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Effect of hormonal growth promotants on palatability and carcass traits of various muscles from steer and heifer carcasses from a *Bos indicus–Bos taurus* composite cross

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Abstract. The effect of several different hormonal growth promotant (HGP) implant strategies on the palatability and carcass traits of different muscles in beef carcasses was investigated using samples from heifer and steer carcasses from a *Bos indicus* composite breed. In experiment 1, there were seven different implant strategies evaluated in heifers that were given different combinations of up to three implants (implanted at weaning, during backgrounding and at feedlot entry). A total of 112 heifers were slaughtered and 11 muscles or portions were collected from both sides [*Mm. adductor femoris*, *gracilus*, *semimembranosus*, *longissimus dorsi lumborum*, *triceps brachii caput longum*, *semispinalis capitis*, *serratus ventralis cervicis*, *spinalis dorsi*, *biceps femoris* (*syn. gluteobiceps*), *tensor fasciae latae*, *gluteus medius* (both the 'D' and the 'eye' portions) *rectus femoris*, *vastus intermedius*, *vastus lateralis* and *vastus medialis*]. These muscles were used to prepare a total of 1030 sensory samples which were aged for either 7 or 21 days and frozen. Thawed samples were cooked using different cooking methods (grill, roast and stir frying) before being evaluated by a consumer taste panel that scored samples for tenderness, juiciness, like flavour and overall liking. Experiment 2 used the steer portion from the same calving, which were treated to a similar array of HGP strategies, except that they were given up to four implants between weaning and slaughter at ~3 years of age. In experiment 2, there was a total of 12 different HGP implant strategies tested. At boning, three muscles (*Mm. psoas major*, *longisimuss dorsi thoracis* and *lumborum* portions) were collected from each of 79 carcasses with a total of 237 steak samples that consumers tested as grilled steaks.

For both experiments, the mean of the HGP implant strategies resulted in increased ossification scores ($P < 0.05$) and decreased marbling scores ($P < 0.05$) compared with the controls, with the effect on ossification being much larger in the older steer groups. In both experiments, the different HGP strategies decreased ($P < 0.05$) all sensory scores compared with the controls, for all cooking method and muscle combinations. In experiment 1, there was no interaction between the mean HGP effect and muscle ($P > 0.05$), and aging rates differed among the muscles ($P < 0.05$). In experiment 2, there was a significant ($P < 0.05$) muscle × HGP treatment interaction, with a decrease in tenderness score due to HGP implant strategies in the *M. longisimuss thoracis* and *lumborum* portions, compared with no significant effect in the *M. psoas major*. For both experiments, there were no significant differences among the different implantation strategies on sensory scores ($P > 0.05$).

Introduction

Cattle breeding and production in northern Australia is typically conducted under extensive rangeland conditions. The climate is characterised by annual wet and dry seasons, with pasture growth and nutrient quality being highly seasonal (Bindon and Jones 2001). To market cattle at a young age, management systems have been developed to enable the sale of weaner cattle within the one season, thereby avoiding periods of low weight gain or weight loss between seasons.

Factors that have contributed to achieving an early sale of store (unfinished) cattle include the introduction of *Bos indicus* genetics and the complementary use of backgrounding cattle in better grazing regions. This in conjunction with the use of feedlots to finish cattle has lead to cattle achieving market specifications and being slaughtered at a younger age. Hormonal growth promotants (HGPs) are commonly used to increase liveweight gains and feed efficiency in each phase of production (Hunter *et al*. 2001). The industry currently uses a

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wide range of HGP programs involving different promotants and implantation times. HGPs are generally implanted during other management activities at weaning, at transporting to a backgrounding property, and at feedlot entry.

While the advantages of HGP implants on liveweight gains and food efficiency are well recognised (Sawyer and Barker 1988), their impact on the quality of meat has been variable. The two experiments reported here were initiated by a major corporate cattle enterprise in northern Australia in conjunction with an implant supplier. The HGP treatments represented potential alternative implant strategies applied at various stages of production. These were compared with non-implanted control groups. This paper does not report on the production gains from the various implant strategies; rather, it reports the impact of the different HGP strategies on eating quality and carcass traits of several selected muscles. In experiment 1, muscles from heifer carcasses were aged for 7 or 21 days after slaughter and prepared using different cooking methods (grill, roast and stir fry). In experiment 2, a different selection of muscles were sampled from steer carcasses at one time after slaughter and only served as grills. Constraints on sensory testing meant that the number of animals and muscles consumers tested in the various strategies were limited: 6–8 animals in experiment 1 and 1–10 animals in experiment 2.

Materials and methods

Cattle and treatments

Experiment 1 (heifers)

A total of 112 heifers were sourced from a three-eighths *Bos indicus*, five-eighths *Bos taurus* composite breed developed by a Queensland-based pastoral company. Calves were born under extensive rangeland conditions, weaned and grown on moderate-quality grassland until the group reached the mean feedlot entry liveweight of 331 kg. At this point, the heifers were divided into two weight groups, the heavier group being placed on a high concentrate ration (sorghum based) for 73 days, whereas the lighter group was maintained on pasture for another 14 days, before being placed on the same concentrate ration for 73 days.

At weaning, the heifers were randomly allocated to one of eight treatments, where they were given up to three HGP implants, administered at weaning, while being backgrounded on pasture, and at the commencement of feedlotting. These treatments are summarised in Table 1. The treatments are coded to identify the time of administration and type of HGP as follows: O, no implant; C1, Compudose-100; 20 mg oestradiol 17-beta; C2, Compudose-200, 24 mg oestradiol 17-beta; C4, Compudose-400, 45 mg oestradiol 17-beta; RG, Revalor-G, 60 mg trenbolone acetate + 12 mg oestradiol 17-beta; RS, Revalor-S, 140 mg trenbolone acetate + 28 mg oestradiol 17-beta; S, Synovex-Plus, 200 mg trenbolone acetate + 28 mg oestradiol benzoate (72% activity of oestradiol 17-beta).

