Reduced age at slaughter in youthful beef cattle: Effects on carcass merit traits

Ó. López-Campos[1], J. A. Basarab[2], V. S. Baron[1], J. L. Aalhus[1], and M. Juárez[1]

[1]*Agriculture and Agri-Food Canada, Lacombe Research Centre, 6000 C & E Trail, Lacombe, Alberta, Canada T4L 1W (e-mail: manuel.juarez@agr.gc.ca); and [2]Alberta Agriculture and Rural Development, Lacombe Research Centre, 6000 C & E Trail, Lacombe, Alberta, Canada T4L 1W1. Contribution number 1201.*
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López-Campos, Ó., Basarab, J. A., Baron, V. S., Aalhus, J. L. and Juárez, M. 2012. **Reduced age at slaughter in youthful beef cattle: Effects on carcass merit traits**. Can. J. Anim. Sci. **92**: 449–463. Two-hundred and twenty-four spring-born British × Continental crossbred steers were used in a 2-yr project to evaluate the effect of production system (calf-fed vs. yearling-fed) and its interaction with breed cross and hormone implant strategies, with and without β-adrenergic agonist on carcass characteristics. Carcasses from yearling-fed steers were 32% heavier ($P < 0.001$), resulting in higher ($P < 0.05$) dressing percentages, grade fat and rib-eye (longissimus thoracis) area (REA) (1.1, 32 and 10%, respectively). However, despite being lighter, the estimated lean yield percentage was 3% greater ($P = 0.010$) in carcasses from calf-fed steers. No difference ($P > 0.05$) was observed for marbling scores between production systems. Use of hormonal implants increased ($P < 0.001$) weights of live animals and carcasses (7 and 9%, respectively). However, non-implanted yearling-fed steers had the lowest proportion of Canada Quality Grade A and the highest proportion of Canada Quality Grade AAA carcasses ($P < 0.001$). Moreover, the observed increase ($P = 0.016$) in marbling scores (up to 37%) from British cross-bred steers disappeared with the use of implants. The only effect observed on carcass traits from the use of β-adrenergic agonists was an increase of 6% in REA ($P = 0.032$). The main production system effect observed for carcass composition was a lower ($P = 0.008$) proportion of bone in carcasses from yearling-fed steers. The use of hormonal implants increased ($P < 0.001$) the proportion of lean and decreased ($P = 0.019$) the proportion of fat ($P < 0.05$). Overall carcass composition of steers with large Continental influence (> 50%) had a higher proportion of lean and bone and a lower proportion of fat than carcasses from 50–75% British steers ($P < 0.001$), which was also reflected in the composition of several individual primal cuts (e.g., rib, short-loin, flank, chuck and plate). The interactions amongst production systems and the other production factors studied were minimal. Therefore, despite expected differences in carcass size, reducing age at slaughter did not have a negative impact on Canadian beef carcass traits.

Key words: β-adrenergic agonist, breed-cross, carcass grading, hormone, implant, marbling

López-Campos, Ó., Basarab, J. A., Baron, V. S., Aalhus, J. L. et Juárez, M. 2012. **L'abattage à un plus jeune âge chez les bovins de boucherie: incidence sur les paramètres qualitatifs de la carcasse**. Can. J. Anim. Sci. **92**: 449–463. Deux cent vingt-quatre bouvillons hybrides britanniques × continentaux nés au printemps ont fait l'objet d'une expérience de deux ans visant à évaluer l'incidence de la méthode d'élevage (engraissement dès le vêlage c. engraissement à partir d'un an) et les interactions de cette dernière avec les stratégies d'hybridation et d'implants hormonaux, avec ou sans agonistes β-adrénergiques, sur les paramètres de la carcasse. Les carcasses des bouvillons engraissés à partir d'un an étaient plus lourdes de 32 % ($P < 0{,}001$), si bien que le rendement de la carcasse, l'épaisseur moyenne du lard dorsal et la superficie du faux-filet étaient plus élevés ($P < 0{,}05$) (de 1,1, 32 et 10 %, respectivement). Toutefois, bien que plus légère, la carcasse des bouvillons engraissés dès le vêlage donne un rendement en viande maigre estimatif de 3 % plus élevé ($P = 0{,}010$). Les auteurs n'ont observé aucune variation ($P > 0{,}05$) entre les deux méthodes d'élevage au niveau du persillé. L'usage d'implants hormonaux accroît ($P < 0{,}001$) le poids de l'animal vivant et de la carcasse (de 7 et 9 %, respectivement). Cependant, les bouvillons sans implants engraissés à partir d'un an se caractérisent par le plus faible pourcentage de carcasses A et la plus forte proportion de carcasses AAA, selon le système canadien de classement de la qualité ($P < 0{,}001$). D'autre part, la hausse ($P = 0{,}016$) de la note pour le persillé observée (jusqu'à 37 %) chez les bouvillons hybrides britanniques disparaît lorsqu'on recourt à des implants. Le seul effet sur les paramètres de la carcasse résultant de l'usage d'agonistes β-adrénergiques qu'on a relevé consiste en une hausse de 6 % de la superficie du faux-filet ($P = 0{,}032$). La principale conséquence de la méthode d'élevage observée sur la composition de la carcasse est une plus faible ($P = 0{,}008$) masse osseuse chez les bouvillons engraissés à partir d'un an. Le recours aux implants hormonaux accroît ($P < 0{,}001$) la proportion de viande maigre et diminue ($P = 0{,}019$) celle de gras ($P < 0{,}05$). La composition générale de la carcasse des bouvillons ayant une forte ascendance continentale (> 50 %) se caractérise par une plus grande proportion de viande maigre et d'os ainsi qu'une plus faible proportion de gras que les carcasses de bouvillons d'ascendance britannique à 50–75 % ($P < 0{,}001$), ce que reflète également la composition de plusieurs coupes primaires (à savoir, côte, longe courte,

Abbreviations: **Bag**, β-agrenergic agonist; **BC**, body cavity; **IM**, intermuscular; **Imp**, implant strategy; **Ps**, production system; **REA**, rib-eye (longissimus thoracis) area; **SQ**, subcutaneous

flanc, épaule et poitrine). Les interactions entre la méthode d'élevage et les autres facteurs de production étudiés s'avèrent minimes. Par conséquent, malgré les différences prévisibles au niveau de la taille de la carcasse, abattre les animaux à un plus jeune âge n'a aucune incidence négative sur les paramètres de la carcasse des bovins de boucherie canadiens.

