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Effect of repeated implants of oestradiol-17β on beef palatability in Brahman and Braham cross steers finished to different market end points

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Abstract. The effect of repeated implantation with 20 mg oestradiol-17β (Compudose 100) on carcass and meat quality traits was investigated using 478 *Bos indicus* and *B. indicus* × *Bos taurus* cross steers finished on either pasture or grain to achieve carcass weight for one of three market end points (domestic, 220 kg; Korean, 280 kg; or Japanese, 340 kg). In the oestradiol-17β treatment group, animals were administered implants at ~100-day intervals, with the number of implants administered to any steer ranging from one to eight. Cattle were slaughtered and at boning the anterior portion of the *M. longissimus lumborum* was removed and frozen after aging for 1 day for later objective meat quality measurements (shear force, compression and cook loss %). The adjoining portion was aged for 14 days before consumer sensory testing using the Meat Standards Australia protocols. Each sample was scored for tenderness, juiciness, like flavour and overall liking by 10 untrained consumers. Implanting increased carcass weights and ossification scores ($P < 0.05$) and reduced marbling scores in comparison to non-implanted carcasses. For tenderness, like flavour, overall liking and MQ4 scores there was a significant ($P < 0.05$) interaction between *B. indicus* content and oestradiol-17β treatment, whereby high *B. indicus* content cattle that were implanted with oestradiol-17β had the lowest sensory scores. The number of implants administered did not affect carcass weights or marbling scores, whereas ossification scores increased in carcasses as the number of implants increased. The number of implants administered had no effect ($P > 0.05$) on sensory scores, or objective meat tenderness.

Additional keywords: beef, *Bos indicus*, consumer sensory scores, hormonal growth promotants, objective meat quality, oestrogenic, repeated implantation.

Introduction

Hormonal growth promotants (HGP) are used extensively in northern Australia to increase liveweight gain and feed efficiency (Hunter *et al*. 2001). These implants contain either oestrogenic or androgenic compounds, or combinations of both. Although the increased liveweight due to HGP implants is well documented, the effect on eating quality is more controversial. A review by Dunshea *et al*. (2005) concluded that the use of commercial HGP implants generally resulted in tougher beef, although Nichols *et al*. (2002) and Dikeman (2007) concluded that any negative effects on tenderness were probably not of commercial importance. More recently, Watson (2008) undertook a meta-analysis of published experiments that contrasted the effects of HGP implants on sensory and objective meat quality measurements and concluded that although the significance of individual experiments varied, when considered in a meta-analysis HGP implants resulted in a significant decrease in tenderness.

Although the mechanisms by which the oestrogenic or androgenic compounds increase muscle growth are uncertain, they are known to have direct effects on protein synthesis or degradation in the muscle cell, or to modify hormone concentrations that in turn influence protein synthesis or degradation in the muscle (Buttery *et al*. 1978; Dunshea *et al*. 2005). Kerth *et al*. (2003) concluded that the mechanisms by which a combination oestrogenic and androgenic implant increased net protein included both an increase in protein synthesis and a decrease in protein degradation. Oestrogenic compounds have been shown to increase plasma concentrations of insulin-like growth factor (Breier *et al*. 1988), which Oksbjerg *et al.* (2004) concluded were likely to impact protein synthesis and degradation rates. Therefore it is likely that the increased

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muscle weight gain in cattle given either a combined oestrogenic–androgenic compound or an implant only containing an oestrogenic compound could be due in part to reduced protein degradation. As discussed by Koohmaraie *et al*. (2002), reduced protein degradation could influence post-mortem proteolysis and ultimately give rise to tougher beef. Several researchers have shown that muscle samples from high *Bos indicus* content carcasses had increased calpastatin activity and decreased tenderness (Shackelford *et al*. 1991; O'Connor *et al*. 1997; Ferguson *et al*. 2000), relative to muscle from *Bos taurus* carcasses. Given that the increased muscle weight arising from use of HGP or *B. indicus* genotypes is likely to be mediated through decreased protein degradation in the live animal, it was important to understand the effects on eating quality and whether or not these effects were simply additive.