Using the above notation, two examples of treatments are; C4-O-S, which denotes that heifers were implanted with C4 at weaning, no backgrounding treatment and they were implanted with S at feedlot entry and O-O-O, which denoted the control treatment (i.e. no treatment at either weaning, backgrounding or feedlot entry). For those heifers in the HGP-treated groups, the implants were inserted subcutaneously in the ear.

All heifers in the treated groups (see Table 1) were implanted with one of three HGPs at weaning (C4, C2 or RG). Some groups received a second implant, of either RG or C2, 246 days after weaning (170 and 184 days before slaughter, respectively) with others and the control group not implanted at this time. All heifer treatment groups were implanted with S at feedlot entry.

Table 1. Summary of treatments for heifers from experiment 1

Treatments and codes are: C2, Compudose-200, 24 mg oestradiol 17-beta; C4, Compudose-400, 45 mg oestradiol 17-beta; RG, Revalor-G, 60 mg trenbolone acetate + 12 mg oestradiol 17-beta; S, Synovex-Plus, 200 mg trenbolone acetate + 28 mg oestradiol benzoate; O, nil. dbs, number of days before slaughter

No. of animals	Treatment code	Weaning		Pasture backgrounding		Feedlot entry	
		Treatment	dbs	Treatment	dbs	Treatment	dbs
				Group 1			
7	O-O-O	Nil	–	Nil	–	Nil	73
7	C4-O-S	Compudose-400	415	Nil	–	Synovex-Plus	73
7	C4-RG-S	Compudose-400	415	Revalor-G	170	Synovex-Plus	73
7	C2-O-S	Compudose-200	415	Nil	–	Synovex-Plus	73
7	C2-C2-S	Compudose-200	415	Compudose-200	170	Synovex-Plus	73
6	C2-RG-S	Compudose-200	415	Revalor-G	170	Synovex-Plus	73
7	RG-O-S	Revalor-G	415	Nil	–	Synovex-Plus	73
6	RG-RG-S	Revalor-G	415	Revalor-G	170	Synovex-Plus	73
				Group 2			
7	O-O-O	Nil		Nil	–	Nil	73
7	C4-O-S	Compudose-400	429	Nil	–	Synovex-Plus	73
7	C4-RG-S	Compudose-400	429	Revalor-G	184	Synovex-Plus	73
7	C2-O-S	Compudose-200	429	Nil	–	Synovex-Plus	73
7	C2-C2-S	Compudose-200	429	Compudose-200	184	Synovex-Plus	73
8	C2-RG-S	Compudose-200	429	Revalor-G	184	Synovex-Plus	73
7	RG-O-S	Revalor-G	429	Nil	–	Synovex-Plus	73
8	RG-RG-S	Revalor-G	429	Revalor-G	184	Synovex-Plus	73

Experiment 2 (steers)

A total of 79 steers were sourced from the same composite herd. Before weaning, the steers were randomly allocated to either early or late weaning treatments, 100 days apart. Within each weaning treatment, animals were randomly allocated to 1 of 12 implant strategies described in Table 2. Steers were grazed on native pasture until the group reached the mean feedlot entry weights of 434 kg, before being fed for 113 days on grain-based rations in a feedlot. During backgrounding steers could potentially receive up to two implants. All steers received either RG or RS before finishing in the feedlot on a concentrate ration (sorghum based) for 113 days.

The notation for the treatments used for the steers was similar to the heifers except that there were potentially four implant times. For example, C4-O-O-RS denoted implantation with C4 at weaning, no early or late backgrounding treatments and RS given at feedlot entry. All treated cattle were implanted with either RG or C4 at weaning, 715 or 615 days before slaughter, respectively. The treated groups received either no further implant before feedlot entry, or one additional implant at one of two times, either 468 or 387 days before slaughter for the early cohort groups, or 386 or 288 days before slaughter for the second treatment group. Implants used during late backgrounding were either RG or C1. At feedlot entry, all treatments except the control group, received either RG or RS implants before a 113-day feeding period.

Slaughter and primal collection

Experiment 1 (heifers)

After 73 days on feed, heifers from both slaughter groups were transported to a commercial abattoir and slaughtered the next morning. Low voltage electrical stimulation (45 V, 100 ms on and 12 ms off, 36 pulses per second) was applied directly after bleeding. Carcasses were assessed by Meat Standards Australia (MSA) graders ~20 h after slaughter (Thompson 2002). The graders collected data on carcass weight, rib fat depth, ossification and marbling scores and ultimate pH (Perry *et al*. 2001). Ossification and marbling scores were scored using the USDA standards (Romans *et al*. 1994).

For the first slaughter of the heifers, the blade (HAM 2300), striploin (HAM 2140) and topside (HAM 2120) primals (Anon. 1998) were collected from both sides of the 54 for subsequent preparation of sensory samples. For the second slaughter of the heifers, both sides from the 58 carcasses were sampled for the chuck (HAM 2260), rump (HAM 2090), striploin (HAM 2140) and knuckle (HAM 2070) primals (Anon. 1998). The numbers of animals from the different treatments for the two slaughter times are shown in Table 1. Primals were vacuum packed, chilled and

Table 2. Summary of treatment for steers from experiment 2

Treatments are: C1, Compudose-100, 20 mg oestradiol 17-beta; C4, Compudose-400, 45 mg oestradiol 17-beta; RG, Revalor-G, 60 mg trenbolone acetate + 12 mg oestradiol 17-beta; RS, Revalor-S, 140 mg trenbolone acetate + 28 mg oestradiol 17-beta; O, Nil. dbs, number of days before slaughter