Mots clés: Agonistes β-adrénergiques, hybrides, classement des carcasses, hormone, implant, persillé

In response to economic, market and environmental concerns different cattle management strategies are being developed to improve efficiency and reduce input costs. Despite known trade-offs between beef quality, production economics and environmental sustainability (Reinhardt 2007; McAllister et al. 2011), reducing age at slaughter has been shown to decrease greenhouse gas production and improve economic returns (López-Campos et al. 2012). In the calf-fed production system, calves are placed on high concentrate rations after weaning and a diet step-up period, which results in improved gain and efficiency (Myers et al. 1999). Furthermore, the calf-fed production system also accelerates intramuscular fat deposition and finishing, producing younger, higher marbled beef, but with lighter carcasses and smaller steak portion size (Schoonmaker et al. 2002).

In North America, the use of growth implants has become a routine management practice in beef cattle production. Hormonal growth promotants such as estradiol benzoate and trenbolone acetate are well known to improve feed efficiency, growth rate and muscle growth (Apple et al. 1991) in grazing and feedlot cattle resulting in substantial economic gains (Foutz et al. 1997; Duckett and Andrae 2001). Using implants may affect carcass and meat quality, reducing marbling scores, increasing rib-eye area and the incidence of dark cutting, as well as decreasing tenderness (Foutz et al. 1997; Roeber et al. 2000; Reiling and Johnson 2003). Smith et al. (2007), however, reported a lack of effect of anabolic implants on intramuscular lipid deposition, particularly in cattle with a high genetic propensity to deposit intramuscular fat.

β-adrenergic agonists are also commonly used in livestock production to accelerate growth by enhancing lean tissue accretion. These compounds work by redirecting nutrients away from fat deposition to protein synthesis, resulting in increased growth rate and feed conversion ratio, as well as increased muscle fiber size and lean meat yield (Gruber et al. 2007; Winterholler et al. 2007).

No single breed excels in all performance and carcass merit traits, justifying the use of breed-crosses to optimize beef production (Wheeler et al. 1997). In North America, and especially in Canada, the most common breed-cross consists of British (mainly Angus and Hereford) × European Continental (mainly Charolais, Simmental and Limousin) breeds in different percentages. These breeds have been chosen for their ability to perform particularly well in Canada's temperate climate and to produce high-quality beef (Agriculture and Agri-Food Canada 2011).

Although published studies have addressed many individual aspects of calf-fed and yearling-fed beef production, their interactions with growth implant, β-adrenergic agonists and breed-cross on carcass quality have not been clarified to date. Hormonal growth promotants and β-adrenergic agonists work through separate mechanisms; however, both act to increase protein deposition. It is not well known whether the aforementioned strategies have synergistic or additive effects on beef quality. Furthermore, the strong interactions between genotype and environment (Albertí et al. 2008) make it necessary to consider both factors together in order to obtain the greatest profitability.

Hence, the objective of this study was to determine the effect of reduced age at slaughter (calf-fed vs. yearling-fed), as well as its interactions with aggressive growth implant strategies, β-adrenergic agonists and breed-cross, on carcass merit traits.

MATERIAL AND METHODS

Animal Management

In this 2-yr study, the animals were maintained at the Lacombe Research Centre, Agriculture and Agri-Food Canada (Lacombe, AB). All dietary treatments and experimental procedures were approved by the Lacombe Research Centre Animal Care Committee. Animals were cared for as outlined under the guidelines established by the Canadian Council on Animal Care (1993). The management of the cow–calf herd has been previously described by Basarab et al. (2007, 2011). In each of 2 yr, 112 spring-born steer calves from five different breed-cross compositions (>75% Continental, 50–75% Continental, 50–50% Continental–British, 50–75% British, >75% British) were assigned at weaning to a 2 × 2 × 2 factorial arrangement of management systems to determine the effect of breed-cross, production system, growth implant and β-adrenergic agonist on carcass merit traits. Steer calves were allocated to production systems and implant groups based on breed-cross, birth date, calf weight (42.2 kg, SD = 6.3 kg) and dam age (4.8 yr, SD = 2.7 yr). The study was balanced for production system, growth implant and β-adrenergic agonist effects (2 × 2 × 2 factorial arrangement), with 28 animals per combination of factors. However, the design was unbalanced for the effect of breed-cross and the different available combinations of breed-cross × production system × growth implant × β-adrenergic agonist had between four and nine animals.

The production systems and treatments were detailed in Basarab et al. (2012). Briefly, calf-fed steers (weight: 268 kg, SD = 5.4 kg; age: 191 d, SD = 3.0 d) were placed into a feedlot pen fitted with eight GrowSafe® feeding stations (GrowSafe® System Inc., Airdrie, AB), where they were fed twice daily ad libitum and adjusted from a high forage-based to a high grain finishing diet over 27–42 d. The adjustment period was followed by an 80–86 d test period where the steers were fed an ad libitum finishing diet twice daily. The average ingredient composition of the diet (DM basis) fed during the finishing phase was 71.6% rolled barley grain, 18.9% barley silage and 9.51% protein supplement and premix. Yearling-fed steers (weight: 266 kg, SD = 4.6 kg; age: 193 d, SD = 3 d), were weaned and then placed on meadow-brome grass (*Bromus riparius* Rehm.) alfalfa (*Medicago sativa* L.) pasture where they rotationally grazed for 52 d. Then, a backgrounding diet (DM basis) consisting of 66.3% barley silage, 20.6% hay, 5.3 barley straw and 7.9% grain was fed for 192 d. After the backgrounding period, the steers grazed meadow brome alfalfa pastures for 90 d. Yearling-fed steers were then placed into a feedlot pen fitted with eight GrowSafe® feeding stations where they were fed twice daily ad libitum and adjusted from a high forage-based diet to a high grain finishing diet over 21–23 d. The 3 wk adjustment period was followed by an 86-d test period where the steers were fed an ad libitum finishing diet twice daily. The average ingredient composition of the diet (DM basis) fed during the finishing phase was 76.3% rolled barley grain, 18.0% barley silage and 5.8% protein supplement and premix. One-half ($n = 56$) of the calf-fed and yearling-fed steers were implanted with 200 mg progesterone and 20 mg estradiol benzoate (Component E-S, Elanco-Animal Health A Division of Eli Lilly Canada Inc., Toronto, ON). Throughout the course of the study, calf-fed animals were re-implanted after being on the finishing diet for 56 d, while yearling-fed animals were re-implanted every 76 d for a total of five implants. Animals assigned to the β-adrenergic agonist treatment were supplemented with 200 mg head^{-1} d^{-1} of ractopamine hydrochloride 28 d before slaughter (Optaflexx, Elanco-Animal Health A Division of Eli Lilly Canada Inc., Toronto, ON).

