Modification of beef quality through steer age at slaughter, breed cross and growth promotants

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Girard, I., Aalhus, J. L., Basarab, J. A., Larsen, I. L. and Bruce, H. L. 2012. **Modification of beef quality through steer age at slaughter, breed cross and growth promotants**. Can. J. Anim. Sci. **92**: 175–188. A 2^3 factorial experiment tested the interactions of slaughter age (12–13 or 18–20 mo), growth implants use (Component E-S, TE-S), ractopamine hydrochloride (RAC) feed supplementation use and breed cross [Hereford–Aberdeen Angus (HAA) or Charolais–Red Angus (CRA)] on pH, temperature, objective colour measurements, relative myoglobin states, sarcomere lengths, shear force, and water losses of m. semitendinosus (ST) and m. gluteus medius (GM) from 112 crossbred steers. In the ST, age affected objective colour measurements by increasing chroma and decreasing lightness (L^*) and hue angle ($P<0.05$). Metmyoglobin (MMB) content of the ST also increased with steer age ($P<0.05$). In the GM, yearling-fed steers had greater MMB content than calf-fed steers, while hue angle varied the opposite way ($P<0.05$). Other variations in meat colour and myoglobin contents were more complex in the GM than the ST as they involved three-way interactions between the different treatments. Shear force and purge loss of the ST increased with implantation ($P<0.05$) with no change in sarcomere length ($P>0.05$). Shear force standard deviation was similar for breed crosses when yearling-fed but greatest for CRA breed cross when calf-fed ($P<0.05$). In both muscles, purge loss was increased by RAC supplementation ($P<0.05$). RAC supplementation did not affect sarcomere length and shear force in both muscles ($P>0.10$). In the GM, shear force increased with age and with CRA genetics ($P<0.05$). Results indicated that producers seeking to reduce beef toughness should consider using British crossbreds, exclude the use of hormonal implants and slaughter process steers at 12 to 13 mo of age.

Key words: Growth implants, ractopamine, beef, growth rate

Girard, I., Aalhus, J. L., Basarab, J. A., Larsen, I. L. et Bruce, H. L. 2012. **Modification de la qualité de la viande bovine par l'âge à l'abattage, les croisements de races, et les promoteurs de croissances**. Can. J. Anim. Sci. **92**: 175–188. Un design expérimental 2^3 a été utilisé pour tester les interactions entre l'âge à l'abattage (12–13 ou 18–20 mois), les hormones de croissance (Component E-S, TE-S), la supplémentation alimentaire avec ractopamine hydrochloride (RAC), et les croisements de race [Hereford–Aberdeen Angus (HAA) ou Charolais–Angus Rouge (CRA)] sur le pH, la température, les mesures objectives de couleur, les contenus en myoglobine, la longueur des sarcomères, la force de cisaillement, et la perte en eau des muscles *semitendinosus* (ST) et *gluteus medius* (GM) de 112 bouvillons. Dans le ST, l'âge a le plus affecté les mesures objectives de couleur en augmentant les valeurs de chroma et en réduisant la clarté (L^*) et la teinte. Le contenu en metmyoglobine (MMB) du muscle ST a aussi augmenté avec l'âge ($P<0.05$). Dans le GM, les bouvillons de 18–20 mois avaient un contenu plus élevé en MMB que les bouvillons de 12–13 mois, alors que la teinte a varié de façon opposée ($P<0.05$). Les variations entre la couleur de la viande et les contenus en myoglobine étaient plus complexes dans le GM que le ST puisque que des interactions triples ont été observées. La force de cisaillement et la perte en eau du ST ont augmenté avec les implants ($P<0.05$) sans que la longueur des sarcomères change ($P>0.05$). La déviation standard de la force de cisaillement était semblable entre les bouvillons de 18–20 mois; par contre, elle était plus élevée pour les bouvillons CRA de 12–13 mois ($P<0.05$). Dans les deux muscles, la perte en eau a augmenté avec RAC ($P<0.05$). La longueur des sarcomères et la force de cisaillement des deux muscles n'ont pas été affectées par RAC ($P>0.10$). Dans le GM, la force de cisaillement a augmenté avec l'âge et le croisement de race CRA ($P<0.05$). Les résultats indiquent que les producteurs désirant augmenter la tendreté de la viande bovine devraient considérer l'utilisation des croisements de race Britannique, exclure l'utilisation d'implants hormonaux, et finir les bouvillons vers 12–13 mois.

Mots clés: Promoteurs de croissance, implants, ractopamine, boeuf, taux de croissance

Abbreviations: **β-AA**, β-adrenergic agonist; **CRA**, Charolais-Red Angus; **DMB**, deoxymyoglobin; **FG**, fast glycolytic; **GM**, gluteus medius; **HAA**, Hereford-Aberdeen Angus; **IMP**, hormonal growth implants; **MMB**, metmyoglobin; **NOIMP**, no hormonal growth implants; **NORAC**, no ractopamine hydrochloride; **OMB**, oxymyoglobin; **RAC**, ractopamine hydrochloride; **SO**, slow oxidative; **ST**, semitendinosus

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Beef growth production strategies are usually formulated so that they have minimal effects on meat appearance and quality. Hormonal growth implants have no (Faucitano et al. 2008) or a slight effect on meat colour (Reiling and Johnson 2003), and the β-adrenergic agonist (β-AA) ractopamine hydrochloride (RAC) does not appear to affect meat colour (Gonzalez et al. 2009). Both hormonal implants (Foutz et al. 1997; Faucitano et al. 2008; Girard et al. 2011) and β-AA (Avendaño-Reyes et al. 2006; Gruber et al. 2008; Strydom et al. 2009) have been implicated in the toughening of beef, and Australia now applies a price penalty to beef from cattle treated with growth promotants in its Meat Standards Australia guaranteed tender program (Thompson et al. 2008). The European Union also banned hormonal implants in 1988, restricting its importation of beef to that from cattle that did not receive hormonal implants (British Society of Animal Science 2010). As Canada seeks to add value to its beef through a Canadian Quality brand (Beef Information Centre 2010), examination of the effects of beef production strategies on the quality and composition of beef produced in Alberta has become a priority (Alberta Livestock and Meat Agency 2009).