As part of a large northern crossbreeding program, steers that ranged from 50 to 100% *B. indicus* content were finished at pasture, or in a feedlot, to three different market end points (domestic, 220 kg; Korean, 280 kg; and Japanese, 340 kg; Upton *et al*. 2001). Within each market category or finishing regime a HGP treatment was applied, in which half the steers received repeated implants of oestradiol-17β and the remainder were not treated. Rather than mimic commercial practice, this treatment was designed to study the growth response to repeated implantation of oestradiol-17β implants at ~100-day intervals. The inclusion of heavy market end points and pasture finishing meant that some individual steers received up to eight implants before slaughter. Sensory analysis was undertaken on meat samples and this provided an opportunity to examine the effect on meat sensory scores of repeated oestradiol-17β implants over a limited range in *B. indicus* content. A preliminary report on the sensory results from 203 animals from this experiment was presented by Hunter *et al*. (2001).

Materials and methods

As part of the Beef Co-operative Research Centre northern crossbreeding experiment a HGP treatment was overlaid on the steer portion. The experimental design was described by Hunter *et al*. (2001) and Upton *et al*. (2001). Briefly, a total of 478 *B. indicus* and *B. indicus* × *B. taurus* cross steers was sourced over three successive calvings for this experiment. At weaning, steers from the different cooperators' properties were allocated to groups to be slaughtered at one of three market end points (domestic, 220 kg; Korean, 280 kg; and Japanese 340 kg carcass weight) and two nutritional finishing regimes (pasture finishing or fed a grain-based ration in a feedlot). Implant strategies included non-implanted controls and implanted groups that were administered 20 mg oestradiol-17β implants (Compudose 100) in the ear at ~100-day intervals. Old implants were removed before new ones were inserted. The 14 slaughter groups, with their respective market categories and finishing regimes, are shown in Table 1. The different slaughter groups contained from 6 to 35 steers in the control and oestradiol-17β treatment groups. The number of implants given to individual animals ranged from one to eight, with more repeat implants being given to steers designated to the Japanese slaughter weights. Due to the drought that prevailed at the conclusion of the experiment, two groups that had been allocated to the Japanese market weight were slaughtered at domestic market weights, and for the purpose of this analysis were relabelled accordingly.

Table 1. Number of steers within market category and finishing regime within control and oestradiol-17β-implanted groups, with the number of implants given to the oestradiol-17β-treated steers

Market category	Finishing regime	Control No. of steers	Implanted steers No. of steers	Implanted steers No. of implants
Domestic	Feedlot	15	12	2
Domestic	Feedlot/pasture	32	32	3–5
Domestic	Pasture	13	13	3
Domestic	Pasture	7	5	3
Domestic	Pasture	19	20	3
Korean	Feedlot	16	18	3
Korean	Feedlot	18	18	3
Korean	Pasture	15	13	5
Korean	Pasture	18	16	5
Japanese	Feedlot	19	17	3
Japanese	Feedlot	16	18	3
Japanese	Feedlot	14	15	5
Japanese	Pasture	20	19	7
Japanese	Pasture	18	19	8

Within each slaughter group *B. indicus* content ranged from 50 to 100%. The number of carcasses in each of the *B. indicus* categories was 342, 35, 24 and 74 for 50, 69, 75 and 100% *B. indicus* content categories, respectively.

Steers were slaughtered when the mean liveweight of each treatment group was predicted to be at the target carcass weight (i.e. 220, 280 and 320 kg for domestic, Korean and Japanese markets, respectively). Steers were finished on either pasture, or in a feedlot on a sorghum-based diet.

When it was estimated that the steers in each slaughter group had reached their target carcass weight, they were transported to one of two commercial abattoirs. At slaughter, carcasses were stimulated using either a high- or low-voltage stimulation system. For one slaughter at each of the abattoirs the stimulator malfunctioned and carcasses were not stimulated.

Carcasses were measured according to the procedures described by Perry *et al*. (2001). On the slaughter day hot carcass weight was recorded, and the following day at grading, ossification and USA marbling scores (Romans *et al*. 1994), 12/13th rib fat depth and ultimate pH were measured. At boning the following day a 25-cm portion of the *M. longissimus lumborum* caudal to the 12/13th rib junction was collected from the left side of each carcass. The anterior 50-mm portion was frozen after 1 day of aging and used to measure objective tenderness, with the remainder used for sensory testing after aging at 1°C for 14 days post-mortem. This portion was denuded of all fat and epimysium and cut into five 25-mm steaks before freezing for sensory tests.

Briefly, a total of five steaks from each carcass were thawed, grilled using a 'Silex' griller to achieve a medium degree of doneness before being halved and served to 10 different consumers who scored then for tenderness, juiciness, like flavour and overall liking using a 0-m to 100-line scale (Watson *et al*. 2008). A composite palatability score (MQ4) was calculated for each sensory score by summing the four sensory scores after weighting tenderness, juiciness, like flavour and overall liking scores by 0.4, 0.1, 0.2 and 0.3, respectively (Watson *et al*. 2008). The 10 sensory scores from each sample were ranked and the highest two and lowest two scores clipped (to reduce the bias and the variance of the estimate; see Watson *et al*. 2008).