Carcass Characteristics

All steers were slaughtered at a backfat end point of 8–10 mm (based on ultrasound measurements using an Aloka 500V diagnostic real time ultrasound machine with a 17-cm 3.5-Mhz linear array transducer; Overseas Monitor Corporation Ltd., Richmond, BC) in four groups of 14 per year and production system (calf- and yearling-fed steers). In 1- to 2-wk intervals, steers were trucked 3 km for processing under conditions similar to commercial slaughter at the federally inspected. Lacombe Research Centre abattoir [Canadian Food Inspection Agency (CFIA) Establishment No. 021], such that implant and β-adrenergic agonist treatments were balanced within each slaughter group. Final live and hot carcass weights were obtained from all steers at the time of slaughter. Hot dressing percentage was calculated as the ratio of hot carcass weight to live weight (dressing percentage = hot carcass weight/slaughter weight × 100). The carcasses were then chilled at 2°C for 24 h, knife-ribbed at the grade site between the 12th and 13th ribs, and assessed for fat thickness, longissimus thoracis area (REA), estimated lean yield (CFIA 1992) and full blue tag quality grade (American Meat Science Association 1990) by two certified graders. The right and left sides were subsequently weighed (cold carcass weight) and the left side of each carcass was separated into nine wholesale cuts or primals (round, sirloin butt, short-loin, flank, chuck, rib, plate, brisket, shank), which were further divided into body cavity, subcutaneous and intermuscular fat depots, lean and bone, as described by Jones et al. (1984). The relative weight of each primal (kilogram of primal per 100 kilogram of carcass) was then calculated. The results from the dissection of the primals were also transformed to proportional tissue weights within individual primals and total proportional tissue weights within the carcass (gram tissue per kilogram of primal/gram tissue per kilogram of carcass).

Statistical Analysis

Statistical analyses for all the studied traits were developed using the MIXED model Covtest procedure of SAS software (SAS Institute, Inc. 2003), including production system, breed-cross, implant and β-agonist and their interactions as fixed effects. The degree of fatness, nested within production system, implant and β-agonist, was used as a covariate. Sire, nested within breed-cross, and pen, nested within production system, implant and β-agonist, were included as random factors. Treatment means were determined using the LSMEANS option and separated using a F-test protected LSD ($P \leq 0.05$). The effects of the β-agonist strategy were not significant ($P > 0.05$) for the majority of the studied traits. Thus, the means for this factor were not included in the tables and were commented in the text only. Among the effects included in the study, very few interactions were statistically significant ($P < 0.05$). Therefore, the means by individual treatments were presented in the tables and the significant interactions were presented as additional figures. Moreover, only interactions with at least one trend ($P < 0.1$) or significant effect ($P < 0.05$) for any of the traits were presented in the tables. Frequency results from carcass yield and quality grade classes were analyzed using a chi-square (χ^2) and Fisher's exact test (PROC FREQ procedure of SAS software using the CHISQ option).

RESULTS

Yearling-fed steers were 29% heavier ($P < 0.001$) than calf-fed steers (Table 1) and, therefore, their carcasses ($P < 0.001$) and dressing percentages ($P = 0.006$) were

Table 1. Effects of production system (Ps), implant strategy (Imp) and β-agonist (Bag) on carcass characteristics

	Production system		Implant strategy		β-agonist			*P* value		
	Calf-fed	Yearling-fed	No Imp	Imp	No Bag	Bag	SEM	Ps	Imp	Bag
Live weight (kg)	556	716	614	658	630	642	14.80	<0.001	<0.001	0.318
Hot carcass weight (kg)	324	427	359	392	370	381	8.875	<0.001	<0.001	0.117
Hot dressing percentage (kg 100 kg^{-1})	58.5	59.7	58.7	59.6	58.8	59.4	0.468	0.006	0.067	0.204
Cooler loss (kg 100 kg^{-1})	1.29	1.28	1.30	1.27	1.30	1.27	0.045	0.682	0.419	0.385
Grade fat (mm)	9.17	12.1	10.0	11.2	11.0	10.3	0.843	<0.001	0.196	0.355
Estimated lean yield (kg 100 kg^{-1})	59.3	57.6	58.7	58.2	57.9	59.0	0.735	0.010	0.516	0.143
Rib eye area (cm^2)	87.6	96.3	90.4	93.5	89.5	94.4	2.640	<0.001	0.208	0.032
Marbling score[z]	462	479	497	443	460	481	24.62	0.306	0.006	0.259

[z]AMSA marbling scores: 0 = devoid, 100 = practically devoid, 200 = traces, 300 = slight, 400 = small, 500 = slightly abundant, 600 = moderately abundant.
Only interactions with at least one trend (P < 0.1) or significant effect (P < 0.05) for any of the traits are presented in the table.

also higher (32 and 1.1%, respectively). Use of hormonal implants also resulted in heavier ($P < 0.001$) live animal and carcass weights (7 and 9%, respectively), with a trend for higher dressing percentages ($P = 0.067$). Grade fat and REA from yearling-fed steers were 32 and 10% higher, respectively ($P < 0.001$), but the estimated yield percentage was 3% higher ($P = 0.010$) in carcasses from calf-fed steers. Although these traits were not affected ($P > 0.05$) by the use of implants, marbling scores for carcasses from both calf- and yearling-fed steers were 11% lower ($P = 0.006$) when combined with hormonal implants. The only effect observed on carcass traits from the use of β-adrenergic agonists was a 6% increase ($P = 0.032$) in REA. No interactive effects ($P > 0.05$) between the production system and the use of implant or β-adrenergic strategies were observed. When the frequencies of estimated yield grade were analyzed (Fig. 1), the χ^2 value for the production system × implant interaction was not significant ($P > 0.05$) and, in all the cases, a greater percentage of Canada Yield Grade 2 carcasses was observed. However, the production system × implant interaction (Fig. 2) was statistically significant ($P < 0.001$) for the carcass quality grade frequencies. The four carcasses graded as B4 (dark cutting) corresponded to yearling-fed implanted steers, while non-implanted yearling-fed steers had the lowest proportion of Canada Quality Grade A and the largest proportion of Canada Quality Grade AAA carcasses. The use of implants, in general, resulted in an 8% reduction in the proportion of AAA and a 12% increase in the proportion of AA carcasses for both calf- and yearling-fed steers.