Within a quality brand, using management systems that reduce animal age at slaughter to enhance the tenderness of meat could be economically beneficial for beef producers. In a survey by Huffman et al. (1996), tenderness was rated by consumers as the factor affecting their eating satisfaction the most. Indeed, a slaughter age for bovine castrates of 12 to 13 mo has been shown to be related to increased intramuscular collagen heat solubility (Hill 1966). Collagen heat solubility decreases as animal age increases because the numbers of heat-stable, trivalent collagen cross-links increase (Shimokomaki et al. 1972), the concentrations of which have been linked positively to increased collagen thermal stability (Horgan et al. 1991). Reducing animal age at slaughter to 12 and 13 mo of age also decreased muscle fibre cross-sectional areas (Girard et al. 2011), which may reduce the toughness of beef (Shimokomaki et al. 1972; Unruh et al. 1986). Reducing the age at slaughter should also reduce animal production costs on the farm as cattle will be kept for a shorter time than the production system that keeps cattle on the farm until 18 to 20 mo of age (Alberta Agriculture and Rural Development 2009). Benefits from the increase in muscle weights resulting from the use of hormonal growth implants (Canadian Cattlemen's Association and Beef Information Centre 2001) are, however, in opposition to the reduction in beef tenderness (Foutz et al. 1997). Nevertheless, if the increase in beef toughness is minimized by certain production systems, the use of growth promotants may still be considered. The study described examined the effects of animal age at slaughter, breed crosses, hormonal growth implants, and RAC feed supplementation on the shear force, water-holding capacity, objective colour, myoglobin contents, and sarcomere length of m. gluteus medius and m. semitendinosus in order to evaluate the impact of various beef production practices on beef meat quality.

MATERIALS AND METHODS

Experimental Design and Animal and Carcass Management

A complete description of animal management, diets, experimental treatments and animal slaughter processing was provided by Girard et al. (2011). Briefly, 112 crossbred Hereford–Aberdeen Angus (HAA; $n = 64$) or Charolais–Red Angus (CRA; $n = 48$) steers (bovine male castrates) were assigned to either of two slaughter ages (12 to 13 mo, calf-fed; or 18 to 20 mo, yearling-fed) and were either not implanted (NOIMP) or implanted (IMP) with hormonal growth promotants and supplemented with (RAC) or without (control) ractopamine in a $2 \times 2 \times 2$ factorial experiment. The 28 implanted steers in the calf-fed treatment were implanted with Component E-S (200 mg progesterone and 20 mg estradiol benzoate with 29 mg of tylosin tartrate, Elanco Animal Health, Guelph, ON) at about 200 d of age. The 28 implanted steers in the yearling-fed treatment were implanted with Component E-S at 200 d of age and were re-implanted with the same product at 280, 350 and 440 d of age and then implanted with Component TE-S about 30 d prior to slaughter. Animals were cared for under guidelines similar to those provided by the Canadian Council on Animal Care (CCAC). Two pens were slaughtered at each kill ($n = 14$ per kill) and arrived at the abattoir the day before slaughter, where steers were fasted overnight with ad libitum access to water. Steers were stunned by captive bolt, exsanguinated and dressed in a manner consistent with commercial practice. Carcasses were split and each half weighed and pasteurized with hot water at 85°C for 10 s and then chilled overnight at 2°C with wind speeds of 5 m s^{-1}.

Twenty-four hours post mortem, the carcasses were fabricated and the m. gluteus medius (GM) and the m. semitendinosus (ST) were harvested from the left carcass side for meat quality investigation. Muscles were individually labelled, weighed and assessed for intramuscular temperature and pH using a Fisher Scientific Accumet AP72 pH meter (Fisher Scientific, Mississauga, ON) equipped with an Orion Ingold electrode (Udorf, Switzerland). Three readings for pH and one for temperature (T_{24h}) were recorded for each muscle, and the mean pH value was calculated (pH_{24h}). Steaks were removed from the proximal to distal ends for the ST and from the anterior to posterior end for the GM. The first trim steak was discarded and the second 2.5-cm-thick steak was used for muscle fibre type determination (Girard et al. 2011), 24 h objective colour and sarcomere length. The remaining muscle was packaged under vacuum and aged at 4°C for 7 d until further meat quality characterization.

Objective Colour Measurements, Myoglobin Relative Contents, Purge Loss, Cooking Loss, and Cooking Time

Objective colour measurement and the proportion of myoglobin states were measured at 24 h post mortem on the steak used for sarcomere length. The steak was cut and allowed to stand for 20 min at 4°C to oxygenate the pigment (Boccard et al. 1981). Objective colour measurements were recorded three times per steak for lightness (L^*), a^* (red–green spectral axis), b^* (yellow–blue spectral axis) (Commission Internationale de l'Éclairage 1978) using a Minolta CR300 with Spectra QC-300 Software (Minolta Canada Inc., Mississauga, ON). Hue and chroma were determined as hue [$H_{ab} = \arctan(b^*/a^*)*57.296$] and chroma [$C_{ab} = (a^{*2} + b^{*2})^{0.5}$]. Deoxymyoglobin (DMB), metmyoglobin (MMB), and oxymyoglobin (OMB) relative contents were determined based on reflex attenuance of incident light by interpolation of the isobestic points 473, 525, 572, and 730 nm at 24 h post mortem (Krzywicki 1979).

After 7 d of ageing, muscles were weighed to determine purge loss, which was expressed in milligrams of water lost per gram of muscle, and intramuscular temperature and pH (pH_{7d}) were recorded as described for 24 h measurements. One 2.5-cm-thick steak was cut and objective colour measurements were recorded as described for 24 h. The steak was weighed, and a spear point temperature probe (Type T copper-constantan, 10 cm in length, AllTemp Sensors Inc., Edmonton, AB) was placed into its mid-point parallel to the longitudinal axis of the steak cross-section. Steaks were grilled at approximately 210°C (Garland Grill ED30B; Condon Barr Food Equipment Ltd., Edmonton, AB) with the internal temperature recorded at 30-s intervals. Steaks were turned when the internal temperature reached 35.5°C and cooked until the internal temperature reached 71°C (monitored with a Hewlett Packard HP34970A Data Logger; Hewlett Packard Co., Boise ID). As soon as 71°C was reached, cooked steaks were placed into polyethylene bags, sealed, cooled in an ice bath to prevent further cooking, and refrigerated overnight at 4°C. Cooking time was expressed in seconds required to cook 1 g of raw steak. The following day, steaks were dried with filter paper to remove excess moisture and the weight of each was recorded to calculate cooking loss expressed in milligrams of water lost per gram of raw steak.