No. of animals	Treatment code	Weaning Treatment	dbs	Early background Treatment	dbs	Late background Treatment	dbs	Finishing Treatment	dbs
				Weaning group 3					
9	O-O-O-O	Nil	–	Nil	–	Nil	–	Nil	113
2	C4-O-O-RS	Compudose-400	715	Nil	–	Nil	–	Revalor-S	113
2	C4-O-O-RG	Compudose-400	715	Nil	–	Nil	–	Revalor-G	113
2	C4-O-C1-RS	Compudose-400	715	Nil	–	Compudose-100	387	Revalor-S	113
2	C4–0-C1-RG	Compudose-400	715	Nil	–	Compudose-100	387	Revalor-G	113
2	C4-RG-O-RS	Compudose-400	715	Revalor-G	468	Nil	–	Revalor-S	113
2	C4-RG-O-RG	Compudose-400	715	Revalor-G	468	Nil	–	Revalor-G	113
2	RG-O-O-RS	Revalor-G	715	Nil	–	Nil	–	Revalor-S	113
2	RG-O-O-RG	Revalor-G	715	Nil	–	Nil	–	Revalor-G	113
1	RG-O-RG-RS	Revalor-G	715	Nil	–	Revalor-G	387	Revalor-S	113
3	RG-O-RG-RG	Revalor-G	715	Nil	–	Revalor-G	387	Revalor-G	113
2	RG-RG-O-RS	Revalor-G	715	Revalor-G	468	Nil	–	Revalor-S	113
2	RG-RG-O-RG	Revalor-G	715	Revalor-G	468	Nil	–	Revalor-G	113
				Weaning group 4					
10	O-O-O-O	Nil	–	Nil	–	Nil	–	Nil	113
3	C4-O-O-RS	Compudose-400	615	Nil	–	Nil	–	Revalor-S	113
3	C4-O-O-RG	Compudose-400	615	Nil	–	Nil	–	Revalor-G	113
3	C4-O-C1-RS	Compudose-400	615	Nil	–	Compudose-100	288	Revalor-S	113
3	C4–0-C1RG	Compudose-400	615	Nil	–	Compudose-100	288	Revalor-G	113
3	C4-RG-O-RS	Compudose-400	615	Revalor-G	386	Nil	–	Revalor-S	113
3	C4-RG-O-RG	Compudose-400	615	Revalor-G	386	Nil	–	Revalor-G	113
3	RG-O-O-RS	Revalor-G	615	Nil	–	Nil	–	Revalor-S	113
3	RG-O-O-RG	Revalor-G	615	Nil	–	Nil	–	Revalor-G	113
4	RG-O-RG-RS	Revalor-G	615	Nil	–	Revalor-G	288	Revalor-S	113
2	RG-O-RG-RG	Revalor-G	615	Nil	–	Revalor-G	288	Revalor-G	113
3	RG-RG-O-RS	Revalor-G	615	Revalor-G	386	Nil	–	Revalor-S	113
3	RG-RG-O-RG	Revalor-G	615	Revalor-G	386	Nil	–	Revalor-G	113

transported to the MSA boning room for storage and preparation into consumer test samples.

Primals were prepared for sensory evaluation within 7 days of slaughter. These samples were aged at 1°C until freezing (−20°C), at 7 or 21 days after slaughter. The topside was separated into three muscles (*Mm. adductor femoris*, *gracilus* and *semimembranosus*), while the *Mm. longissimus dorsi lumborum* and *triceps brachii caput longum* were removed from the striploin and blade primals, respectively. The chuck was separated into three muscles (*Mm. semispinalis capitis*, *serratus ventralis cervicis* and *spinalis dorsi*), and the rump was separated into four muscles [*Mm. biceps femoris*, *tensor fasciae latae* and *gluteus medius* (this muscle was separated into two portions along the natural seam with the larger ventral portion termed the 'D' and the remaining dorsal portion termed the 'eye')]. The knuckle was separated into four muscles (*Mm. rectus femoris*, *vastus intermedius*, *vastus lateralis* and *vastus medialis*).

Experiment 2 (steers)

Steers were transported to a commercial abattoir (different from that used in experiment 1 for the heifers), and slaughtered the next morning. No electrical stimulation was applied; however, carcasses received electrical inputs via the hide puller rigidity probe. Carcasses were graded 20 h after slaughter as described above.

The striploin, cube roll (HAM 2240) and tenderloin (HAM 2150) primals (Anon. 1998) were removed from the 79 carcasses for subsequent preparation of sensory samples. In contrast to experiment 1, primals were only collected from one side of the carcass. The numbers of animals sampled are shown in Table 2.

The cube roll, striploin and tenderloin were used to prepare sensory samples from the *Mm. longissimus thoracis*, *longissimus lumborum* and *psoas major*, respectively. In total, there were 237 sensory samples prepared for grilling from 79 animals with three muscles from every animal. Samples were aged for 7 days before freezing at −20°C.

Sample preparation and sensory testing

The preparation of denuded muscles into consumer samples was in accordance with MSA protocols (a detailed description of the sensory protocols are provided in the Accessory Publication to the online version of the paper by Watson *et al*. 2008). Grill steaks were trimmed to blocks before slicing into 25-mm-thick steaks, which were wrapped individually in plastic and frozen. Roasting blocks were trimmed to 75 by 75 by 150 mm dimensions before netting and freezing. Stir-fry samples (10 by 10 by 75 mm) were sliced from a tempered block before cooking. Table 3 summarised the number of muscles collected from the different treatments and the cooking and aging treatments applied.