Samples for objective measurement were thawed for 48 h at 4°C before being denuded of all fat and epimysium and trimmed to a 250-g block. Blocks were cooked in a water bath at 70°C for 1 h before cooling under running water for 0.5 h. Samples were stored at 4°C overnight and weighed. Cook loss was calculated as the weight loss during cooking as a percentage of raw block weight. Shear force was measured on six strips measuring 15 × 6.6 mm (1 cm^2 in cross-section), which were cut parallel to the fibre direction. Wedges, which were 10-mm thick in the centre, cut with fibre direction parallel to the cut surface, were used to measure compression by twice driving a cylindrical rod into the sample and measuring the separate peak force values. Full details of the objective methods are given by Perry *et al*. (2001).

Statistical analysis

When tenderness score was graphed against shear force, one sample had a shear force of 14.1 kg, sarcomere length of 1.46 mm, and a tenderness score of 71 on a 100-point scale. This was clearly an outlier and was discarded. Of the 478 animals, there was a total of 475 animals with complete datasets for analysis of carcass and meat quality traits.

Carcass traits (carcass weight, ossification score, USA marbling score, rib fat and ultimate pH), objective meat quality measurements (shear force, compression and cook loss %) and sensory scores (tenderness, juiciness, like flavour, overall liking and MQ4 score) were analysed using a mixed model (SAS 1997). The model contained fixed effects for market category (domestic, Korean or Japanese market), finishing regime (grain or grass), HGP treatment (control *v.* the mean of those with one or more oestradiol-17β implants), number of implants (one to eight implants) nested within HGP treatment, and covariates for *B. indicus* content (50–100%) and age at slaughter. The effect of stimulation was included in models for sensory and objective meat quality traits, but not in the models for carcass traits. Slaughter group nested within market category, finishing regime and stimulation treatment was included as a random term. First-order interactions were tested and non-significant ($P > 0.05$) interactions excluded from the analyses.

Results

The experimental design was potentially confounded whereby animals in the heavier market categories were given a greater number of implants than those animals in the lighter market categories. The extent of the confounding was tested by including first-order interactions between market category, finishing regime, HGP treatment, number of implants, *B. indicus* content, age and, where appropriate, stimulation treatment in the analyses. For carcass traits, no first-order interactions were significant ($P > 0.05$) and none were included in the analyses. For sensory and objective meat quality traits the only significant ($P < 0.05$) interaction was between *B. indicus* content and HGP treatment for tenderness, like flavour, overall liking and MQ4 scores and approached significance for juiciness score ($P < 0.10$). This interaction was included in all meat quality analyses.

Although the distribution of *B. indicus* content was highly skewed, it did provide reasonable coverage of the range from 50 to 100% *B. indicus* content. *B. indicus* content was used in the analyses as a continuous variable, rather than a fixed effect. Deviations from the linear relationship were tested by the addition of curvilinear terms to the models. For carcass traits, sensory and objective meat quality the curvilinear term was not significant ($P > 0.05$) and so only the linear term was included in the models.

Mean carcass traits for the control and implanted groups are shown in Table 2. Given the three market categories there was a large range in carcass weight, ossification and USA marbling scores, fat depth and slaughter age. Although the mean ultimate pH was low at 5.6, several carcasses within both the control (six carcasses) and implanted groups (two carcasses) had ultimate pH readings greater than 6.0.

As expected, carcass weights differed significantly between the three market categories ($P < 0.05$, Table 3). From the regression coefficient in Table 3 it was calculated that those steers with a 100% *Bos indicus* content had carcasses that were 19 kg lighter than those from 50% *B. indicus*-content steers. Implantation with oestradiol-17β implants resulted in a 17-kg increase in carcass weight relative to the controls ($P < 0.05$, Table 3). Within the HGP-treated groups the number of oestradiol-17β implants given between weaning and slaughter had no significant effect on carcass weight ($P > 0.05$, Table 3).