Sarcomere Length

Sarcomere length was measured as described by Aalhus et al. (1999). Two grams of muscle freed of fat and connective tissues were removed, scissor-minced, and mixed in 20 mL of a 0.02 M EGTA/0.25 M sucrose solution in a 50-mL centrifuge tube. Samples were homogenized for 10 s at 6000 RPM [Polytron Homogenizer PT3100 and a 2-cm generator (Brinkmann Instruments Inc., Mississauga, ON, Canada)]. One drop of each sample was placed on a slide with a cover slip for observation with an Axioscope (Zeiss, Germany) equipped with a Sony DXC 930 Colour Video Camera (Sony Corporation, Japan). Three sarcomere lengths were measured per image with Image Pro-Plus software V4.0, (Mediacybernetics, Silver Spring, MD) and 10 images were analysed per muscle sample. Lengths were averaged and expressed in micrograms.

Warner-Bratzler Shear Force

Six 1.9-cm diameter cores per steak were removed from cooked steaks parallel to the grain of the muscle fibres. Peak shear force (SF) was measured perpendicular to the muscle fibres using a Texture Analyser (Model TA.XT plus, Texture Technologies Corp, New York) equipped with a Warner-Bratzler shear head at a cross-head speed of 200 mm min^{-1}. Peak shear force was recorded in kilograms (Texture Exponent 32 Software, TextureTechnologies Corp., Hamilton, MA) and the six peak shear forces recorded per muscle were averaged and the standard deviation (STD) calculated.

Statistical Analysis

Data were analyzed as a $2 \times 2 \times 2$ factorial design using the MIXED procedure (SAS Institute, Inc. 2003) with sources of variation including age at slaughter, hormonal growth promotants, β-AA feed supplementation, and breed crosses, and their two-, three-, and four-way interactions. Pen nested within slaughter age × implant × β-agonist was included as a random effect. The initial model included day of kill as a source of variation, but it was removed when it was found not to be significant ($P > 0.05$) in an analysis of covariance. Denominator degrees of freedom were calculated using the Kenward-Roger approximation. Differences between treatment or interaction means were separated using the F-test protected LSD procedure ($P \leq 0.05$). For significant main or interaction effects ($P < 0.05$), differences between treatment and interaction means were computed using least square means and separated with pair-wise comparisons using the PDIFF option.

RESULTS

Temperature and pH

Muscle temperature and pH results are presented in Tables 1 and 2 for the ST and GM muscles, respectively, and in Fig. 1. Muscle T_{24h} was not affected by any of the treatments in either muscle. Mean muscle pH_{24h} of the ST was not affected by treatments; however, in the GM, mean muscle pH_{24h} was involved in a three-way interaction where RAC calf-fed HAA steers had a higher ($P < 0.05$) mean muscle pH than CRA steers of the same treatment (Fig. 1). Mean muscle pH_{7d} of the ST tended ($P = 0.08$) to be greater in HAA steers than CRA steers, while in the GM, mean muscle pH_{7d} was significantly greater ($P < 0.05$) in HAA steers than in CRA steers.

Table 1. Effect of age at slaughter, implantation strategy, ractopamine hydrochloride feed supplementation, and breed cross on meat pH, temperature, objective colour measurements, and myoglobin relative contents of the m. semitendinosus

	Age at slaughter		Implantation		Ractopamine feeding			Breed cross		
Variables	Calf-fed	Yearling-fed	NOIMP[z]	IMP[z]	NORAC[z]	RAC[z]	SEM[y]	HAA[z]	CRA[z]	SEM[x]
n =	56	56	56	56	56	56	–	64	48	–
24 h post mortem										
pH	5.66	5.67	5.67	5.66	5.69	5.64	0.04	5.67	5.66	0.03
Temperature (°C)	6.84	6.91	6.80	6.95	6.82	6.93	0.14	6.80	6.95	0.13
7 d post mortem										
pH	5.58	5.62	5.60	5.60	5.64	5.56	0.05	5.61*x*	5.59*y*	0.04
Lightness (*L**)	47.80*b*	44.88*a*	46.29	46.39	46.15	46.53	0.38	46.64*x*	46.04*y*	0.33
Chroma (%)	25.04*b*	26.34*a*	25.58	25.80	26.00	25.38	0.32	25.84	25.54	0.27
Hue angle (°)	46.06*b*	42.58*a*	44.00	44.65	43.69*b*	44.95*a*	0.32	44.32	44.33	0.31
MMB[w]	0.12*b*	0.14*a*	0.13	0.14	0.13	0.13	0.00	0.14	0.13	0.00
DMB[w]	0.04	0.05	0.06	0.04	0.05	0.04	0.01	0.05	0.04	0.01
OMB[w]	0.83	0.81	0.81	0.83	0.81	0.83	0.01	0.82	0.82	0.01

[z]CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus; IMP, hormonal growth implants; NOIMP, no hormonal growth implants; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.
[y]Pooled standard error of the mean (SEM) for production systems, implantation, and ractopamine feeding.
[x]Pooled standard error of the mean (SEM) for breed cross.
[w]Summation of MMB, DMB, and OMB relative contents within a treatment effect may not equal 1.00 due to number rounding.
a, *b* Means within the same row within a main effect with different letters are significantly different ($P < 0.05$).
x, *y* Means within the same row within a main effect with different letters tend to be significantly different ($P < 0.10$).

Table 2. Effect of age at slaughter (A), implantation strategy (I), ractopamine hydrochloride feed supplementation (R), and breed cross (B) on meat pH, temperature, objective colour measurements, and myoglobin relative contents of the m. gluteus medius, including interactions

	Age at slaughter		Implantation		Ractopamine feeding			Breed cross			Interaction	
Variables	Calf-fed	Yearling-fed	NOIMP[z]	IMP[z]	NORAC[z]	RAC[z]	SEM[y]	HAA[z]	CRA[z]	SEM[x]	I × R × B	A × R × B
n =	56	56	56	56	56	56	–	64	48	–	–	–
24 h post mortem												
pH	5.63	5.58	5.61	5.60	5.63	5.58	0.03	5.62	5.59	0.03	NS	*
Temperature (°C)	6.59	6.63	6.61	6.60	6.48	6.74	0.22	6.70	6.52	0.19	NS	NS
7 d post mortem												
pH	5.57	5.57	5.57	5.57	5.61	5.53	0.06	5.58a	5.56b	0.04	NS	NS
Lightness (*L**)	41.38*x*	39.26*y*	39.69	40.95	40.42	40.23	0.68	40.86	39.79	0.56	NS	NS
Chroma (%)	27.83	29.39	28.41	28.82	28.91	28.31	0.59	28.99*a*	28.23*b*	0.45	*	NS
Hue angle (°)	37.43*a*	35.72*b*	36.27	36.87	36.47	36.67	0.27	36.72	36.42	0.23	NS	NS
MMB[w]	0.17*b*	0.19*a*	0.18	0.18	0.18	0.18	0.00	0.18	0.18	0.00	NS	NS
DMB[w]	0.08	0.06	0.07	0.07	0.07	0.07	0.01	0.07	0.07	0.01	*	*
OMB[w]	0.75	0.75	0.75	0.75	0.75	0.75	0.01	0.75	0.75	0.01	*	*