Live and carcass weights, as well as dressing percentage and cooler shrink loss, were not affected ($P > 0.05$) by the breed-cross combinations (Table 2). On the other hand, the increase in the contribution of British breeds led, in general, to higher grade fat ($P < 0.001$) and lower estimated yield ($P < 0.001$) and REA ($P = 0.003$). Nevertheless, grade fat and REA were similar ($P > 0.05$) for cattle with >75% British breeding and cattle with 50 to 75% Continental breeding. Furthermore, breed-cross interacted with implant strategy for marbling score ($P = 0.016$). Thus, in non-implanted steers the marbling scores increased up to 37% (Fig. 3) with increasing influence of British breeds, while this effect disappeared with the use of implants.

While implant strategy and β-adrenergic agonist did not affect the percentage yield of the primal cuts ($P > 0.05$), a decrease ($P = 0.018$) was observed for the proportion of shank from yearling-fed steers (Table 3). On the other hand, the proportion of round ($P = 0.058$) and chuck ($P = 0.052$) tended to be lower and higher, respectively, for yearling-fed steers. A trend ($P = 0.089$) was observed for the interactive effect between production system and implant strategy regarding the proportion of short loin tended. The proportion of short loin tended to be slightly higher in non-implanted calf-fed and implanted yearling-fed steers. Over the whole

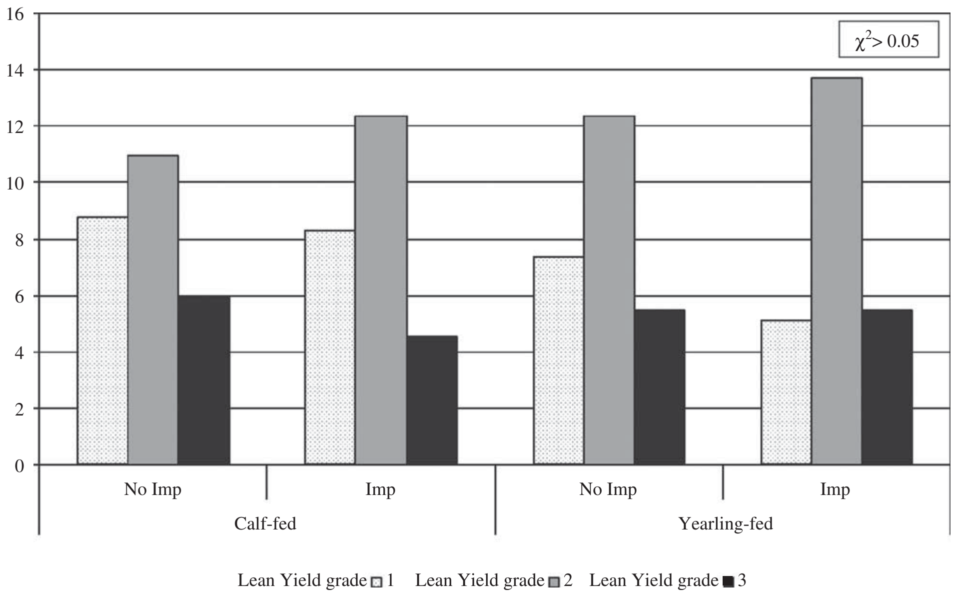

Fig. 1. Effect of production system and implant strategy on carcass lean yield grade frequencies.

carcass, the proportion of bone was lower ($P = 0.008$) in carcasses from yearling-fed steers. The use of hormonal implants resulted in a greater proportion ($P < 0.001$) of lean ($P = 0.019$) and lower proportion of body cavity, intermuscular ($P = 0.011$) and total fat ($P = 0.044$). Again, the effect of using β-adrenergic agonist on carcass traits was not significant ($P > 0.05$).

The proportion of round and plate were higher ($P < 0.05$) in carcasses from 50–75% British steers than in those in which the British influence was < 50% (Table 4). Carcasses from steers with high Continental influence (> 75%) also had a higher proportion ($P = 0.010$) of round than those from steers with 50–75% British influence. The results from the total carcass dissection again showed a breed-cross effect on percentage of total lean, bone and fat, as well as on percentage of body cavity and intermuscular fat ($P < 0.001$). No effect was observed for subcutaneous fat ($P > 0.05$). Carcasses from steers with 50–75% British influence had lower proportions ($P < 0.05$) of lean and bone and much higher proportions of body cavity, intermuscular and total fat than those from steers with > 50% Continental

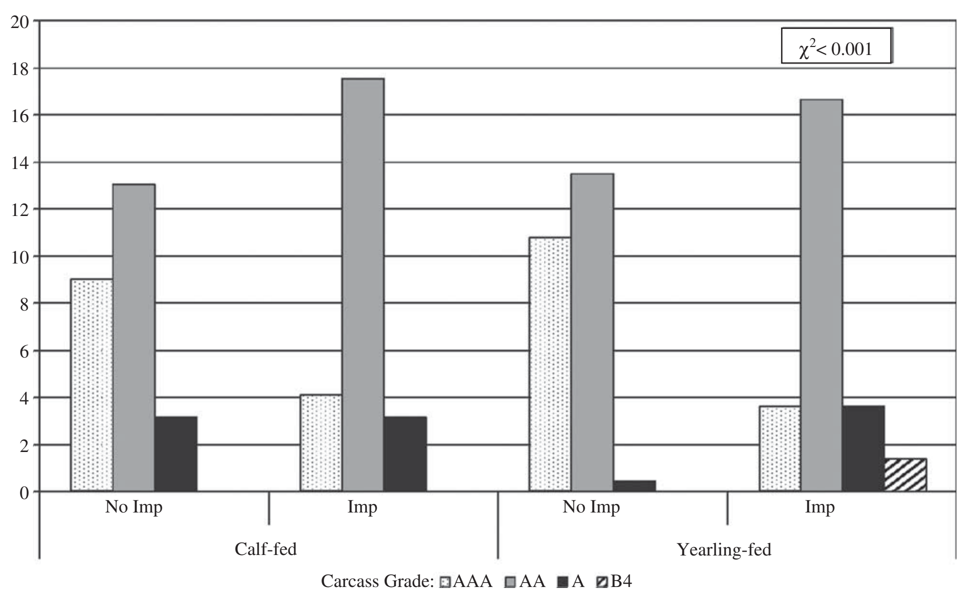

Fig. 2. Effect of production system and implant strategy on carcass grade frequencies.

