), ether extract and ash according to AOAC methods (2004). Analysis of neutral detergent fibre of the diet is reported in Table 1. Samples of the diet were mixed ration once a day at 0830 h. Feed composition of the diet was calculated as proposed by Mertens (1992). Diet chemical composition is presented in Table 1.

Animal growth performance and health status
The bulls were weighed at the outset, on day 27 and on day 55. The average daily gain (ADG) was calculated as the difference between two subsequent BWs. The pen DM intake was recorded 3 days a week as the difference between the amount of diet delivered and the feed residue in the manger 24 h later. Pen feed conversion ratio was calculated by dividing the average intake by the ADG.

Bull health status was monitored daily by recording all individual pathological events and medical treatment.

Blood parameters
Jugular vein blood samples were taken from all the animals in the morning at days 6, 27, 48 and 56. Heparinized vacutainer tubes (Becton Dickinson, Meylan Cedex, France) were used for blood glucose determination measured using a BM Hitachi 911 analyser (ROCHE, Basel, Switzerland).

Insulin evaluation specimens were collected in anticoagulant-free vacutainer tubes (Becton Dickinson) and analysed by a chemiluminescent technique using an automatic analyser (Immulite One, Medical System, Genoa, Italy).

Table 1 Feed composition and chemical analysis of the diet given to the bulls during the experimental period

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>kg as fed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize silage</td>
<td>5.0</td>
</tr>
<tr>
<td>Maize meal</td>
<td>3.5</td>
</tr>
<tr>
<td>Dried sugar beet pulp</td>
<td>1.3</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>1</td>
</tr>
<tr>
<td>Soy bean meal</td>
<td>0.9</td>
</tr>
<tr>
<td>Molasses</td>
<td>0.8</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>0.7</td>
</tr>
<tr>
<td>Proteins, minerals and vitamins premix</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Chemical Composition

<table>
<thead>
<tr>
<th>Dry matter (DM)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein</td>
<td>60.7 ± 2.1</td>
</tr>
<tr>
<td>Ether extract</td>
<td>13.7 ± 0.4</td>
</tr>
<tr>
<td>Ash</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Neutral detergent fibre (NDF)</td>
<td>5.9 ± 0.4</td>
</tr>
<tr>
<td>Non-fibrous carbohydrates content (NSC)</td>
<td>28.5 ± 1.5</td>
</tr>
</tbody>
</table>

Chemical Composition (DM basis): 38% of crude protein, 2% of fat, Ca, 180 g; Na, 104 g; P, 70 g; Mg, 35 g; Zn, 3400 mg; Mn, 1500 mg; Fe, 200 mg; Cu, 200 mg; I, 60 mg; Co, 20 mg; Se, 10 mg; Mb, 10 mg; 1 000 000 IU of vitamin A; 120 000 IU of vitamin D; 100 mg of vitamin E; 20 mg of vitamin K; 5000 mg of vitamin PP; 100 mg of vitamin B1; 50 mg of vitamin B2; 0.4 mg of vitamin B12.

Behavioural observations
Bulls were observed for 9 consecutive hours at days 23, 37 and 51, starting from 0900 h. The animals were directly observed by trained personnel using the scan-sampling technique with a 5-min interval between two subsequent scans. At each scan, the number of animals per pen that were lying, inactive, eating, ruminating, sniffing-licking or grooming was recorded. The number of conflicts and mounting performed within each pen during the entire observation session was also recorded with the behaviour sampling technique (Martin and Bateson, 1993).