[z]CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus; IMP, hormonal growth implants; NOIMP, no hormonal growth implants; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.
[y]Pooled standard error of the mean (SEM) for production systems, implantation, and ractopamine feeding.
[x]Pooled standard error of the mean (SEM) for breed cross.
[w]Summation of MMB, DMB, and OMB relative contents within a treatment effect may not equal 1.00 due to number rounding.
a, *b* Means within the same row within a main effect with different letters are significantly different ($P < 0.05$).
x, *y* Means within the same row within a main effect with different letters tend to be significantly different ($P < 0.10$).
*, **, *** $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively; NS, non significant.

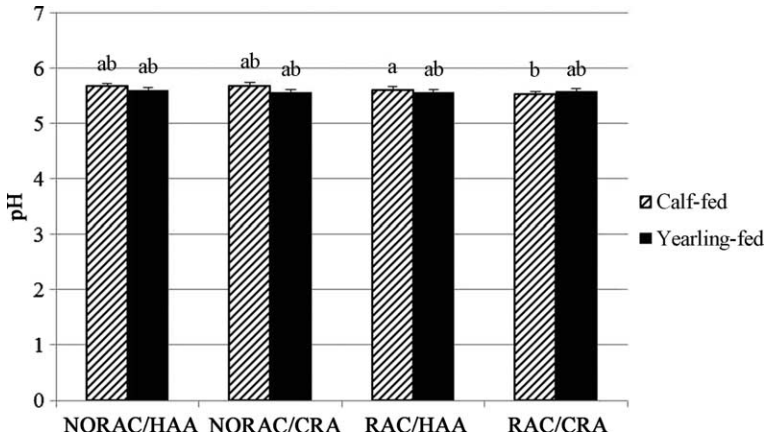

Fig. 1. Mean pH_{24h} of the m. gluteus medius as affected by an interaction between RAC, age at slaughter, and breed cross. a, b Columns with different letters are significantly different ($P < 0.05$). Error bars are pooled standard error of the mean (SEM). Abbreviations: CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.

Objective Colour Measurements

Results for objective colour measurements are presented in Tables 1 and 2 and Fig. 2. Age at slaughter was the factor that affected raw muscle colour the most. In the ST, raw steaks were significantly lighter ($P < 0.05$), had greater ($P < 0.05$) mean hue angle, and lower ($P < 0.05$) mean chroma values when from the calf-fed steer carcasses than from yearling-fed steer carcasses. Only mean hue angle increased ($P < 0.05$) with dietary supplementation of RAC in the ST, indicating an increase in yellow pigments. HAA raw steaks tended to be lighter ($P = 0.09$) than CRA raw steaks in the ST, but mean L^* value of the GM was unchanged. In the GM, there was a tendency for lighter ($P = 0.06$) raw steaks from calf-fed steers than yearling-fed steer carcasses, with greater ($P < 0.05$) mean hue angle and no change in mean chroma. In this same muscle, mean chroma was significantly higher ($P < 0.05$) in HAA than CRA steers when implanted and supplemented with RAC (Fig. 2).

Myoglobin Relative Contents

Treatment effects and those of their interactions on mean muscle myoglobin relative contents are presented in Tables 1 and 2 and Figs. 3 and 4. Mean MMB relative content was significantly higher for both the ST ($P < 0.05$) and the GM ($P < 0.05$) from yearling-fed steer carcasses than from calf-fed steer carcasses. Mean DMB and OMB relative contents were not altered by age at slaughter in the ST, but were involved in a three-way interaction in the GM where mean DMB relative content was greater ($P < 0.05$) in muscles from the carcasses of yearling-fed CRA steers supplemented RAC than those of HAA steers of the same age (Fig. 3a). Mean OMB

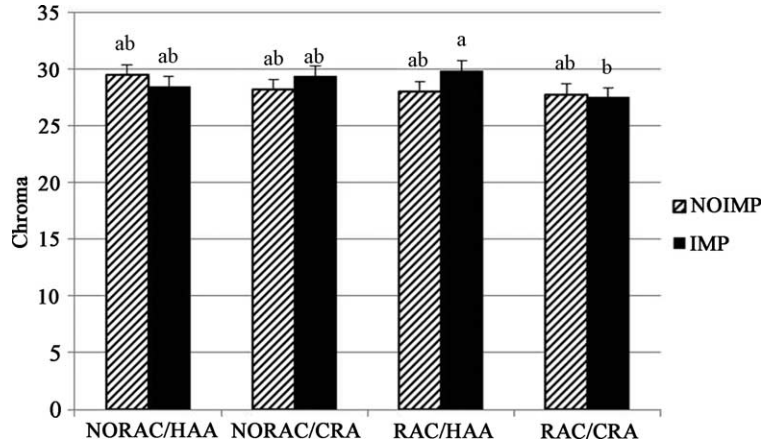

Fig. 2. Mean chroma value of the m. gluteus medius as affected by an interaction between RAC, implantation strategy, and breed cross. a, b Columns with different letters are significantly different ($P < 0.05$). Error bars are pooled error of the mean (SEM). Abbreviations: CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus; IMP, hormonal growth implants; NOIMP, no hormonal growth implants; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.

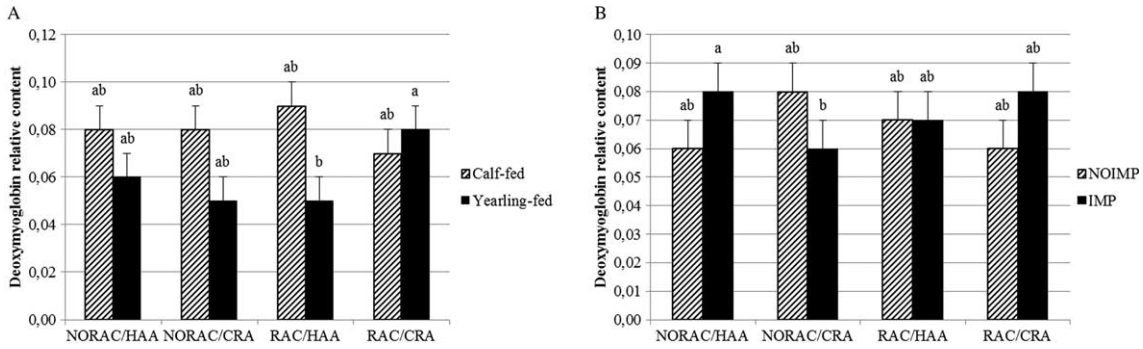

Fig. 3. Mean deoxymyoglobin content of the m. gluteus medius. (A) Effect of an interaction between RAC, age at slaughter, and breed cross. (B) Effect of an interaction between RAC, implantation strategy, and breed cross. a, b Columns with different letters are significantly different ($P < 0.05$). Error bars are pooled error of the mean (SEM). Abbreviations: CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus; IMP, hormonal growth implants; NOIMP, no hormonal growth implants; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.