The consumer testing and cooking protocols have been described in detail by Watson *et al*. (2008). Briefly, each of the sensory samples was tasted by 10 untrained consumers who were each presented with seven samples, which comprised a starter sample, followed by six experimental samples. The samples from both experiments 1 and 2 were tested by consumers in conjunction with other beef samples from a range of trials. Samples from experiment 1 were grilled, roasted or stir fried, whereas those from experiment 2 were all grilled. Consumers were asked to score grilled steaks, roasted slices and stir-fried samples for tenderness, juiciness, like flavour and overall liking by placing marks on 100-mm lines anchored with the following definitions: tenderness (very tough to very tender); juiciness (very dry to very juicy); like flavour (dislike extremely to like extremely); overall liking (dislike extremely to like extremely). A composite meat quality or palatability score

Table 3. The number of samples sensory tested from each slaughter day, muscle and cooking method for heifers from experiment 1

Muscle	Primal	Grill		Roast		Stir fry	
		7 days	21 days	7 days	21 days	7 days	21 days
		Slaughter group 1					
M. triceps brachii	Blade	54	54	–	–	–	–
M. longissimus dorsi	Striploin	54	58	–	–	–	–
M. adductor femoris	Topside	14	14	–	–	–	–
M. gracilis	Topside	–	–	–	–	14	14
M. semimembranosus	Topside	–	–	54	54	–	–
		Slaughter group 2					
M. semispinalis capitis	Chuck	12	14	12	14	–	–
M. serratus ventralis cervicis	Chuck	12	14	14	18	–	–
M. spinalis dorsi	Chuck	–	–	–	–	11	20
M. biceps femoris (cap)	Rump	42	–	–	–	16	–
M. tensor fasciae latae	Rump	–	–	–	–	24	–
M. gluteus medius (D portion)	Rump	58	58	–	–	–	–
M. gluteus medius (eye portion)	Rump	16	16	8	17	–	–
M. longissimus lumborum	Striploin	54	58	–	–	–	–
M. rectus femoris	Knuckle	–	–	33	23	–	–
M. vastus intermedius	Knuckle	–	–	–	–	10	5
M. vastus lateralis	Knuckle	–	–	24	19	–	–
M. vastus medialis	Knuckle	–	–	–	–	15	9

(MQ4) was formed for each evaluation 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 (Polkinghorne *et al*. 1999; Watson *et al*. 2008). Prior to calculating mean sensory scores for each sample, the two highest and two lowest scores were clipped (to reduce the bias and the variance of the estimate; see Watson *et al*. 2008).

Statistical analysis

Experiment 1 (heifers)

The low number of animals per cell precluded treating the HGP effect in the normal manner; rather, the degrees of freedom were partitioned into two separate contrasts. The first was a single degree of freedom contrast between the control and the mean HGP effect for all treatments, and the second, a contrast between the seven different HGP treatments.

Carcass traits were examined in a model that contained terms for slaughter day, the contrast between the control and mean HGP effect, and the contrast between the seven HGP treatments. Sensory scores were examined in models that contained terms for slaughter day, the contrast between control and the mean HGP effect, and the contrast between the seven HGP treatments, muscle, cooking method and days aged. First order interactions were tested and the muscle × days aged and muscle × cooking method terms were found to be significant ($P < 0.05$) for several of the sensory traits and, therefore, were included in the final models. In contrast, the interactions between the two HGP terms and muscle were tested and found to be non-significant ($P > 0.05$) for all sensory traits and were not included in the final models.

Experiment 2 (steers)

The degrees of freedom for HGP effect were partitioned into similar contrasts as for experiment 1. Carcass traits were examined using models that contained terms for weaning, the contrast between the control and mean HGP effect, and the contrast between the 12 HGP treatments. Sensory scores were examined using models that contained terms for weaning group, HGP effects (the contrast between control and the mean HGP effect and the contrast between the 12 HGP treatments), muscle and the first order interactions between muscle and the two HGP terms.

Results

Carcass traits

Experiment 1 (heifers)

Carcasses from heifers treated with HGPs were 12 kg heavier, had a 20-point increase in ossification score and a 35-point decrease in US marbling score than the control carcasses ($P < 0.05$, Tables 4 and 5), whereas there was little difference in rib fat and ultimate pH. Within the different HGP treatments there were no differences in carcass weight, ossification and US marbling scores, rib fat and ultimate pH (Table 4).

Experiment 2 (steers)

Similarly, carcasses from steers treated with HGPs were 23 kg heavier, had a 132-point increase in ossification score and a 41-point decrease in marbling score than the control carcasses ($P < 0.05$, Tables 4 and 5). There was a trend for carcasses from steers treated with HGPs to have greater rib fat ($P = 0.051$, Tables 4 and 5), although there was no difference in ultimate pH. Within the 12 different HGP treatments there was an effect on carcass weight and ossification ($P < 0.05$, Table 4), whereby the mean carcass weight of treatments C4-O-C1-RS, C4-O-O-RG and RG-O-RG-RG was 329 kg, compared with 353 kg for the remaining groups. Similarly for ossification score, the significant effect between HGP treatments was due to treatment RG-O-O-RG, which had a mean ossification score of 224, compared with a mean of 313 for the other strategies ($P < 0.05$). However, it should be noted that given the low cell numbers within specific treatment groups in this experiment, and the confounded nature of strategies applied, it was difficult to draw firm conclusions from these results about any one of the strategies compared with the others.

Sensory scores

Experiment 1 (heifers)

Samples from heifer carcasses treated with HGPs had sensory scores which were 4–6 units lower than the control samples

Table 4. *F*-ratios for the main effects in experiments 1 and 2

Effects in experiment 1 included slaughter day, control *v.* mean hormone growth promotant (HGP) treatment and the interaction between HGP treatments on carcass traits for heifers and experiment 2 with effects for weaning group, control *v.* mean HGP treatment and the interaction between HGP treatments on carcass traits for steers. NDF, DDF, numerator and denominator degrees of freedom. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; n.s., not significant

Independent variables	NDF, DDF	Carcass weight	Ossification score	US marbling score	Rib fat	Ultimate pH
			Experiment 1 (*heifers*)			
Slaughter day	1, 103	29.21***	2.39n.s.	2.67n.s.	0.29n.s.	11.78**
Control *v*. mean HGP	1, 103	13.56***	7.98**	5.74*	0.53n.s.	0.53n.s.
HGP treatment	6, 105	0.66n.s.	0.71n.s.	1.18n.s.	0.74n.s.	0.74n.s.
			Experiment 2 (*steers*)			
Weaning group	1, 65	0.23n.s.	3.45n.s.	0.09n.s.	0.03n.s.	0.22n.s.
Control *v.* mean HGP	1, 65	13.52***	183.06***	4.05*	3.95n.s.	0.00n.s.
HGP treatment	11, 65	1.97*	3.17**	1.45n.s.	0.28n.s.	1.31n.s.