Slaughter measurements and meat quality evaluation
All the bulls were slaughtered in the morning at day 57, and their carcasses were weighed both after slaughter and 24 h later in order to calculate individual dressing percentage. Carcasses were also graded for conformation and fatness according to the European grading system (OFIVAL, 1984). Twenty-four hours after slaughter, a joint sample of Longissimus Thoracis muscle was excised from the 7th to the 9th rib of each right half carcass. The samples were vacuum packed and stored at 4°C in a chilling room for a 7-day ageing period. After ageing, meat samples were analysed for pH, DM, CP, ether extract and ash according to AOAC methods (2004). Meat colour was measured with a CR 100 Chromameter (Minolta Camera, Osaka, Japan) equipped with C illuminant on samples exposed to air for 1 h at 2°C (Boccard et al., 1981). Colour data were expressed using the Hunter Lab system. Drip losses were measured as weight losses of the meat sample used for colour determination hung in a plastic bag at 4°C for 24 h. Weight cooking losses were determined on 2.5-cm-thick steaks cooked in a water bath at 75°C for 50 min and cooled in...
running tap water for 40 min (Boccard et al., 1981). Meat
tenderness was instrumentally measured using a Warner
Blitzer shear force meter (Instron Ltd, High Wycombe, UK)
on cylindrical core samples of cooked meat 1.25 cm in
diameter (Joseph, 1979).

Statistical analysis
Bull growth and slaughter performance, and meat quality
data were submitted to one-way ANOVA within PROC-
GLM (SAS, 1990) in order to evaluate the effect of dexam-
ethasone treatment. The animal was the experimental
unit and the treatment effect was tested using pen within
treatment variance as the error term. Considering that feed
intake and feed conversion ratio were calculated on group
pen basis, data were reported as means of the pen and not
processed.

Behavioural data were transformed into frequencies before
undergoing statistical analysis. This data transformation
was obtained by dividing the number of animals per scan
observed performing a given behaviour by the total number
of animals housed in the pen. The normal distribution of the
behavioural and blood variables included in the dataset was
tested by SAS PROC UNIVARIATE (1990) with the Shapiro-
Wilk test. All the variables tested showed values of $W > 0.80$
and were therefore considered normal and submitted to
ANOVA within SAS PROC-GLM (1990). The total frequency
of all behavioural variables was analysed adopting the
SAS repeated measurement option. The statistical model
considered the effects of treatment, pen within treatment,
observation day and treatment per observation day. For
these variables as well, the treatment effect was tested
using pen within treatment variance as the error term. The
same model was adopted to analyse the blood parameters;
the experimental unit was the single animal.

Results

Animal health status and growth performance
The health status of the bulls was satisfactory during the
entire experimental period with the exception of one
Control bull, which showed clinical signs of trauma to the
cornea of one eye at day 30. The animal was treated for
several days with specific drugs and therefore excluded
from the experiment. None of the other bulls received
specific medical treatment.

Average live weights were similar in both Dexa per os and
Control bulls due to the wide variation within groups (Table 2).
ADG, on the other hand, was higher in the animals treated
(1515 v. 1177 g/day; $P < 0.05$), but this result was due to the
different gains recorded only in the first 26 days of the
experiment (Table 2). Untreated and treated animals showed
similar DM intakes, whereas on average feed conversion ratio
of bulls receiving dexamethasone seems improved (Table 2).

Blood parameters
Plasma glucose was significantly higher in the animals
receiving dexamethasone only at the first collection made
after 1 day of drug administration (Figure 1). No effect of
treatment was observed in the next 2 sampling days. The
Control group showed higher glucose concentration at day
56 (Figure 1).

The administration of dexamethasone per os increased
insulin concentration from the second sampling day.

Behaviour
The results of the behavioural observations are shown in
Figure 2. Eating, ruminating, sniffing-licking and inactive
behaviour were not affected by the administration of Dexamethasone per os. Grooming and lying frequencies were always lower

Table 2 Growth performance of Control and treated (Dexa) bulls during the experimental period