relative content was greater ($P < 0.05$) in the muscles of carcasses from yearling-fed HAA steers supplemented RAC than those of CRA steers (Fig. 4a). Also, mean DMB and OMB relative contents of the GM were each involved in three-way interactions that included IMP, RAC, and breed types. In these interactions, when steers were implanted but not fed RAC, mean DMB relative content was greater ($P < 0.05$) in muscles of carcasses from HAA steers than those from CRA steers (Fig. 3b), whereas mean OMB relative content was greater ($P < 0.05$) in muscles of carcasses from CRA steers than from HAA steers of the same treatments (Fig. 4b).

Sarcomere Length, Purge Loss, Cooking Loss and Cooking Time

Data for sarcomere length, purge loss, cooking loss and cooking time are presented in Tables 3 and 4 for the ST and GM, respectively, and Fig. 5. For both ST and GM muscles, sarcomere length was not affected by any main effects or their interactions. Purge loss was greater ($P < 0.05$) for steaks from the ST muscles of yearling-fed than calf-fed steer carcasses, but cooking loss tended to be greater ($P = 0.08$), and cooking time was longer ($P < 0.05$) when steaks were from the ST muscles of calf-fed steer carcasses than when from those of yearling-fed steer carcasses. Purge loss was greater in ST steaks from carcasses of IMP treated steers than NOIMP steers ($P < 0.05$), and from carcasses of RAC-fed steers than NORAC steers ($P < 0.05$). Cooking loss and cooking time of the ST were not affected by IMP and RAC treatments. HAA steaks from ST muscles tended to have a smaller ($P = 0.05$) amount of purge loss, and to take longer ($P = 0.09$) to cook than steaks from CRA steers. In the GM, purge loss was involved in a three-way interaction with IMP, RAC, and age at slaughter where purge loss was increased ($P < 0.05$) in steaks from the carcasses of calf-fed steer that received RAC, while steaks from the carcasses of yearling-fed steers had increased purge loss when treated with both RAC and

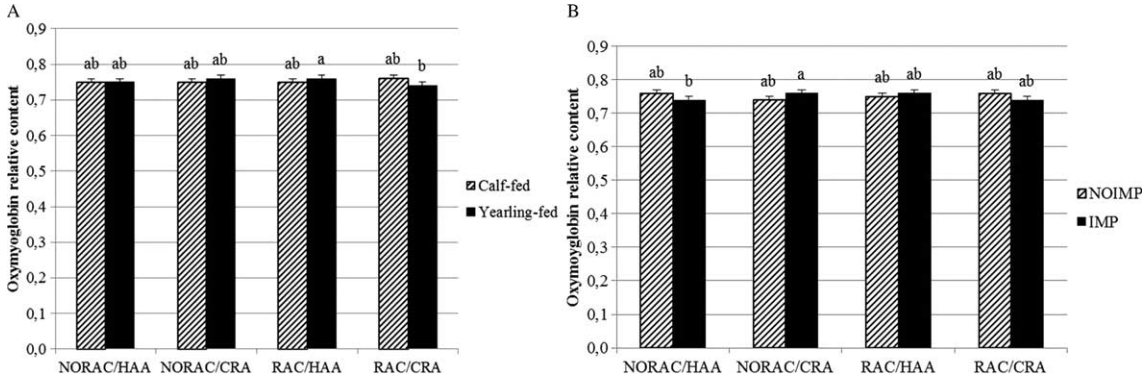

Fig. 4. Mean oxymyoglobin content of the m. gluteus medius. (A) Effect of an interaction between RAC, age at slaughter, and breed cross. (B) Effect of an interaction between RAC, implantation strategy, and breed cross. a, b Columns with different letters are significantly different ($P < 0.05$). Error bars are pooled error of the mean (SEM). Abbreviations: CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus; IMP, hormonal growth implants; NOIMP, no hormonal growth implants; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.

Table 3. Effect of age at slaughter (A), implantation strategy, ractopamine hydrochloride feed supplementation, and breed cross (B) on cooking loss, cooking time and shear force of the m. semitendinosus, including significant interactions

	Age at slaughter		Implantation		Ractopamine feeding			Breed cross			Interaction
Variables	Calf-fed	Yearling-fed	NOIMP[z]	IMP[z]	NORAC[z]	RAC[z]	SEM[y]	HAA[z]	CRA[z]	SEM[x]	A × B
n =	56	56	56	56	56	56	–	64	48	–	–
Sarcomere length (μm)	1.87	1.88	1.88	1.87	1.82	1.93	0.05	1.90	1.85	0.04	NS
Purge loss (mg g^{-1})	11.21*b*	12.94*a*	11.10*b*	13.05*a*	11.15*b*	13.00*a*	0.44	11.51*x*	12.64*y*	0.42	NS
Cooking loss (mg g^{-1})	277.8*x*	253.62*y*	258.53	272.9	265.02	266.4	8.18	265.65	265.77	7.312	NS
Cooking time (s g^{-1})	7.12*a*	4.87*b*	6.48	5.50	5.80	6.19	0.41	6.34*x*	5.65*y*	0.35	NS
Shear force (kg)	6.47*b*	8.31*a*	6.92*b*	7.87*a*	7.25	7.53	0.26	7.37	7.41	0.21	*
STD[w]	1.11*b*	1.34*a*	1.17	1.28	1.24	1.21	0.07	1.20	1.26	0.08	*

[z]CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus; IMP, hormonal growth implants; NOIMP, no hormonal growth implants; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.
[y]Pooled standard error of the mean (SEM) for production systems, implantation, and ractopamine feeding.
[x]Pooled standard error of the mean (SEM) for breed cross.
[w]Standard deviation of shear force.
a, *b* Means within the same row within a main effect with different letters are significantly different ($P < 0.05$).
x, *y* Means within the same row within a main effect with different letters tend to be significantly different ($P < 0.10$).
*, **, *** $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively; NS, non significant.