Table 5. Predicted means (±s.e.) for control *v.* mean hormone growth promotant (HGP) treatment on carcass traits of heifers (experiment 1) and steers (experiment 2)

Treatment	Carcass weight (kg)	Ossification score	US marbling score	Rib fat (mm)	Ultimate pH
			Experiment 1 (*heifers*)		
Control	219 (±3)	167 (±7)	209 (±14)	6.4 (±0.6)	5.45 (±0.02)
Mean HGP	231 (±1)	187 (±3)	174 (±5)	5.5 (±0.2)	5.47 (±0.01)
			Experiment 2 (*steers*)		
Control	324 (±5)	173 (±9)	403 (±18)	7.9 (±1.1)	5.45 (±0.02)
Mean HGP	347 (±3)	305 (±5)	362 (±10)	10.5 (±0.6)	5.46 (±0.01)

($P < 0.05$, Tables 6 and 7). There were no significant differences between the seven HGP strategies ($P > 0.05$, Table 6). For each of the HGP implant strategies tested, sensory scores for the individual HGP treatments were lower than the controls (data not shown).

The muscle × days aged interaction was significant ($P < 0.05$) for tenderness, overall liking and MQ4 scores. Predicted means in Table 8 showed that, from 7-day to 21-day aging, the greatest improvement in tenderness score occurred in the *Mm. longissimus dorsi lumborum*, *semispinalis capitis*, *spinalis dorsi*, *vastus lateralis* and *vastus medialis*, with an increase of ~6–11 units in tenderness score. The remainder of the muscles in Table 8 showed little change in tenderness, overall liking or MQ4 scores over the 14-day period.

The muscle × cooking interaction was significant ($P < 0.05$) for all sensory scores, although due to the imbalance in the design this interaction only applied to four muscles. Predicted means for the muscle × cooking interaction in these muscles was shown in Table 9. For the *M. semispinalis capitis* there were no significant differences in sensory scores between grilling and roasting. In contrast, roasting the *M. gluteus medius* resulted in a large increase in all sensory scores compared with grilling, and this effect was most evident for tenderness score. Stir-frying compared with grilling resulted in a large increase in all sensory scores for the *M. biceps femoris*, again the increase being largest for tenderness score.

Table 6. *F*-ratios for the effect of control *v.* mean hormone growth promotant (HGP) treatment, the contrast between HGP treatments, muscle, cooking, days aged, muscle × days aged and muscle × cooking on sensory scores on tenderness, juiciness, like flavour, overall liking and composite palatability (MQ4) for heifers from experiment 1

NDF, DDF; numerator and denominator degrees of freedom. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Independent variable	NDF, DDF	Sensory score: Tenderness	Juiciness	Like flavour	Overall liking	MQ4
			Experiment 1 (*heifers*)			
Slaughter day	1, 103	6.18*	2.00	2.34	4.35*	4.52*
Control *v.* mean HGP	1, 891	8.69**	5.66*	8.93**	7.04**	7.74**
HGP treatment	6, 891	1.15	1.16	1.39	0.96	1.10
Muscle	15, 891	35.74***	28.93****	20.11***	29.37***	33.85***
Cooking	2, 891	19.64***	8.70***	6.69**	9.55***	13.33***
Days aged	1, 891	25.39***	1.50	2.30	11.63***	15.42***
Muscle × days aged	13, 891	2.00*	1.49	1.34	1.85*	1.99*
Muscle × cooking	2, 891	13.01***	8.61***	7.67***	9.16***	11.05***
			Experiment 2 (*steers*)			
Weaning group	1, 131	0.89	1.30	0.09	0.73	0.91
Control *v.* mean HGP	1, 131	9.51**	9.20**	6.41*	6.36*	7.85**
HGP treatment	11, 131	1.23	1.32	1.72	1.31	1.22
Muscle	2, 131	379.13***	192.68***	234.78***	328.84***	366.11***
Muscle × HGP *v.* control	2, 131	7.98***	0.62	1.93	1.87	3.92*
Muscle × HGP treatment	22, 131	1.11	0.78	1.02	1.00	0.96

Table 7. Predicted means (±s.e.) for sensory scores for tenderness, juiciness, like flavour, overall liking and composite palatability (MQ4) for the contrast between the control *v.* the mean hormone growth promotant (HGP) effect adjusted for the effects of muscle, cooking and days aged for heifers from experiment 1

	Tenderness		Juiciness		Like flavour		Overall liking		MQ4	
	Control	HGP	Control	HGP	Control	HGP	Control	HGP	Control	HGP
Sensory score (±s.e.)	56.3 (±2.1)	50.1 (±0.9)	57.2 (±1.6)	53.2 (±0.8)	58.8 (±1.4)	54.6 (±0.7)	56.9 (±1.7)	52.2 (±0.8)	56.6 (±1.7)	51.7 (±0.8)

Table 8. Predicted means for sensory scores for tenderness, juiciness, like flavour, overall liking and composite palatability (MQ4) for the interaction between muscle and days aged for heifers from experiment 1

Standard errors for each measured parameter refer to both the 7 and 21 day scores