There was a trend for ossification score to increase with market category ($P < 0.10$, Table 3), whereby those animals slaughtered at Japanese carcass weights had higher ossification scores than those slaughtered at domestic carcass weights, even

Table 2. Mean, variance and range for carcass and meat quality traits for steers from the control and oestradiol-17β-implanted groups

Trait	Control groups (*n* = 240)			Oestradiol-17β-implanted groups (*n* = 235)		
	Mean	s.d.	Range	Mean	s.d.	Range
Carcass traits						
Carcass weight (kg)	281	57	145–440	298	60	180–420
Ossification score	157	30	100–380	189	57	110–500
Marbling score	233	88	100–560	229	79	100–430
Rib fat (mm)	5.6	3.7	1–20	5.6	4.1	1–20
Ultimate pH	5.6	0.2	5.3–6.3	5.6	0.2	5.3–6.6
Slaughter age (days)	788	168	511–1190	787	168	528–1180
Sensory scores (0–100 scale)						
Tenderness	43.3	14.3	5–78	38.7	14.9	5–75
Juiciness	46.1	11.3	14–75	44.6	12.5	11–74
Like flavour	48.6	11.2	12–78	46.4	12.0	7–73
Overall liking	45.6	12.4	11–77	42.3	13.5	8–73
MQ4	45.2	11.9	10–77	41.9	12.8	8–71
Objective meat quality						
Shear force (kg)	5.8	2.6	3.1–17.7	5.8	2.4	3.2–16.9
Compression (kg)	1.90	0.32	1.08–2.79	1.94	0.32	1.31–2.95
Cook loss %	22.9	1.7	17.3–27.3	23.0	1.6	17.6–28.6

Table 3. Predicted means (s.e.) for market category, finishing regime hormonal growth promotant (HGP) treatment, number of implants, *Bos indicus* content, interaction between *B. indicus* content and HGP treatment and slaughter age effects on carcass traits
*, $P<0.05$; **, $P<0.01$; *, $P<0.001$; n.s., not significant

Effect and level	Carcass weight (kg)	Ossification score	Marbling score	Rib fat (mm)	Ultimate pH
		Fixed effects			
Market category					
Domestic	271 (7)	152 (7)	167 (19)	3.5 (0.9)	5.5 (0.0)
Korean	294 (5)	161 (7)	217 (18)	5.2 (0.8)	5.6 (0.0)
Japanese	319 (6)	181 (5)	297 (17)	7.9 (0.8)	5.6 (0.0)
Significance	**	$P=0.07$	***	*	n.s.
Finish regime					
Grain	321 (6)	167 (6)	237 (16)	7.2 (0.8)	5.5 (0.0)
Grass	268 (5)	186 (5)	216 (14)	3.9 (0.6)	5.6 (0.0)
Significance	***	$P=0.05$	n.s.	*	*
HGP treatment					
Control	286 (3)	155 (3)	235 (10)	5.6 (0.4)	5.6 (0.0)
Oestradiol-17β	303 (5)	198 (5)	219 (11)	5.5 (0.5)	5.6 (0.0)
Significance	***	***	*	n.s.	n.s.
No. of implants (HGP)					
1	316 (14)	162 (15)	239 (25)	5.6 (1.2)	5.6 (0.1)
2	293 (7)	168 (8)	235 (15)	4.6 (0.7)	5.6 (0.1)
3	298 (4)	187 (4)	242 (11)	5.7 (0.5)	5.6 (0.0)
4	299 (9)	175 (9)	229 (17)	5.1 (0.8)	5.7 (0.1)
5	305 (5)	180 (5)	218 (12)	5.9 (0.6)	5.6 (0.0)
6	305 (21)	231 (24)	180 (40)	6.9 (1.8)	5.5 (0.1)
7	309 (10)	277 (11)	200 (20)	5.4 (0.9)	5.6 (0.1)
8	303 (10)	201 (10)	208 (20)	5.2 (0.9)	5.6 (0.1)
Significance	n.s.	***	n.s.	n.s.	n.s.
		Regression coefficients			
Bos indicus content	–0.317 (0.077)	–0.029 (0.084)	–0.396 (0.130)	–0.010 (0.006)	0.000 (0.000)
Significance	***	n.s.	**	n.s.	n.s.
Slaughter age	0.193 (0.027)	0.057 (0.028)	–0.029 (0.061)	0.001 (0.003)	0.000 (0.000)
Significance	***	*	n.s.	n.s.	n.s.

after adjustment to the same age. There was a trend for lower ossification scores in carcasses from grain-finished compared with pasture-finished steers ($P<0.10$, Table 3). Implantation with oestradiol-17β resulted in a 43 point (or 28%) increase in ossification score compared with the control group ($P<0.05$, Table 3). The number of oestradiol-17β implants given also affected ossification score ($P<0.05$, Table 3), with an increase in ~80 units (or a 50% increase) in ossification over the eight implants. *B. indicus* content had no effect on ossification score ($P>0.05$, Table 3).