Table 4. Effect of age at slaughter, implantation strategy, ractopamine hydrochloride feed supplementation, and breed cross on cooking loss, cooking time and shear force of the m. gluteus medius

	Age at slaughter		Implantation		Ractopamine feeding			Breed cross		
Variables	Calf-fed	Yearling-fed	NOIMP[z]	IMP[z]	NORAC[z]	RAC[z]	SEM[y]	HAA[z]	CRA[z]	SEM[x]
n =	56	56	56	56	56	56	–	64	48	–
Sarcomere length (μm)	1.64	1.71	1.68	1.67	1.61	1.74	0.05	1.68	1.67	0.04
Purge loss (mg g^{-1})	13.5	13.51	13.65	13.35	11.56*b*	15.44*a*	0.56	13.54	13.46	0.51
Cooking loss (mg g^{-1})	220.66	224.59	216.05	229.21	225.69	219.57	7.50	219.63	225.62	6.30
Cooking time (s g^{-1})	2.43	2.25	2.38	2.30	2.48*x*	2.20*y*	0.10	2.31	2.37	0.10
Shear force (kg)	5.29*b*	6.37*a*	5.59	6.07	5.71	5.94	0.28	5.64*b*	6.01*a*	0.22
STD[w]	1.06	1.27	1.08	1.25	1.19	1.14	0.07	1.21	1.12	0.07

[z]CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus; IMP, hormonal growth implants; NOIMP, no hormonal growth implants; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.
[y]Pooled standard error of the mean (SEM) for production systems, implantation, and ractopamine feeding.
[x]Pooled standard error of the mean (SEM) for breed cross.
[w]Standard deviation of shear force.
a, *b* Means within the same row within a main effect with different letters are significantly different ($P < 0.05$).
x, *y* Means within the same row within a main effect with different letters tend to be significantly different ($P < 0.10$).

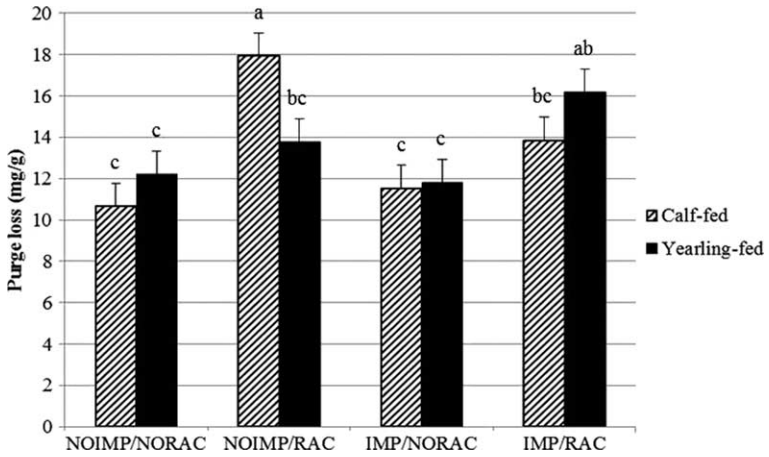

Fig. 5. Purge loss of the m. gluteus medius as affected by an interaction between RAC, implantation strategy, and age at slaughter. a–c Columns with different letters are significantly different ($P < 0.05$). Error bars are pooled error of the mean (SEM). Abbreviations: IMP, hormonal growth implants; NOIMP, no hormonal growth implants; NORAC, no ractopamine hydrochloride; RAC, ractopamine hydrochloride.

IMP (Fig. 5). Neither cooking loss nor cooking time was affected by age at slaughter, RAC, IMP, and breed cross in the GM, although there was a trend ($P = 0.09$) for cooking time to be lengthened in NORAC steers.

Peak Shear Force and its Standard Deviation

Results for peak shear force (SF) and standard deviation (STD) of SF are presented in Tables 3 and 4 and Fig. 6. In the ST, mean peak SF was involved in a two-way interaction and was greatest ($P < 0.05$) in steaks from the carcasses of yearling-fed steers of both crossbreds (Fig. 6a), but steaks from the HAA steer carcasses exhibited the greatest increase. Mean STD of SF was also involved in a two-way interaction with age at slaughter and breed cross, and was lower ($P < 0.05$) in calf-fed HAA steer carcasses than those from all other treatments within this interaction (Fig. 6b). Implanting steers increased ST peak SF ($P < 0.05$) without affecting its STD, while RAC did not affect SF and STD of this muscle. Mean peak SF increased ($P < 0.05$) in the GM from the carcasses of yearling-fed steers and its STD tended to be greater ($P < 0.05$) than that from the carcasses of calf-fed steers. Peak SF varied with breed cross in the GM and was greater ($P < 0.05$) in muscles from CRA steers than in those from HAA steers. Mean peak SF of the GM and its STD were not affected by IMP and RAC treatments.

DISCUSSION

Of all the meat quality characteristics measured in meat science, SF is probably of the most interest because toughness is the most important factor affecting the appreciation of meat by consumers (Miller et al. 1995). Meat toughness is known to increase with age of steers (Shorthose and Harris 1990), meaning that the increase in the quantity of meat yielded with animal age will be at the expense of its tenderness. Hormonal growth implants also increase the final live weight and hot carcass

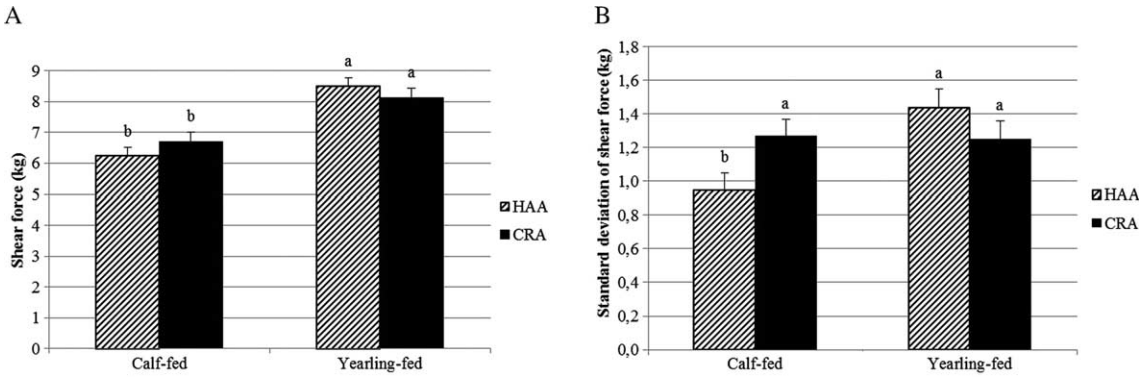

Fig. 6. (A) Shear force of the m. semitendinosus and (B) its standard deviation as affected by an interaction between age at slaughter and breed cross. a, b Columns with different letters are significantly different ($P < 0.05$). Error bars are pooled error of the mean (SEM). Abbreviations: CRA, Charolais–Red Angus; HAA, Hereford–Aberdeen Angus.