Muscle	Primal	Tenderness			Juiciness			Like flavour			Overall liking			MQ4		
		7 days	21 days	s.e.	7 days	21 days	s.e.	7 days	21 days	s.e.	7 days	21 days	s.e.	7 days	21 days	s.e.
M. longissimus dorsi lumborum	Striploin	39.4	50.7	1.5	43.3	48.2	1.3	49.7	55.4	1.1	44.1	52.4	1.3	43.2	51.8	1.2
M. triceps brachii	Blade	53.0	54.4	2.0	54.3	54.4	1.8	57.5	56.8	1.6	56.2	56.3	1.7	54.6	55.0	1.7
M. adductor femoris	Topside	39.3	42.9	3.4	39.4	39.6	3.1	46.7	46.6	2.7	41.2	43.5	3.0	41.1	43.7	2.8
M. gluteus profundus	Topside	56.9	57.5	3.4	66.4	64.8	3.1	66.2	64.5	2.7	62.5	63.7	3.0	60.6	60.9	2.8
M. semimembranosus	Topside	32.7	36.3	2.0	40.8	40.5	1.8	43.6	45.2	1.6	38.0	39.7	1.7	37.2	39.7	1.7
M. semispinalis capitis	Chuck	54.7	62.7	2.5	62.7	61.6	2.3	59.4	61.1	2.0	57.4	61.7	2.2	56.9	61.4	2.1
M. serratus ventralis cervicis	Chuck	60.3	64.2	3.3	66.3	64.0	2.3	62.5	61.1	2.0	61.5	61.7	2.2	61.3	62.6	2.1
M. spinalis dorsi	Chuck	52.9	58.8	3.3	67.4	65.5	3.0	59.4	60.1	2.7	56.0	57.5	2.4	55.7	59.1	2.3
M. gluteus medius (eye portion)	Rump	53.8	57.5	2.5	48.3	52.4	2.3	53.9	57.4	2.0	51.9	55.7	2.2	52.8	56.2	2.1
M. gluteus medius (D portion)	Rump	42.0	50.2	1.9	42.0	47.0	1.7	50.8	53.6	1.5	46.2	51.1	1.7	44.8	50.7	1.6
M. rectus femoris	Knuckle	62.0	64.7	2.5	54.7	53.1	2.4	62.6	60.6	2.0	60.3	59.2	2.3	60.5	60.4	2.1
M. vastus intermedius	Knuckle	50.0	50.7	4.6	57.0	55.7	4.3	48.2	50.8	3.8	47.4	51.9	4.1	48.8	50.7	3.8
M. vastus lateralis	Knuckle	36.1	45.4	2.7	41.9	49.4	4.3	48.5	52.9	2.2	41.5	49.7	2.4	40.5	48.6	2.3
M. vastus medialis	Knuckle	49.5	61.3	3.6	61.0	65.9	3.4	58.4	59.7	2.9	54.1	58.8	3.2	53.3	59.9	3.1

Table 9. Predicted means (± average s.e.) for sensory scores for tenderness, juiciness, like flavour, overall liking and composite palatability (MQ4) for the interaction between muscle and cooking method for heifers from experiment 1

Muscle	Primal	Tenderness		Juiciness		Like flavour		Overall liking		MQ4	
		Grill	Roast	Grill	Roast	Grill	Roast	Grill	Roast	Grill	Roast
M. semispinalis capitis	Chuck	58.9	58.5	65.0	59.3	62.4	58.2	61.7	57.5	60.4	57.8
M. serratus ventralis cervicis	Chuck	59.3	65.2	66.0	64.3	63.1	60.5	61.8	61.3	61.2	62.8
M. gluteus medius (eye portion)	Rump	44.9	66.4	44.9	55.8	51.1	60.2	47.9	59.8	47.4	61.7
(± average s.e.)		(±2.5)	(±2.5)	(±2.1)	(±2.2)	(±2.0)	(±2.0)	(±2.2)	(±2.2)	(±2.1)	(±2.1)
		Grill	Stir fry	Grill	Stir fry	Grill	Stir fry	Grill	Stir fry	Grill	Stir fry
M. biceps femoris (cap)	Rump	58.5	72.2	58.6	71.9	61.9	72.1	60.3	72.8	59.4	71.9
(± average s.e.)		(±2.2)	(±3.2)	(±2.0)	(±2.9)	(±1.7)	(±2.6)	(±1.9)	(±2.8)	(±1.8)	(±2.7)

Table 10. Predicted means (± average s.e.) for the control *v.* the mean hormone growth promotant (HGP) × muscle interaction for sensory scores for tenderness, juiciness, like flavour, overall liking and composite palatbality (MQ4) for steers from experiment 2

Muscle	Primal	Tenderness		Juiciness		Like flavour		Overall liking		MQ4	
		Control	HGP	Control	HGP	Control	HGP	Control	HGP	Control	HGP
M. longissimus thoracics	Cube roll	55.0	42.2	54.8	46.2	60.5	52.9	56.7	48.5	56.1	46.3
M. longissimus dorsi lumborum	Striploin	54.8	43.3	53.4	46.5	57.4	52.3	54.8	48.3	54.5	46.9
M. psoas major	Fillet	82.5	81.8	77.3	72.4	79.5	77.4	81.4	78.7	80.5	78.4
(± average s.e.)	–	(±2.9)	(±1.6)	(±2.6)	(±1.5)	(±2.2)	(±1.3)	(±2.5)	(±1.4)	(±2.5)	(±1.4)

Experiment 2 (steers)

There was a significant interaction between muscle × control *v.* mean HGP treatment for both tenderness and the MQ4 score ($P < 0.05$, Table 6). Table 10 showed the predicted means for tenderness and MQ4 score for the three muscles. Relative to the control treatment, the mean HGP effect elicited a decrease of 8–13 units in sensory scores for the two portions of the *M. longissimus*, whereas there was no effect on the *M. psoas major*. Within the different HGP strategies there were no significant interactions with muscle ($P > 0.05$, Table 6). Although the data are not shown, relative to the controls each of the 11 HGP treatments resulted in a decrease in tenderness score for the *M. longissimus thoracics* portion, although 10 of the 11 treatments resulted in a decrease in tenderness score for the *M. longissimus lumborum*, while the 11th was similar to the control.

Discussion

This study showed that muscles from different HGP implant strategies resulted in lower consumer palatability ratings compared with the control treatment for a range of muscles prepared using different cooking procedures. For all the muscles selected in experiment 1, the decrease in tenderness due to the HGP treatment was similar. However, in experiment 2, the HGP effect differed among muscles. Although the low numbers of animals per treatment cell and the large number of HGP implant strategies tested in experiments 1 and 2 made it difficult to directly compare specific strategies and implants, it was evident that muscles from all HGP-treated carcasses had lower tenderness scores than the control group for all muscles tested, with the exception of the *M. psoas major*, which showed no effect of HGP implantation strategies on tenderness score.