Table 2. Effects of breed-cross and its interactions on carcass characteristics

	Breed-cross										P value		
	>75% Cn[z]		50–75% Cn		50%Cn–50%Br[z]		50–75% Br		>75% Br				
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Bc[z]	Bc × Ps[z]	Bc × Imp
Live weight (kg)	640	12.4	647	12.9	626	18.2	642	10.7	625	28.6	0.749	0.095	0.121
Hot carcass weight (kg)	382	7.10	383	7.05	365	10.91	379	6.37	369	17.2	0.393	0.125	0.052
Hot dressing percentage (kg 100 kg^{-1})	59.7	0.42	59.4	0.45	58.4	0.67	58.9	0.25	59.1	1.11	0.346	0.685	0.449
Cooler loss (kg 100 kg^{-1})	1.28	0.04	1.30	0.04	1.28	0.06	1.27	0.03	1.30	0.10	0.788	0.553	0.882
Grade fat (mm)	9.16*c*	0.63	9.65*bc*	0.70	7.67*c*	1.24	14.6*a*	0.35	12.1*b*	2.22	<0.001	0.301	0.167
Estimated lean yield (kg 100 kg^{-1})	59.7*a*	0.60	59.0*ab*	0.66	61.7*a*	1.08	54.8*c*	0.33	56.9*bc*	1.91	<0.001	0.120	0.080
Rib eye area (cm^2)	96.1*a*	2.65	90.6*ab*	2.87	98.0*ab*	4.11	84.7*b*	1.66	90.2*ab*	6.84	0.003	0.901	0.292
Marbling score	430*b*	22.0	432*b*	22.9	538*a*	29.6	484*a*	18.7	467*ab*	44.9	0.003	0.169	0.016

[z]Ps, production system; Imp, implant strategy; Cn, continental; Br, British.
[y]AMSA marbling scores: 0 = devoid, 100 = practically devoid, 200 = traces, 300 = slight, 400 = small, 500 = slightly abundant, 600 = moderately abundant.
a–c Values in the same row with different letters are significantly different ($P < 0.05$).
Only interactions with at least one trend ($P < 0.1$) or significant effect ($P < 0.05$) for any of the traits were presented in the table.

influence. No interaction ($P > 0.05$) was observed for these traits between the breed-cross and the production system or the use of implants or β-adrenergic agonists.

The decrease in the proportion of bone in carcasses from yearling-fed steers was observed ($P < 0.05$) in the round, chuck, brisket and shank (Table 5). On the other hand, the proportion of lean in the chuck ($P = 0.027$) and shank ($P < 0.001$) was greater in carcasses from yearling-fed than in those from calf-fed steers. The only effects observed in the proportion of fat were the decreases in intermuscular fat in the sirloin butt ($P = 0.043$) and body cavity fat in the rib ($P = 0.006$) in carcasses from yearling-fed steers. The increase in the proportion of lean from the use of implants was statistically significant ($P < 0.05$) in the flank, plate, brisket and shank, and tended to be higher ($P > 0.05$ and < 0.10) in the round and rib. The only effect on the proportion of bone was a slight decrease ($P = 0.008$) in in the round and a slight increase ($P = 0.030$) in the brisket of implanted steers. The overall decrease in the proportion of body cavity fat when using implants was also observed ($P < 0.05$) in the proportion of body fat in the sirloin butt, short-loin, rib and plate, as well as a trend ($P = 0.062$) in the brisket. Similarly, the proportion of intermuscular fat in the sirloin butt, short-loin, flank, chuck and rib was lower ($P < 0.05$) when implants were used. Only the proportion of subcutaneous fat in the plate decreased ($P = 0.029$) by the use of implants. The only effect of using β-adrenergic agonists was a decrease in the proportion of bone in the brisket ($P = 0.015$).

The proportion of lean in all the individual cuts was affected ($P < 0.05$) by the cross-breed (Table 6). In fact, as observed in the full dissection, in most of the primal cuts the proportion of lean was lower in carcasses from 50–75% British steers compared with 50–75% Continental and, especially to > 75% Continental. For the round, short-loin, flank, chuck and plate, the proportion of bone was higher ($P < 0.05$) in carcasses from > 75% Continental steers than in those from 50–75% British steers. For the short-loin, chuck and plate, carcasses from 50–75% Continental steers also had a higher proportion of bone. While most primal cuts from carcasses from > 75% British steers had a similar proportion of bone compared with those from 50–75% British steers, this breed-cross had the greatest proportion of bone in the short-loin ($P < 0.001$). As observed for the full dissection of the carcass, no breed-cross effect was noted for the proportion of body cavity fat in most primal cuts. Only in the short-loin, a greater ($P = 0.014$) proportion of body cavity fat was observed for 50–75% British steers compared with 50–75% and > 75% Continental steers. On the other hand, carcasses from steers with 50–75% British influence had greater proportion of subcutaneous fat in the round, sirloin butt, flank and rib and greater percentage of intermuscular fat in the round and chuck ($P < 0.05$). Carcasses from steers with 50–75% British influence also had the greatest