weight of steers (Calkins et al. 1986; Perry et al. 1991; Roeber et al. 2000; Platter et al. 2003), and they have been implicated in meat toughening (Foutz et al. 1997; Faucitano et al. 2008), although not always (Cranwell et al. 1996; Kerth et al. 2003). Similarly, the use of RAC, which is considered a mild β-AA, unlike clenbuterol and zilpaterol hydrochloride, has not always resulted in the toughening of meat (Strydom et al. 2009). Growth promotants can, therefore, be an alternative for increasing meat yield from carcasses in young steers as long as meat quality characteristics, especially tenderness, are not negatively affected.

Increases in cooked meat peak SF with animal age can originate from two fractions of the muscle: muscle fibres (Crouse et al. 1991) and connective tissue (Cross et al. 1973). Collagen, the main protein of connective tissues in skeletal muscles, can contribute to peak SF with both its quantity and its heat insolubility (Boccard et al. 1979). Muscle fibres are the structural units of muscles and undergo proteolysis post mortem by proteases, which may include calpains, cathepsins, and caspases (Nelson and Traub 1983; Taylor et al. 1995; Kemp et al. 2006; Houbak et al. 2008). Calpain activity depends on its ante mortem level but also on the level of its inhibitor, calpastatin (Hopkins and Taylor 2004). Indeed, as observed with lambs in Pringle et al. (1993), an increased concentration of calpastatin and a decreased content of μ-calpains post mortem resulted in increased peak SF, most likely due to a reduced rate of proteolysis ante mortem.

In the present study, age at slaughter was associated with increased peak SF of both the ST and the GM, and this increase was particularly marked in the ST. Collagen did not appear to contribute to tenderness variations with age in the ST because there was only a trend towards decreasing collagen solubility in yearling-fed steers (Girard et al. 2011); therefore, reduced post mortem protein proteolysis most likely is responsible for the increase in ST peak SF. The yearling-fed steers had a slow growth rate and thus may have had a lower protein turnover than calf-fed steers, which implies reduced degradation from proteases ante and post mortem (Koohmaraie et al. 2002). Elastin, the content of which is high in the ST and could affect its SF, was not quantified in the current study; however, Cross et al. (1973) found no significant correlation between ST elastin content and SF. In the GM, the increase in peak SF was most likely due to decreased collagen solubility as the intramuscular collagen heat solubility, estimated using the method of Hill (1966), decreased from 52.31 to 34.02% over time (Girard et al. 2011). Reduced post mortem proteolysis may have also been a factor contributing to the increase in GM peak SF observed at the yearling-fed slaughter age as there was a toughening effect associated with the use of CRA genetics (Girard et al. 2011).

IMP use was associated with an increase in peak SF in the ST. This increase was most likely due to characteristics of the myofibrillar component of the muscle as IMP use did not affect total and soluble collagen contents (Girard et al. 2011). The average cross-sectional area of fibres has been shown to contribute to the increase in peak shear force up to 6 d post mortem (Crouse et al. 1991). As measurements in the present study were taken at 7 d post mortem, the increased cross-sectional areas of the fibres associated with hormonal implantation did not likely contribute to the increased peak SF, but rather a reduction in post mortem proteolysis may account for the increased peak SF. The action of hormonal implants on muscle growth and protein deposition occurs through an increase in protease inhibitor activities rather than a decrease in the protease activities (Gerken et al. 1995). Protease and protease inhibitor activities were not measured in the present study, but based on Koohmaraie et al. (2002), it can be suggested that calpastatin and/or cystatin levels may have increased before death and remained at this high level after death and inhibited activity of calpains and cathepsins ante and post mortem, resulting in lower post mortem proteolysis in IMP steers than in NOIMP steers. Consequently, hormonal growth implants increased muscle weight as expected (Girard et al. 2011) but they had an adverse effect on ST tenderness. Their use to improve red meat yield in young steers should therefore be questioned if meat toughness becomes an issue. Ageing meat longer than 7 d could, however, reduce the impact of hormonal implants on meat tenderness (Barham et al. 2003).

Purge losses in the ST increased with age at slaughter, steroid implantation, and ractopamine and increased in the GM depending on ractopamine, age at slaughter, and implantation. Purge loss is the water expelled from the myofibres during ageing and reflects, along with cooking loss, the overall water-holding capacity of meat. Purge loss is an economic concern as it reduces the saleable weight (Offer and Cousins 1992) and decreases the juiciness of meat (Van Oeckel et al. 1999). The nutritive value of meat is also affected because soluble protein is lost with purge (Savage et al. 1990); therefore, low purge losses are desirable. Growth promotants like the β-AA zilpaterol hydrochloride, however, can increase drip loss, although RAC has not been shown to have this effect (Strydom et al. 2009). Therefore, even if growth promotants are used to enhance the profitability of beef carcasses by improving muscle weight, they can have adverse effects and reduce the meat saleable weight.

The growth promotant RAC increased purge loss in both muscles, but the extent of the effect differed between them. RAC consistently increased purge loss in the ST, as it was significant as a main effect, while RAC interacted with age at slaughter and implantation for purge in the GM. For the GM interaction, RAC appeared to be the most important factor because the main effects for age at slaughter and implantation were

not significant but that of RAC was. Increased purge loss is usually associated with higher L^* values (Ryu and Kim 2006) and protein denaturation (Penny 1977), but these changes were not observed concomitantly with the effect of RAC. Waritthaitham et al. (2010) showed no relationship between bovine muscle fibre type and purge loss when these authors studied the m. longissimus dorsi, but Ryu and Kim (2006) noted with pork that the greatest water losses happened in meat having the greatest number of fast glycolytic (FG) fibres. Muscles from the carcasses of animals that received RAC, however, had a shift from slow oxidative (SO) to FG fibres in the GM (Girard et al. 2011), which may have contributed to the GM purge loss. According to Geesink et al. (1993), FG fibres bind less water than SO fibres because FG fibres have a greater ratio of water to protein than SO fibres. As a result, SO fibres would have less water than FG fibres relatively to the fibre size and the close proximity of the proteins to the water molecules would allow protein to bind water molecules more effectively in SO than FG fibres. Although this hypothesis was suggested for cooking loss by Geesink et al. (1993) and not purge loss, it can be applied to purge loss as well because the mechanism of water retention in uncooked meat is similar. Further research into both the occurrence and the exact mechanism of drip loss in beef from cattle supplemented with RAC is warranted.