<table>
<thead>
<tr>
<th>Items</th>
<th>Unit</th>
<th>Control</th>
<th>Dexa</th>
<th>s.e.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live weight</td>
<td>kg</td>
<td>495.4</td>
<td>490.8</td>
<td>13.66</td>
</tr>
<tr>
<td>Beginning of trial</td>
<td>kg</td>
<td>522.5</td>
<td>541.3</td>
<td>17.37</td>
</tr>
<tr>
<td>At day 27</td>
<td>kg</td>
<td>558.9</td>
<td>572.7</td>
<td>14.28</td>
</tr>
<tr>
<td>Average daily gain</td>
<td>g/day</td>
<td>1045b</td>
<td>1942a</td>
<td>236.88</td>
</tr>
<tr>
<td>From day 0 to day 26</td>
<td>g/day</td>
<td>1300</td>
<td>1119</td>
<td>181.32</td>
</tr>
<tr>
<td>From day 27 to day 54</td>
<td>g/day</td>
<td>1177b</td>
<td>1515a</td>
<td>48.54</td>
</tr>
<tr>
<td>Dry matter intake</td>
<td>kg/day</td>
<td>8.2 ± 0.49</td>
<td>8.7 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>kg/day</td>
<td>8.0 ± 0.59</td>
<td>9.0 ± 0.33</td>
<td></td>
</tr>
<tr>
<td>From day 0 to day 26</td>
<td>kg/day</td>
<td>8.1 ± 0.51</td>
<td>8.8 ± 0.15</td>
<td></td>
</tr>
<tr>
<td>From day 27 to day 54</td>
<td>kg/day</td>
<td>6.3 ± 1.37</td>
<td>8.1 ± 0.67</td>
<td></td>
</tr>
<tr>
<td>From day 0 to day 54</td>
<td>kg/day</td>
<td>6.9 ± 0.65</td>
<td>5.8 ± 0.38</td>
<td></td>
</tr>
</tbody>
</table>

Different superscript letters (a, b) within row indicate significant differences $P < 0.05$. 

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in the animals receiving corticosteroid than in the Control group. The number of mounting events and the number of conflicts among pen mates were unaffected by treatment (Figure 3).

Slaughter performance and meat quality evaluation
Dressing percentage calculated on warm carcass was the only slaughter measurement significantly affected by the administration of dexamethasone, and was higher in the bulls treated (Table 3). With regard to meat quality traits, the pH and chemical composition of the Control group and the bulls treated were similar. Only colour was modified by treatment, with the Control bulls showing higher redness (Table 3).

Discussion
The study was conducted as an attempt to identify the illegal administration of dexamethasone to beef cattle during the finishing period through variations in performance and behaviour.

Courtheyn et al. (2002) reported that providing glucocorticoids in low dosages increases feed intake and ADG and improves the feed conversion ratio. In our study, however, although the use of dexamethasone significantly increased ADG, feed intake for both Control and treated animals was similar, and therefore this gain in the weight of the bulls treated might be related to an improved feed efficiency. ADG increased particularly in the first part of the
promoter effect of dexamethasone has also been discussed in other studies. Johnson and Silcox (1986), in fact, obtained a decrease in ADG in yearling Angus bulls given 20 mg of dexamethasone twice weekly during an 84-day finishing period, whereas Corah et al. (1995) did not observe any difference in ADG between the Control group and animals treated with 100 mg implants 60 and 30 days prior to slaughter. Tarantola et al. (2004) observed the lowest daily gain and the worst feed conversion ratio in veal calves receiving a prolonged oral low dose of dexamethasone.

Regarding the blood parameters involved in energy metabolism, the higher glycaemia detected in the bulls treated with dexamethasone after 1 day of treatment might be the result of the effect of the glucocorticoids on both gluconeogenesis promotion in the liver and the drop in peripheral glucose utilization (Eisenstein, 1973; Schimmer and Parker, 2001). Either by increasing fat deposition and/or interstitial water retention but not through muscle development (Schimmer and Parker, 2001), this metabolic pattern in the animals treated may have been responsible for the increase in ADG in the first part of the trial. During the same period, dexamethasone, acting as endogenous glucocorticoid, and hyperglycaemia might have promoted insulin production by the pancreatic β cells. The reduction of glycaemia observed during the last part of the experiment in the bulls treated is likely due to the hypoglycaemic role of insulin (Insel et al., 1975; Mori et al., 2004). The organism’s response to prolonged oral administration of a low dosage of dexamethasone in terms of the hepatic synthesis of glucose is immediate, whereas response in terms of insulin production seems to require a longer adaptation period. This hypothesis is partially supported by the studies conducted by Istasse et al. (1989) and Corah et al. (1995), who detected an immediate increase in glucose following corticosteroid supply and a subsequent increase in insulin production. These works do not, however, permit the plotting of insulin release trends in relation to time of treatment.