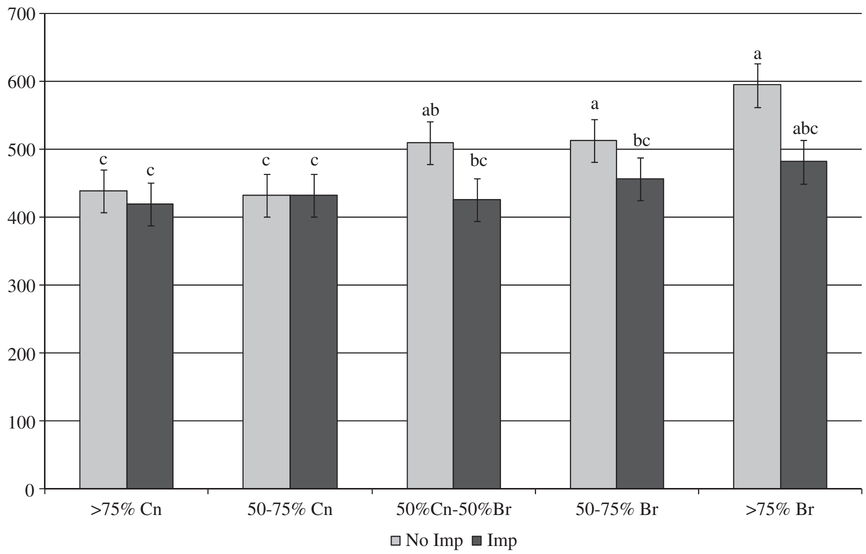

Fig. 3. Effect of breed-cross and implant strategy on carcass marbling scores. *a–c* Values with different letters are significantly different ($P < 0.05$).

percentage of subcutaneous fat in the short-loin ($P < 0.05$). The proportions of subcutaneous fat of the chuck and shank and intermuscular fat of the rib and plate were higher in carcasses from steers with 50–75% British influence than in carcasses from steers with > 50% Continental influence and carcasses from steers with > 75% of British influence ($P < 0.05$). Plates from carcasses from steers with > 50% British influence had greater percentage of subcutaneous fat than those from steers with > 75% Continental influence ($P < 0.05$). Biskets from carcasses from steers with 50–75% British influence had greater percentage of intermuscular fat than those from steers with > 75% Continental influence ($P < 0.05$). No difference among breed-crosses ($P > 0.05$) was observed for the proportion of intermuscular fat in the sirloin butt and short-loin.

DISCUSSION

Carcass Quality Characteristics

Beef quality, production economics and environmental sustainability influence the choice between producing calf-fed or yearling-fed steers in North America. Eng (2006) estimated that in the United States of America more feeder cattle move through the yearling-fed (76%) vs. calf-fed (24%) production systems. In contrast, Basarab et al. (2011) estimated that in Canada this ratio is closer to 55:45 in favor of the yearling-fed beef production system. Griffin et al. (2007) reported an increase in carcass weight and no effect on marbling scores, in agreement with Winterholler (2008), resulting in an advantage for yearling-fed compared with calf-fed steers. However, Griffin et al. (2007) also reported an increase in fat thickness for yearling-fed steers. In the present study, similar effects, including greater grade fat, plus an increase in REA in the yearling-fed steers, were observed even if animals with similar weights were allocated to the different production systems. Nevertheless, Brewer et al. (2007) reported lower marbling scores and quality grades for yearling-fed compared with calf-fed steers. In the present study, no differences were found between production systems regarding marbling scores. In contrast to the US market, the current Canadian Beef Grading system penalizes carcasses with excessive fat thickness. Therefore, among other factors, such as feeding costs, greater grade fat scores, as observed in the present study for carcasses from yearling-fed steers, would mean a decrease in the profitability. Moreover, while Griffin et al. (2007) reported lower feeding costs for yearling-fed steers, López-Campos et al. (2012) found opposite values from data obtained in Canada, due to differences in land-use and feedstuff prices.

In North America, growth promotants, especially hormonal implants, are commonly used to enhance animal performance, reducing costs and improving profitability. The main effects of hormonal implants include increased feed intake, daily gain and feed efficiency (Apple et al. 1991). Since fat tissues develop in the late stages of growth, implanted animals tend to produce more muscle and less fat than non-implanted animals (Reinhardt 2007). In the present study, implanted animals were over 40 kg heavier, with a trend to greater dressing percentage. Implanted steers needed to achieve greater live weights than non-implanted animals in order to obtain comparable degrees of fatness. Hence, similar marbling scores would be expected, since marbling deposition is usually linked to deposition of external fat. However, previous studies have reported how implant strategies can "decouple" the deposition of these two fat depots (Bruns et al. 2005;

Table 3. Effects of production system (Ps), implant strategy (Imp) and β-agonist (Bag) on carcass components and full dissection values

	Production system		Implant strategy		β-agonist			*P* value			
	Calf-fed	Yearling-fed	No Imp	Imp	No Bag	Bag	SEM	Ps	Imp	Bag	Ps × Imp
Primal cut yields (g kg^{-1})											
Round	240	231	234	237	23.6	23.6	6.400	0.058	0.528	0.946	0.355
Sirloin butt	85.4	85.1	85.3	85.1	8.49	8.56	2.431	0.866	0.936	0.732	0.320
Short loin	66.8	66.7	66.4	67.2	6.59	6.77	1.985	0.936	0.671	0.268	0.089
Flank	59.1	61.3	61.5	58.9	6.08	5.96	1.934	0.231	0.196	0.505	0.977
Chuck	279	289	283	285	28.4	28.5	5.249	0.052	0.626	0.818	0.148
Rib	96.0	96.3	96.4	95.9	9.65	9.58	2.230	0.878	0.826	0.758	0.123
Plate	76.4	75.5	77.7	74.2	7.51	7.68	2.311	0.650	0.142	0.463	0.721
Brisket	61.9	65	62.3	64.5	6.42	6.26	2.460	0.182	0.384	0.510	0.890
Shank	39.9	37.4	39.6	37.7	3.86	3.87	1.149	0.018	0.120	0.88	0.518
Carcass composition (g kg^{-1})											
Lean	562	571	556	577	567	567	8.760	0.297	0.019	0.969	0.978
Bone	146	138	143	142	144	142	3.200	0.008	0.820	0.406	0.840
Body-cavity fat	26.1	24.6	27.7	23.1	25.7	25.2	1.238	0.198	<0.001	0.655	0.695
Subcutaneous fat	91.7	92.1	92.0	91.8	91.4	92.5	4.183	0.917	0.973	0.771	0.929
Intermuscular fat	172	173	180	165	172	174	6.095	0.871	0.011	0.749	0.825
Total fat	290	289	300	279	289	291	10.15	0.976	0.044	0.799	0.958

Only interactions with at least one trend ($P < 0.1$) or significant effect ($P < 0.05$) for any of the traits were presented in the table.