There was also a marked increase (15–25 points) in the carcass ossification score for carcasses from the HGP implant strategies in the two separate experiments. Where steers of similar breeding were finished to heavier carcass weights and first implanted with HGP at weaning, the increase in ossification scores for the different HGP implant strategies were substantially larger than for the short-fed heifers. For the steers, the mean increase in ossification score for all HGP strategies was 130 units, although this was quite variable with the increase for specific implant strategies ranging from 50 to 160 units. Other studies have reported an increase in ossification score with the use of single or multiple implant programs (Platter *et al*. 2003; Scheffler *et al*. 2003). The greater increase in ossification scores in the HGP-treated steers compared with the heifers could reflect the length of time the animals were implanted before slaughter, although length of time implanted was confounded with sex and HGP implant strategy.

The range of HGP implant strategies examined in both experiments also resulted in decreases in marbling scores, despite the low number of animals per subgroup. When averaged over all HGP implant strategies, the decrease in marbling was ~15% for heifers, and 10% for steers. The literature on the effect of HGP implants on marbling score is variable (see review by Montgomery *et al*. 2001), although most studies showed small decreases (Dikeman 2003). Bruns *et al*. (2001) proposed that the lower marbling in carcasses which received implants early in an animal's life could delay the deposition of marbling and, therefore, have a greater impact than implants administered closer to slaughter. Another mechanism may be that anabolic implants stimulate increased protein deposition (Bergen and Merkel 1991), which effectively dilutes the fat content within a muscle.

In both experiments, the different HGP implant strategies resulted in a substantial decrease in sensory scores relative to the controls. In experiment 1, the differences were ~4–6 sensory units, regardless of the muscle. Thompson *et al*. (2008) tested seven different muscles and showed that the magnitude of the HGP effect on sensory scores differed between muscles, with the highest effect in those muscles with the fastest aging rate. In experiment 1, the low numbers of animals per cell, and the fact only three muscles were in common between the experiments and in the present experiment one of those (*M. biceps femoris* cap) had only one aging period may have precluded the HGP treatment × muscle interaction from achieving significance. In contrast, steers in experiment 2 showed a large HGP treatment × muscle interaction on tenderness score, with the *M. longissimus dorsi* showing a large HGP effect, and little effect in the *M. psoas major*. This result aligns with the hypothesis that muscles that displayed negligible improvement in tenderness with aging, exhibited the lowest HGP response and vice versa.

The application of HGP implants showed increased ossification and decreased marbling scores. Other studies have reported that increased ossification scores were associated with decreased tenderness (Smith *et al*. 1982, 1988; Park *et al*. 2008). Similarly, a decrease in marbling has also been associated with decreased tenderness and flavour scores (Dikeman 1996; Thompson 2004). An argument often put forward is that the HGP-mediated decrease in tenderness simply reflects the increased ossification and decreased marbling scores (Nichols *et al*. 2002). To test this hypothesis, sensory data from experiments 1 and 2 were reanalysed with ossification and marbling scores included as covariates. In experiment 1, differences in tenderness score due to HGP treatment decreased from 6.2 to 4 units after adjustment to the same ossification and marbling scores, whereas in experiment 2 these adjustments had little effect on the tenderness scores of the three muscles tested. This suggested that HGP implants resulted in a decrease in sensory scores over and above the effect of increased ossification and decreased marbling scores.

There is a dearth of literature on differences in aging rates between muscles. In experiment 1, the balanced numbers of samples for most muscles aged 7 and 21 days showed that aging rates varied between the different muscles. Koohmaraie *et al*. (2002) proposed that the major contributors to variation in tenderness within a muscle included the rate of proteolysis, sarcomere length and connective tissue. Increased sarcomere length impacts aging rates by causing an initial increase in tenderness with slower subsequent ageing, so that ultimately

tenderness scores in stretched and unstretched muscle converge (Tornberg 1996).

In experiment 1, several muscles were cooked by more than one method. Although only based on four muscles, there was a significant muscle × cooking method interaction. Dransfield (1994) showed that prolonged heating during extended cooking gelatinised connective tissue, relative to grilled samples. In their data, samples cooked under low temperatures for a relatively short period (60°C for 20 min) showed a positive relationship between toughness and collagen content. However, under a higher temperature and longer cooking time (90°C for 180 min) this relationship was no longer evident. Unfortunately, this interaction does not explain our results. According to Dransfield (1994), the *M. semispinalis*, would have had the highest collagen content. However, in our experiment, no difference in sensory scores due to cooking technique was shown. In addition, the *M. gluteus medius*, which again according to Dransfield (1994) had a relatively low collagen content, resulted in higher sensory scores for roasting as opposed to grilling in our experiment. In our results, cooking the *M. biceps femoris* as a stir-fry resulted in an increase of 10–14 units in sensory scores compared with grilled samples. These differences could be due to a combination of differences in cooking time and temperature and slice thickness (grill samples were 25 mm, whereas the stir-fry samples were 10 mm thick). It should also be noted that the *M. biceps femoris* samples in our experiment were from the rump (top sirloin butt) primal or proximal caudal portion of the muscle. Other MSA experiments (data not shown) have consistently demonstrated significantly greater eating quality scores from the proximal relative to the distal portion in the outside flat (outside round) primal. Further work is required to understand the different mechanisms by which cooking method interacts with different muscle types and different positions within some muscles.

Conclusion

This study showed that a range of different HGP implant strategies resulted in a decrease in sensory scores, particularly tenderness. Although there was little apparent difference among the implant strategies, the caveat here was that animal numbers for the different strategies were small and, therefore, the results may have been different if sample size was increased. The magnitude of the HGP effect on sensory scores varied with muscle.