The administration of Deya per os had a moderate effect on cattle behaviour, inducing a reduction of the time spent lying and grooming. These changes in behaviour cannot be considered relevant in making a clear distinction between treated and untreated animals. In terms of animal welfare, the prolonged standing time measured for the bulls treated might have limited their opportunity for rest (Rotger et al., 2006), and according to Mogensen et al. (1997), this might have a negative affect on daily gain. Moreover, the reduction

In addition to the aforementioned factors, the prolonged oral administration of dexamethasone might have resulted in a reduction of the voluntary water intake (Schimmer and Parker, 2001). Either by increasing fat deposition and/or interstitial water retention but not through muscle development (Schimmer and Parker, 2001), this metabolic pattern in the animals treated may have been responsible for the increase in ADG in the first part of the trial. During the same period, dexamethasone, acting as endogenous glucocorticoid, and hyperglycaemia might have promoted insulin production by the pancreatic β cells. The reduction of glycaemia observed during the last part of the experiment in the bulls treated is likely due to the hypoglycaemic role of insulin (Insel et al., 1975; Mori et al., 2004). The organism’s response to prolonged oral administration of a low dosage of dexamethasone in terms of the hepatic synthesis of glucose is immediate, whereas response in terms of insulin production seems to require a longer adaptation period. This hypothesis is partially supported by the studies conducted by Istasse et al. (1989) and Corah et al. (1995), who detected an immediate increase in glucose following corticosteroid supply and a subsequent increase in insulin production. These works do not, however, permit the plotting of insulin release trends in relation to time of treatment.

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### Table 3 Slaughter performance and meat quality evaluated on Longissimus Thoracis muscle of Control and treated (Dexa) bulls

<table>
<thead>
<tr>
<th>Items</th>
<th>Unit</th>
<th>Control</th>
<th>Dexa</th>
<th>s.e.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcass traits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carcass weight</td>
<td>kg</td>
<td>333.8</td>
<td>348.3</td>
<td>8.03</td>
</tr>
<tr>
<td>Warm</td>
<td></td>
<td>325.6</td>
<td>340.1</td>
<td>7.48</td>
</tr>
<tr>
<td>Chilled</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dressing percentage</td>
<td>%</td>
<td>79.7</td>
<td>60.8</td>
<td>0.32</td>
</tr>
<tr>
<td>Warm carcass</td>
<td></td>
<td>58.2</td>
<td>59.4</td>
<td>0.37</td>
</tr>
<tr>
<td>Chilled carcass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEUROP score</td>
<td>score</td>
<td>8.3</td>
<td>7.5</td>
<td>0.57</td>
</tr>
<tr>
<td>Fatness</td>
<td>score</td>
<td>5.8</td>
<td>5.0</td>
<td>0.55</td>
</tr>
</tbody>
</table>

| Meat quality traits          |       |         |      |        |
| pH                          |       | 5.7     | 5.7  | 0.04   |
| Dry matter                  | %     | 27.0    | 27.9 | 1.09   |
| Crude protein                | % DM  | 75.1    | 71.1 | 2.73   |
| Ether extract                | % DM  | 22.4    | 25.2 | 2.80   |
| Ash                         | % DM  | 3.7     | 3.5  | 0.18   |
| Cholesterol                 | mg/100 g | 65.4 | 66.4 | 2.16   |
| Lightness                    | L     | 44.1    | 46.6 | 0.96   |
| Redness                      | $L_a$ | 23.3    | 22.7 | 0.92   |
| Yellowness                   | $L_b$ | 43.9    | 44.6 | 0.71   |
| Drip weight loss             | %     | 1.52    | 1.75 | 0.11   |
| Cooking weight loss          | %     | 32.9    | 33.3 | 1.05   |
| Shear force                  | kg/cm²| 1.9     | 2.1  | 0.13   |

1 = Poor to 15 = Excellent.