Reinhardt 2007). In this sense, numerous studies have reported that implants decrease quality grade and marbling score in beef (Duckett and Andrae 2001; Reiling and Johnson 2003; Reinhardt 2007). Consistent with these findings, marbling score in the present study was decreased 5% by the use of implants in both production systems. In this sense, Brewer et al. (2007), in a study with implanted steers, reported that carcasses from calf-fed steers had greater marbling scores than carcasses from yearling-fed steers. Although this same effect has been reported in previous studies, other authors have reported no effect of hormonal implants on marbling scores (Smith et al. 2007). In contrast, Wertz et al. (2002) suggested that the increased length of time on a high-concentrate diet likely accounted for the higher extractable lipid values. These authors concluded that early-weaning heifers and finishing them in an accelerated program allows intramuscular fat deposition while heifers are gaining more efficiently compared with heifers grown on pasture and finished as 2-yr-olds. In addition, the hormones, dosage, duration and phase of administration may have a great influence on the effects of hormonal strategies on carcass traits (Parr et al. 2011). Previous studies (Herschler et al. 1995; Scanga et al. 1998) have also reported darker longissimus muscle color or greater incidence of "dark cutters" when implants are used in beef programs. In the present study, B4 carcasses were only observed in implanted yearling-fed steers. This interaction suggests a link between long-term aggressive hormonal implants in older animals and the incidence of "dark cutters". On the contrary, Foutz et al. (1997) did not detect "dark cutting" issues in a study with implanted yearling-fed steers (predominantly Limousin × British). Therefore, the interaction between production systems and implant strategies on beef carcass color requires further investigation.

β-adrenergic agonists improve production gains by initiating the signal transduction pathways and transcription of proteins, and thus increasing protein deposition with minimum effect on adipose tissue (Mills 2002). Although their mechanism of action is different to that from hormonal implants, the modifications in the metabolism of proteins could potentially affect carcass traits. Bryant et al. (2010) reported an increase in REA, as observed in the present study, as the main effect from using ractopamine in feedlot steers, with and without implants. Bryant et al. (2010) also observed an increase in carcass weight and dressing percentage, but no other significant effects were observed on carcass yield, fatness and marbling scores. These effects were not observed at lower levels of ractopamine administration (100 mg head^{-1} d^{-1}) and no interaction was observed with hormonal implants, perhaps due to their different mechanisms of action. Quinn et al. (2008) did not observe any effect on carcass weight until ractopamine levels were increased up to 300 mg head^{-1} d^{-1} and still no effect was observed on adipose tissue.

Table 4. Effects of breed-cross and its interactions on carcass components and full dissection values

	Breed-cross										*P* value	
	>75% Cn[z]		50–75% Cn		50%Cn–50%Br[z]		50–75% Br		>75% Br			
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Bc[z]	Bc × Ps[z]
Primal cut yields (g kg^{-1})												
Round	241*a*	0.55	238*a*	0.57	240*ab*	0.85	226*b*	0.44	234*ab*	1.38	0.010	0.688
Sirloin butt	86.6	0.18	86.6	0.2	87.7	0.35	83.3	0.13	82.5	0.61	0.280	0.625
Short loin	67.6	0.15	64.9	0.16	66.3	0.27	67.0	0.12	68.0	0.47	0.522	0.335
Flank	56.6*b*	0.14	57.0*b*	0.15	63.0*a*	0.29	62.5*a*	0.07	62.0*ab*	0.53	0.002	0.068
Chuck	282	0.38	281	0.41	285	0.79	286	0.20	288	1.44	0.699	0.510
Rib	96.4	0.17	94.4	0.19	95.8	0.34	97.7	0.09	96.5	0.61	0.632	0.704
Plate	70.0*b*	0.18	73.0*ab*	0.2	83.9*a*	0.35	77.3*a*	0.10	75.5*ab*	0.63	0.011	0.583
Brisket	62.8	0.17	65.0	0.18	59.5	0.36	66.9	0.10	62.9	0.62	0.143	0.998
Shank	38.6	0.09	38.7	0.1	41.5	0.18	37.1	0.05	37.4	0.31	0.294	0.490
Carcass composition (g kg^{-1})												
Lean	588*a*	8.52	577*a*	9.27	560*ab*	13.7	543*b*	4.60	568*ab*	23.6	<0.001	0.834
Bone	148*a*	2.24	146*a*	2.45	142*ab*	4.33	137*b*	1.63	142*ab*	7.37	<0.001	0.224
Body-cavity fat	80.8*b*	3.77	87.7*b*	4.20	90.7*ab*	6.70	107*a*	2.07	93.8*ab*	11.3	<0.001	0.630
Subcutaneous fat	23.7	0.98	24.4	1.08	27.2	1.72	26.2	0.57	25.6	2.99	0.151	0.991
Intermuscular fat	160*b*	5.57	166*b*	6.12	180*ab*	9.36	187*a*	3.33	171*ab*	15.8	<0.001	0.705
Total fat	264*b*	9.58	278*b*	10.5	298*ab*	15.8	319*a*	5.56	291*ab*	26.6	<0.001	0.734

[z]Ps, production system; Imp, implant strategy; Cn, continental; Br, British.
[a–c]Values in the same row with different superscripts are significantly different ($P < 0.05$).
Only interactions with at least one trend ($P < 0.1$) or significant effect ($P < 0.05$) for any of the traits were presented in the table.

Table 5. Effects of production system (Ps), implant strategy (Imp) and β-agonist (Bag) on dissection values of individual carcass primals (g kg^{-1})