Marbling scores were significantly ($P<0.05$, Table 3) affected by market category, with the heavier Japanese carcasses having the highest marbling, followed by the Korean carcasses, with the domestic carcasses having the lowest marbling scores. Oestradiol-17β treatment decreased marbling score by 16 units (7%, $P<0.05$, Table 3), whereas increasing *B. indicus* content from 50 to 100% reduced marbling scores by 20 units (~8%, $P<0.05$, Table 3). Within the HGP-treated groups the number of implants did not affect marbling score ($P>0.05$, Table 3).

There was an increase in fatness with the heavier market categories ($P<0.05$, Table 3), and also in grain-fed compared with pasture-fed carcasses. There were no significant treatment effects (i.e. market category, finishing regime, HGP treatment, number of HGP implants, *B. indicus* content or age) on ultimate pH ($P>0.05$, Table 3).

Generally, mean sensory scores for the striploin were low (Table 2), with some individual scores as low as 10 sensory units on a 0–100-point scale, in both the control and implanted groups. Objective meat quality measurements also confirmed the presence of some very tough samples in both the control and implanted treatment groups, with individual shear forces as high as 17 kg.

Predicted means for sensory scores and objective measurements are shown in Tables 4 and 5. Market category had no significant effect on the sensory scores and objective meat quality measurements ($P>0.05$, Tables 4 and 5). Grain feeding resulted in an increase of 7 to 8 units in like flavour and MQ4 scores compared with pasture finishing, with the exception of tenderness and juiciness scores where there was little effect of finishing regime (Table 4). Grain feeding caused a decrease in shear force and compression ($P<0.05$) measurements ($P<0.05$, Table 5).

The interaction between *B. indicus* content and oestradiol-17β was significant for tenderness, like flavour, overall liking and MQ4 score ($P<0.05$, Table 4), and approached significance for juiciness score ($P<0.10$, Tables 4 and 5). Figure 1 shows

Table 4. Predicted means (±s.e.) for market category, finishing regime, hormonal growth promotant (HGP) treatment, number of implants, stimulation, *Bos indicus* content, interaction between *B. indicus* content and HGP treatment and slaughter age effects on sensory scores

*, $P<0.05$; **, $P<0.01$; *, $P<0.001$; n.s., not significant

Effect and level	Tenderness	Juiciness	Like flavour	Overall liking	MQ4
		Fixed effects			
Market category					
Domestic	39.9 (4.1)	47.2 (2.6)	46.3 (3.0)	42.7 (3.6)	40.0 (4.1)
Korean	43.8 (3.6)	48.5 (3.1)	48.9 (2.5)	46.5 (2.7)	42.0 (3.6)
Japanese	41.2 (3.6)	43.4 (3.5)	49.2 (2.6)	43.5 (3.1)	43.5 (3.6)
Significance	n.s.	n.s.	n.s.	n.s.	n.s.
Finish regime					
Grain	44.4 (3.4)	49.7 (2.7)	51.6 (2.5)	47.6 (3.2)	48.3 (2.8)
Grass	38.8 (2.9)	45.7 (2.1)	44.6 (2.1)	40.9 (2.2)	40.7 (2.4)
Significance	n.s.	n.s.	$P=0.07$	n.s.	$P=0.09$
HGP treatment					
Control	44.2 (2.3)	48.3 (1.6)	49.4 (1.8)	46.0 (1.8)	46.1 (1.6)
Oestradiol-17β	39.1 (2.7)	47.0 (2.0)	46.9 (1.4)	42.5 (2.2)	42.9 (2.0)
Significance	n.s.	n.s.	n.s.	n.s.	n.s.
No. of implants (HGP)					
1	45.0 (5.8)	51.5 (5.0)	51.5 (4.6)	48.2 (5.0)	48.5 (4.8)
2	34.0 (3.3)	41.9 (2.8)	43.6 (2.5)	37.8 (2.9)	37.8 (2.7)
3	39.1 (2.2)	46.7 (1.8)	46.2 (1.6)	41.9 (1.9)	42.0 (1.9)
4	38.9 (3.9)	49.2 (3.3)	47.6 (3.0)	41.6 (3.4)	43.0 (3.2)
5	41.1 (2.6)	46.8 (2.2)	48.9 (2.0)	44.2 (2.3)	44.0 (2.2)
6	36.8 (9.0)	43.6 (7.7)	39.7 (7.1)	38.7 (7.8)	38.8 (7.5)
7	38.3 (4.4)	46.5 (3.7)	46.6 (3.4)	41.5 (3.8)	42.3 (3.7)
8	39.7 (4.4)	50.2 (3.7)	49.0 (3.4)	45.7 (3.8)	44.4 (3.6)
Significance	n.s.	n.s.	n.s.	n.s.	n.s.
		Stimulation treatment			
High voltage	50.2 (3.7)	54.1 (2.5)	53.1 (2.7)	51.5 (3.0)	51.5 (3.0)
Low voltage	41.2 (2.3)	44.5 (1.6)	47.8 (1.7)	44.1 (1.9)	44.0 (1.8)
No stimulation	33.5 (5.2)	44.6 (2.5)	42.9 (3.7)	36.5 (4.2)	37.5 (4.2)
Significance		*	*	*	n.s.
		Regression coefficients			
B. indicus content	–0.14 (0.04)	–0.11 (0.04)	–0.09 (0.03)	–0.13 (0.04)	–0.11 (0.04)
Significance	***	***	***		***
Slaughter age	–0.01 (0.01)	0.00 (0.01)	–0.00 (0.01)	–0.00 (0.01)	–0.00 (0.01)
Significance	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction					
B. indicus × HGP					
Oestradiol-17β	–0.15 (0.06)	–0.10 (0.05)	–0.12 (0.05)	–0.12 (0.05)	–0.12 (0.05)
Significance	*	$P=0.05$	*	*	*