2 = Minimum to 15 = Maximum.

Different superscript letters (a, b) within row indicate significant differences at P < 0.05.

![Figure 3](https://www.cambridge.org/core/terms)

**Figure 3** Number of mounting (s.e.d. = 0.62) and conflicts (s.e.d. = 0.56) in Control bulls (---) and in animals treated with dexamethasone per os (--a--) from day 5 to day 53 of the trial.
of auto- and allo-grooming observed in the same animals might also be an expression of their lack of interest in pen mates.

Recent studies on humans (Kam and Yarrow, 2005; Trenton and Currier, 2005) have shown that some of the side-effects of the corticosteroid abuse by athletes included significant psychiatric symptoms, such as aggressiveness, violence, mania and other status of psychosis. In this study, conflicts and mounting occurred with a low frequency in both the Control group and treated bulls, especially when considering the results of previous studies in which bulls did not receive corticosteroids (Gottardo et al., 2003).

Consistent with Corah et al. (1995), the bulls treated had an improved carcass dressing percentage but in our study this was not due to an increase in carcass musclearity because there was no significant difference in SEUROP scores. Considering that dressing percentage calculated on chilled carcass was similar in both Control and treated animals, the Dexa group carcasses probably had higher water losses during the chilling process, and this supports the hypothesis of increased interstitial water retention due to treatment. In our study, carcass fatness was similar in both treated and untreated animals, and this confirmed the result obtained by Brethour (1971). The same author reported contrasting carcass fatness results in a subsequent study using different dexamethasone administration protocols (Brethour, 1972). However, Istasse et al. (1989) observed no differences in the lean meat and adipose tissue percentages of the carcass of the animal treated and its monoozygotic twin used for Control, whereas Corah et al. (1995) reported a greater thickness of external fat in steers treated.

Regarding meat quality traits, the administration of Dexa per os did not affect intramuscular fat deposition measured as ether extract. The literature available is controversial for this parameter as well, probably due to differences in dexamethasone administration time, dosage and method. Johnson and Silcox (1986) observed that treatment decreased marbling scores in Angus finishing bulls, whereas Istasse et al. (1989) recorded increased muscle ether extract content and improved degrees of marbling, while Brethour (1972) and Dicke et al. (1974) reported intramuscular fat deposition.

Tarantola et al. (2004) studied the effect of corticosteroid on meat colour in veal calves, observing that animals treated per os had lighter and paler meat than the Control calves. This supports our findings with adult cattle, even if precisely how the treatment affected myoglobin concentration and oxidation level is unclear.

Conclusion

Farmers currently appear to be using dexamethasone illegally as a growth promoter for increased economic benefits. The results of our study suggest that low dosages of dexamethasone per os increase cattle growth in the short period due to hyperglycaemia, which may be responsible for increased fat deposition or interstitial water retention.

The corticosteroid's initially strong growth effect declined, however, as the administration period is prolonged to 50 days, and was probably weakened by insulin response. The effect of low dosage on behaviour was not evident enough to permit a clear distinction between untreated and treated bulls, even if the reduced lying and grooming of the latter may be related to impaired animal welfare.

The increased warm carcass dressing percentage observed in treated bulls at the slaughterhouse may provide farmers with a certain economic benefit, given that chilled dressing percentage is routinely calculated as a fixed percentage of warm carcass weight. This benefit may be limited in the European market, however, by the lack of any increase in carcass fleshness or fatness.

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References


Martinus Nijhoff Publishers, The Hague, NL.

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Dexamethasone treated bulls: performance and behaviour

containing glucocorticoids (dexamethasone esters), progestagen (chlormadinone acetate) and oestrogen (ethinyl oestradiol) on testosterone, insulin-like growth factor-1 (IGF-1), IGF-binding proteins and spermatogenic cells in finishing bulls. Animal Production 59, 189–196.