The implications from this study are that a range of HGP implant strategies affected both carcass traits and the palatability of different muscles. HGP implanted carcasses had lower marbling and higher ossification scores, which are known to impact on palatability. However, even after adjustment for marbling and ossification scores, the effect on palatability was still evident. Therefore, in a carcass grading scheme that accounted for marbling and ossification score (such as MSA), an adjustment for HGP implant status would still be necessary. The variation in the magnitude of the HGP effect between muscles meant that a grading scheme that graded individual cuts would provide the best description of the HGP effect for the consumer.

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References

Anon. (1998) 'Handbook of Australian meat.' 6th edn. (AUS-MEAT: Brisbane)

Bergen WG, Merkel RA (1991) Body composition of animals treated with paritioning agents: implications for human health. *The FASEB Journal* **5**, 2951–2957.

Bindon BM, Jones NM (2001) Cattle supply, production systems and markets for Australian beef. *Australian Journal of Experimental Agriculture* **41**, 861–877. doi: 10.1071/EA01052

Bruns KW, Priticard RH, Wittig TG (2001) The effect of growth and implantation exposure on carcass composition and quality in steers. *Journal of Animal Science* **79**(Suppl. 1), 31.

Dikeman ME (1996) The relationship of animal leanness to meat tenderness. *Reciprocal Meat Conference* **49**, 87–101.

Dikeman ME (2003) Metabolic modifiers and genetics: effects on carcass traits and meat quality. *Brazil Journal of Food Technology* **6**(Special Issue), 1–38.

Dransfield E (1994) Tenderness of meat, poultry and fish. In 'Advances in meat research. Quality attributes and their measurement in meat, poultry and fish products. Vol. 9.' (Eds AM Pearson, TR Dutson) pp. 289–315. (Blackie Academic & Professional: London)

Hunter RA, McCrabb GJ, O'Neill CJ (2001) The influence of hormonal growth promotants on marbling. In 'Proceedings of the Beef Quality CRC marbling symposium'. pp. 129–131.

Koohmaraie M, Kent MP, Shackelford SD, Veieth E, Wheeler TL (2002) Meat tenderness and muscle growth: is there any relationship? *Meat Science* **62**, 345–352. doi: 10.1016/S0309-1740(02)00127-4

Montgomery TH, Dew PF, Brown MS (2001) Optimizing carcass value and the use of anabolic implants in beef cattle. *Journal of Animal Science* **79** (Suppl.), E296–E306.

Nichols WT, Galyean ML, Thomson DU, Hutcheson JP (2002) Review: effects of steroid implants on the tenderness of beef. *The Professional Animal Scientist* **18**, 202–210.

Park BY, Hwang IH, Cho SH, Yoo YM, Kim JH, Lee JM, Polkinghorne R, Thompson JM (2008) Effect of carcass suspension and cooking method on the palatability of three beef muscles as assessed by Korean and Australian consumers. *Australian Journal of Experimental Agriculture* **48**, 1396–1404.

Perry D, Shorthose WR, Ferguson DM, Thompson JM (2001) Methods used in the CRC program for the determination of carcass yield and beef quality. *Australian Journal of Experimental Agriculture* **41**, 953–958. doi: 10.1071/EA00092

Platter WJ, Tatum JD, Belk KE, Scanga JA, Smith GC (2003) Effects of repetitive use of hormonal implants on beef carcass quality, tenderness, and consumer ratings of beef palatability. *Journal of Animal Science* **81**, 984.

Polkinghorne R, Watson R, Porter M, Gee A, Scott J, Thompson J (1999) Meat Standards Australia. A 'PACCP'-based beef grading scheme for consumers. 1. The use of consumer scores to set grade standards. In 'Proceedings of the 45th international congress of meat science and technology, 1–6 August 1999, Yokohama, Japan'. pp. 14–15.

Romans JR, Costello WJ, Carlson CW, Greaser ML, Jones KW (1994) 'The meat we eat.' (Interstate Publishers, Inc.: Danville, IL)

Sawyer GJ, Barker DJ (1988) Growth promotants in cattle in Australia. *Australian Veterinary Journal* **65**, 101–108. doi: 10.1111/j.1751-0813.1988.tb14425.x

Scheffler JM, Buskirk DD, Rust SR, Cowley JD, Doumit ME (2003) Effect of repeated administration of combination trenbolone acetate and estradiol implants on growth, carcass traits, and beef quality of long-fed Holstein steers. *Journal of Animal Science* **81**, 2395–2400.

Smith GC, Cross HR, Carpenter ZL, Murphey CE, Savell JW, Abraham HC, Davis GW (1982) Relationship of USDA maturity groups to palatability of cooked beef. *Journal of Food Science* **47**, 1100–1107. doi: 10.1111/j.1365-2621.1982.tb07627.x

Smith GC, Berry BW, Savell JW, Cross HR (1988) USDA maturity indices and palatability of beef rib steaks. *Journal of Food Quality* **11**, 1–13. doi: 10.1111/j.1745-4557.1988.tb00860.x

Thompson J (2002) Managing meat tenderness. *Meat Science* **62**, 295–308. doi: 10.1016/S0309-1740(02)00126-2

Thompson JM (2004) The effects of marbling on flavour and juiciness scores of cooked beef, after adjusting to a constant tenderness. *Australian Journal of Experimental Agriculture* **44**, 645–652. doi: 10.1071/EA02171

Thompson JM, McIntyre BM, Tudor GD, Pethick DW, Polkinghorne R, Watson R (2008) Effects of hormonal growth promotants (HGP) on growth, carcass characteristics, the palatability of different muscles in the beef carcass and their interaction with aging. *Australian Journal of Experimental Agriculture* **48**, 1405–1414.

Tornberg E (1996) Biophysical aspects of meat tenderness. *Meat Science* **43**, S175–S191. doi: 10.1016/0309-1740(96)00064-2

Watson R, Gee A, Polkinghorne R, Porter M (2008) Consumer assessment of eating quality – development of protocols for Meat Standards Australia (MSA) testing. *Australian Journal of Experimental Agriculture* **48**, 1360–1367.

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