that the negative effect of oestradiol-17β implants on beef tenderness was more pronounced as the proportion of *B. indicus* increased from 50 to 100%. The decline in sensory scores was particularly marked in the oestradiol-17β-treated samples from 100% *B. indicus* carcasses, which had a mean tenderness score of 28 units on a 0–100-point scale, which was 11 units less than the controls. If the interaction term for *B. indicus* content × HGP treatment was excluded from the analyses, the HGP treatment term was significant for tenderness ($P<0.01$), overall liking and MQ4 scores ($P<0.05$), approached significance for like flavour ($P=0.07$) and compression ($P=0.08$), and was not significant for juiciness score or shear force ($P>0.05$). Without the interaction term the HGP treatment resulted in lower sensory scores and higher compression values.

Stimulation had a significant effect on sensory scores and shear force ($P<0.05$, Tables 4 and 5). In all cases the lowest sensory scores and highest peak force values were obtained for groups that received no stimulation treatment. The comparison between stimulation systems was confounded by abattoir, although generally the high-voltage system resulted in higher sensory scores than the low-voltage stimulation system ($P<0.95$, Table 4).

After adjustment for market category, finishing regime, *B. indicus* content and oestradiol-17β treatment, whether animals were given one to eight implants from weaning to

Table 5. Predicted means (±s.e.) for market category, finishing regime, hormonal growth promotant (HGP) treatment, number of implants, stimulation, *Bos indicus* content, interaction between *B. indicus* content and HGP treatment and slaughter age effects on objective meat quality

*, $P<0.05$; **, $P<0.01$; *, $P<0.001$; n.s., not significant

Effect and level	Shear force (kg)	Compression (kg)	Cooking loss (%)
	Fixed effects		
Market category			
Domestic	6.9 (0.8)	1.9 (0.1)	22.9 (0.5)
Korean	5.5 (0.7)	2.0 (0.1)	22.6 (0.4)
Japanese	6.9 (0.8)	1.8 (0.1)	23.2 (0.4)
Significance	n.s.	n.s.	n.s.
Finish regime			
Grain	5.4 (0.8)	1.8 (0.1)	22.4 (0.4)
Grass	7.4 (0.5)	2.1 (0.1)	23.4 (0.3)
Significance	*	**	n.s.
HGP treatment			
Control	6.4 (0.5)	1.9 (0.0)	22.8 (0.2)
Oestradiol-17β	6.4 (0.5)	1.9 (0.0)	23.1 (0.3)
Significance	n.s.	n.s.	n.s.
No. of implants (HGP)			
1	6.7 (0.8)	1.9 (0.1)	23.4 (0.7)
2	6.5 (0.6)	1.9 (0.1)	23.3 (0.4)
3	6.6 (0.5)	1.9 (0.0)	22.8 (0.3)
4	6.5 (0.6)	1.9 (0.1)	23.2 (0.5)
5	6.6 (0.5)	1.9 (0.0)	22.6 (0.3)
6	5.1 (1.1)	1.9 (0.2)	22.9 (1.1)
7	6.8 (0.7)	2.0 (0.1)	23.0 (0.5)
8	6.5 (0.7)	1.9 (0.1)	23.2 (0.5)
Significance	n.s.	n.s.	n.s.
Stimulation			
High voltage	5.4 (0.8)	1.9 (0.1)	23.1 (0.4)
Low voltage	4.9 (0.5)	1.9 (0.0)	23.0 (0.3)
No stimulation	8.9 (1.1)	1.9 (0.1)	22.1 (0.6)
Significance	*	n.s.	n.s.
	Regression coefficients		
B. indicus content	0.01 (0.00)	0.00 (0.00)	0.01 (0.00)
Significance	***	n.s.	***
Slaughter age	–0.00 (0.00)	0.00 (0.00)	–0.00 (0.00)
Significance	n.s.	n.s.	n.s.
	Interaction		
B. indicus × HGP			
Oestradiol-17β	0.01 (0.01)	0.00 (0.00)	–0.00 (0.01)
Significance	n.s.	n.s.	n.s.