The cause of the increase in mean purge loss in the ST due to RAC administration was unclear. RAC administration affected the ST meat quality characteristics little except through interactions and by increasing muscle hue angle. Hue angle has been associated with purge loss (Joo et al. 1999) and it may be indicative of changes happening in protein structures. Increased purge loss due to protein denaturation is usually associated with increased L^* values (Penny 1977; Ryu and Kim 2006) along with increased chroma values (Joo et al. 1999). The absence of changes in mean L^* value due to RAC in the ST suggests that increased purge losses in the present study were not associated with protein denaturation. Factors such as the storage temperature, post mortem proteolysis, and the rate of pH decline can denature and/or affect the protein state (Lawrie and Ledward 2006); however, in the current study, storage conditions were the same, post mortem proteolysis as indicated by peak SF was not affected by RAC, and although the rate of pH decline was not measured, ultimate pH values did not differ between control and RAC treated ST muscles.

Purge losses in the ST were also related to treatment effects on the inherent properties of the muscles (Girard et al. 2011). Increases in purge loss due to age at slaughter coincided with increased muscle mass, which may have increased the early post mortem temperature of the muscles from the yearling-fed carcasses as large muscles would be expected to cool slower than small muscles. A reduced cooling rate of early post mortem muscle can increase purge through increased protein denaturation (Penny 1977). Increases in purge due to protein denaturation are usually accompanied by an increase in L^*, but this was not observed, possibly because of the increase in myoglobin concomitant with age (Seideman et al. 1984).

The change in purge loss due to treatment was greatest in the ST of implanted steers, with no change in any colour characteristics or relative myoglobin contents. Increases in purge with steroid hormone implantation appeared to be related to a reduction in intramuscular fat content related to this treatment (Girard et al. 2011). Purge decreases as intramuscular fat increases because fat displaces muscle, thereby reducing the amount of water available for purge (Mörlein et al. 2007). Purge losses with implantation may also have been related to a disproportionate increase in the cross-sectional area of the FG muscle fibres, which was observed for the same steers by Girard et al. (2011) in an interaction involving implantation, RAC and breed. Again, FG fibres have a higher water to protein ratio than SO fibres (Geesink et al. 1993). Interestingly, in the GM, purge loss was not affected by implantation where a shift from intermediate fast oxidative glycolytic fibres to small size SO fibres was observed (Girard et al. 2011).

The results of this study suggest that if RAC is fed to yearling-fed cattle, purge loss can be minimized by not implanting steers. In calf-fed steers, implanting and feeding RAC minimized purge loss relative to feeding RAC only. The use of RAC in western Canadian beef steer production management should be considered carefully as RAC did not increase muscle growth (Girard et al. 2011) and decreased the water-holding capacity of the ST and GM muscles in the present study. RAC fed to beef heifers in western Canadian production management systems may have similar effects to those observed for beef steers in Girard et al. (2011) and the present experiment but this remains to be studied. The use of hormone implants may be best determined by the desirable characteristics of the market being targeted as muscle weights were improved (Girard et al. 2011), even though the GM and ST were toughened and purge loss increased in the ST.

Colour stability can be an indicator of shelf-life and wholesomeness of the meat product (Troy and Kerry 2010). Moreover, the appearance and colour of meat is of paramount importance for consumers (Risvik 1994) as it is used by consumers to indicate the freshness of a meat product (Boles and Pegg 2005). The bright red colour of meat is more attractive than a brown (Smith et al. 2000) or purple colour (Carpenter et al. 2001). Myoglobin relative contents are good indicators of the red pigment of meat as the OMB gives meat its bright red colour and MMB the brown colour (Troy and Kerry 2010). The stability of myoglobin is related to the availability of oxygen (Boles and Pegg 2005) and is affected by several factors, one of which is the presence

of aerobic bacteria. These bacteria reduce the concentration of oxygen and lead to the formation of MMB (Seideman et al. 1984), which is why consumers associate brownish meat with spoiled meat. Nevertheless, most loss of meat colour at retail is due to a lack of oxidative stability beyond 3 d of retail storage (Egan et al. 1988). The concentration of myoglobin in muscles also increases with age and makes meat from old steers darker than that from young steers (Seideman et al. 1984).

Age at slaughter was the factor affecting colour most in the ST and the GM. Both the GM and ST had significantly greater MMB content in carcasses from yearling-fed steers than in those from calf-fed steers, meaning that the appearance of meat may be more brown in a yearling-fed steer than in a calf-fed steer. MMB content of forage-fed steers has been hypothesized to be greater than in grain-fed steers because of the level of exercise of steers on pasture (Muir et al. 1998), but other studies did not report this difference (Sapp et al. 1999; O'Sullivan et al. 2003). So, results of the current study may support the hypothesis that forage-based diets increase MMB muscle content, but diet treatments were confounded with age in the current study (Seideman et al. 1984). The hue angle of beef from the calf-fed steers indicated an increased amount of yellow pigment, which should have made the beef appear lighter than in yearling-fed steers. In the ST, beef from the calf-fed steer carcasses was lighter and in the GM, beef tended to be lighter in calf-fed steers than yearling-fed steers, confirming the observation of Seideman et al. (1984). Increased beef lightness might improve the attractiveness of calf-fed beef to consumers; therefore, finishing beef at a young age may produce a meat product that better satisfies consumer's expectation for appearance and meat colour. Nevertheless, because meat was not evaluated in retail display by panellists, this assertion cannot be confirmed and whether the difference in meat colour due to age at slaughter observed in this study could be perceived by consumers was not explored.

CONCLUSION

Results indicate that reducing age at slaughter and excluding Continental breed crosses decreased cooked meat toughness of ST and GM steaks. Although RAC did not affect cooked muscle SF, its use requires further consideration, given that it did not increase muscle yield of youthful cattle in this study and was associated with increased purge loss. SF of meat can be partly controlled by management practices used on the farm; therefore, production systems focussing on increasing beef yield should incorporate Continental crossbreds, hormone implants, and slaughter steers at between 18 and 20 mo of age. Producers seeking to reduce beef toughness should consider using British crossbreds, exclude the use of hormonal implants and slaughter process steers at 12 to 13 mo of age.

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