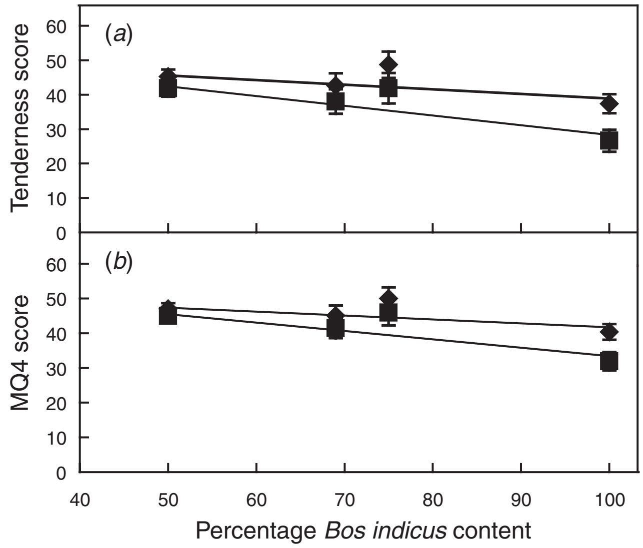

Fig. 1. The plot for (*a*) tenderness and (*b*) MQ4 scores as functions of % *Bos indicus* content for implanted (■) and control (◆) groups. The lines represent the fitted linear regression equations and the symbols the predicted means and standard error bars when *B. indicus* content was fitted as a fixed effect.

slaughter had no significant effect on any of the sensory scores ($P>0.05$ Table 4).

Discussion

Use of oestradiol-17β implants in 100% *B. indicus* steers resulted in a larger decrease in palatability of *M. longissimus* samples compared with implants administered to 50% *B. indicus* cross steers (see Fig. 1). Recently, Thompson *et al*. (2008) showed that HGP implants containing a combination of androgenic and oestrogenic compounds had a negative effect on palatability, which they proposed was a result of decreased post-mortem proteolysis in implanted carcasses. Although the different HGP implants varied in their active ingredients and therefore possibly the pathways by which they accrete protein in the body, Vernon and Buttery (1978) and more recently Dunshea *et al*. (2005) concluded that decreased protein degradation in the live animals was likely to be involved for both oestrogenic and androgenic compounds. As discussed by Koohmaraie *et al*. (2002), compounds that decrease protein degradation in the live animal will decrease post-mortem proteolysis and impact negatively on tenderness. In high *B. indicus* content carcasses the increase in calpastatin was associated with increased toughness (e.g. Shackelford *et al*. 1991; O'Connor *et al*. 1997; Ferguson *et al*. 2000). Presumably, in our study the effects on protein degradation from the oestradiol-17β implants and *B. indicus* content interacted synergistically to give the lowest protein turnover rate and consequently produce the toughest meat in the oestradiol-17β-implanted carcasses from high *B. indicus* cattle. In northern Australia a variety of HGP implants are given routinely to high *B. indicus* content cattle, a combination that our results indicate would incur the greatest penalty in eating quality of the *M. longissimus*. Further research is required to confirm the repeatability of these results and the magnitude of the interaction in other muscles in the carcass. It is of note that if the interaction is ignored then the HGP treatment resulted in lower tenderness, overall liking and MQ4 scores compared with the control group.

Increased ossification scores in this experiment were in agreement with other studies that showed that oestrogenic implants advanced skeletal maturity (Vanderwert *et al*. 1984). In this experiment, multiple oestrogenic implants over the lifetime of the animal tended to further increase ossification scores, which was in agreement with Platter *et al*. (2003). As expected, market category also influenced ossification score, with heavier carcasses having higher ossification scores. Grain feeding resulted in a decrease in ossification score compared with pasture finishing. In the present study ossification score was corrected for slaughter age and so the differences did not simply reflect a slower growth and older carcasses in the pasture-fed groups. Boleman *et al*. (1996) reported that mature cows fed a high grain ration had decreased ossification scores, with the effect being more pronounced when given a high protein supplement.

Implantation with oestradiol resulted in decreased marbling score, which was in agreement with Gerken *et al*. (1995). Although androgenic implants may not result in a reduction of marbling (Apple *et al*. 1991), certainly combined oestrogenic and androgenic implants do decrease marbling (Platter *et al*. 2003; Thompson *et al*. 2008). What was of note in the present study was that repeated implants of oestradiol did not cause further decreases in marbling score. This was in contrast to Mader *et al*. (1985) and Loy *et al*. (1988) who reported that repeated implantation with low-potency oestrogenic implants resulted in further decreases in marbling, compared with a single implant. A point of difference may be that in the present study the old implants were removed as new ones were inserted into the ear, which would have resulted in a more constant delivery of oestradiol to the animal compared with programs that simply reimplanted.

When carcasses were inadvertently not stimulated this resulted in lower sensory scores and higher shear forces (Hwang *et al*. 2003). It was interesting that there was a difference between stimulation treatments in that higher sensory score were achieved using the high-voltage compared with the low-voltage system, with the exception of juiciness. Hwang and Thompson (2001) compared high- and low-voltage systems and concluded that if applied to achieve the same pH or temperature decline there was little difference in the effect on sensory scores. This suggested that the different systems may not have been applied optimally in the different abattoirs, with the low-voltage system resulting in too rapid a pH decline and subsequently heat toughening of product in the low-voltage stimulation samples. This would be consistent with the high-voltage samples having a higher shear force at 1 day of aging (Thomson *et al*. 2008). However, caution should be exercised in interpreting too much into these results as the different systems were confounded by abattoir and as such, differences in eating quality could arise from several processes.

Generally, the sensory scores in the present study were low and shear forces high, due in part to the high *B. indicus* content (i.e. between 50 and 100%), and the oestradiol-17β implants. In addition, several groups were not stimulated, which further contributed to the low sensory scores and high shear forces. What was of interest in the present study was that there was no significant interaction between stimulation and HGP treatments. If this had been significant it would have suggested that proteolysis had a different role in palatability in samples from the stimulated and non-stimulated carcasses. Although the means between HGP and control groups for the three stimulation treatments differed in significance they showed that the samples from control carcasses had higher sensory scores by 4–8 units compared with implanted carcasses. However, given that there were only 89 carcasses in the non-stimulated group this was not a particularly sensitive test. The lack of an interaction between HGP and stimulation does suggest that proteolysis was occurring in all samples, which is in agreement with McDonagh *et al.* (1999) who showed that cold shortened meat with sarcomeres as low as 1.5 microns still underwent post-mortem proteolysis.

Repeated application of between one and eight implants between weaning and slaughter had little additional effect on eating quality on the *M. longissimus dorsi*. As discussed earlier some caution in the extrapolation of these results must be used because old implants were removed as new implants were applied. Platter *et al*. (2003) examined the effect of up to five anabolic implants as part of various management strategies on consumer sensory results. They showed that the highest consumer tenderness scores were for the control group, compared with groups that had two, three, four or five anabolic implants.

Conclusion

The present study showed that steers implanted with oestradiol-17β had higher carcass weights and ossification scores but lower marbling scores than control steers. Repeated oestradiol-17β implants from weaning to slaughter gave no further changes in carcass weight or marbling score, but carcasses that received more than one implant had higher ossification scores.

There was a *B. indicus* content by oestradiol-17β treatment interaction, which indicated that the negative effect of oestradiol-17β implants on beef tenderness was more pronounced as the proportion of *B. indicus* increased from 50 to 100%. This has implications for the Australian beef production system in northern Australia that routinely administers oestradiol-17β implants to high *B. indicus* content cattle. Further research is required to confirm the transportability of this interaction. Administration of repeated implants (between one and eight implants) had little effect on sensory scores or objective meat quality. All implant strategies reduced eating quality relative to the controls.

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