		Production system		Implant strategy		β-agonist			*P* value			
		Calf-fed	Yearling-fed	No Imp	Imp	No Bag	Bag	SEM	Ps	Imp	Bag	Ps × Imp
Round	Lean	655	665	654	666	659	661	8.170	0.130	0.088	0.705	0.551
	Bone	161	148	158	151	155	154	3.118	<0.001	0.008	0.667	0.427
	BC[z] fat	5.58	4.86	5.05	5.39	5.23	5.22	0.648	0.249	0.619	0.987	0.719
	SQ[z] fat	103	109	107	105	106	106	6.920	0.351	0.800	0.935	0.804
	IM[z] fat	75.2	73.5	76.4	72.4	75.2	73.6	3.405	0.503	0.177	0.547	0.091
Sirloin	Lean	591	596	589	598	595	593	9.663	0.552	0.403	0.822	0.771
Butt	Bone	138	136	135	139	137	137	3.725	0.524	0.287	0.968	0.547
	BC fat	42.7	41.7	46.2	38.2	41.4	43.0	3.898	0.787	0.046	0.667	0.994
	SQ fat	117	124	115	126	122	119	7.705	0.350	0.209	0.718	0.162
	IM fat	113	103	115	100	106	110	5.255	0.043	0.007	0.439	0.194
Short	Lean	562	551	553	559	555	558	10.99	0.276	0.587	0.793	0.688
Loin	Bone	144	151	144	151	151	144	5.660	0.200	0.300	0.238	0.565
	BC fat	78.5	71.2	80.9	68.8	74.8	74.9	5.573	0.132	0.034	0.975	0.209
	SQ fat	159	165	156	168	162	161	9.180	0.448	0.242	0.897	0.460
	IM fat	57.8	62.4	66	54.2	57.2	63.0	5.315	0.353	0.042	0.280	0.846
Flank	Lean	452	457	439	470	460	449	15.64	0.743	0.035	0.401	0.818
	Bone	6.37	7.00	6.03	7.33	6.66	6.70	0.750	0.382	0.102	0.958	0.944
	IM fat	542	537	555	523	534	545	15.81	0.713	0.030	0.409	0.837
Chuck	Lean	599	618	594	622	609	608	9.570	0.027	0.005	0.910	0.763
	Bone	136	127	132	131	133	130	4.030	0.023	0.900	0.530	0.929
	BC fat	11.4	11.6	12.0	11.0	12.7	10.2	1.555	0.878	0.560	0.118	0.654
	SQ fat	69.9	63.6	68.8	64.8	63.8	69.7	3.948	0.083	0.334	0.124	0.339
	IM fat	183	181	193	171	183	181	7.478	0.652	0.006	0.862	0.967
Rib	Lean	496	501	487	510	502	496	12.21	0.650	0.076	0.585	0.387
	Bone	174	173	175	172	175	173	7.900	0.949	0.776	0.786	0.361
	BC fat	31.7	26.3	32.8	25.2	29.6	28.4	2.063	0.006	<0.001	0.548	0.765
	SQ fat	127	124	123	128	123	128	6.100	0.522	0.391	0.453	0.506
	IM fat	171	175	182	163	170	176	7.338	0.570	0.018	0.466	0.856
Plate	Lean	440	437	423	454	439	438	12.80	0.812	0.023	0.967	0.634
	Bone	110	110	110	110	109	110	4.215	0.996	0.950	0.842	0.602
	BC fat	103	101.5	111	93.6	106	98.6	6.235	0.836	0.011	0.269	0.253
	SQ fat	62.1	66.2	68.9	59.4	67.0	61.3	4.143	0.270	0.029	0.157	0.037
	IM fat	286	286	288	284	280	292	11.28	0.991	0.779	0.248	0.445
Brisket	Lean	434	437	423	447	432	439	9.965	0.774	0.025	0.477	0.482
	Bone	147	136	135	148	149	135	5.775	0.034	0.030	0.015	0.516
	BC fat	29.3	26.9	31.5	24.7	25.4	30.8	3.433	0.465	0.062	0.117	0.918
	SQ fat	165	164	171	157	165	164	11.04	0.922	0.172	0.927	0.458
	IM fat	224	235	238	221	228	231	9.800	0.250	0.097	0.700	0.782
Shank	Lean	458	487	465	480	474	471	7.170	<0.001	0.024	0.611	0.360
	Bone	375	349	367	357	362	362	8.323	0.001	0.230	0.982	0.552
	IM fat	168	164	169	163	165	168	9.675	0.524	0.427	0.667	0.937

[z]BC, body cavity; SQ, subcutaneous; IM, intermuscular.
Only interactions with at least one trend ($P<0.1$) or significant effect ($P<0.05$) for any of the traits were presented in the table.

Table 6. Effects of breed-cross and its interactions on dissection values of individual carcass primals (g kg^{-1})

		Breed-cross										*P* value		
		>75% Cn[z]		50–75% Cn		50%Cn–50%Br[z]		50–75% Br		>75% Br				
		Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Bc	Bc × Ps[z]	Bc × Imp
Round	Lean	672*a*	7.72	663*a*	8.27	661*ab*	11.7	641*b*	5.33	664*ab*	19.1	0.001	0.824	0.259
	Bone	160*a*	2.81	157*ab*	3.02	153*ab*	4.54	152*b*	1.98	150*b*	7.60	0.048	0.174	0.313
	BC fat	5.11	0.44	4.34	0.48	4.86	0.90	5.31	0.28	6.49	1.52	0.246	0.632	0.799
	SQ fat	92.3*b*	5.90	104*b*	6.33	104*ab*	9.27	122*a*	4.36	107*ab*	15.2	<0.001	0.836	0.388
	IM fat	71.1*b*	3.07	71.9*b*	3.30	76.7*ab*	4.79	80.0*a*	2.34	72.6*ab*	7.98	0.015	0.293	0.270
Sirloin Butt	Lean	627*a*	9.47	615*ab*	10.4	574*abc*	15.6	564c	5.29	588*bc*	26.2	<0.001	0.594	0.396
	Bone	138	2.49	140	2.79	134	5.61	135	1.30	138	10.4	0.676	0.727	0.409
	BC fat	38.1	2.57	38.2	2.53	47.6	5.46	44.4	1.84	42.6	9.41	0.650	0.517	0.563
	SQ fat	102*c*	5.64	111*b*c	6.36	112*ab*c	11.2	150*a*	3.18	128*ab*	19.9	<0.001	0.990	0.503
	IM fat	98	4.77	98	5.25	136	8.25	106	2.51	102	14.7	0.101	0.060	0.104
Short Loin	Lean	580*a*	9.95	571*a*	10.9	563*ab*	17.01	520*b*	5.33	547*ab*	29.9	<0.001	0.748	0.516
	Bone	147*b*	3.42	147*b*	3.34	141*ab*c	8.12	137*c*	1.93	165*a*	14.7	<0.001	0.780	0.056
	BC fat	66.6*b*	5.71	70.3*b*	6.22	84.8*a*	8.77	73.3*ab*	3.08	79.2*ab*	15.0	0.014	0.941	0.645
	SQ fat	147*b*	7.28	153*b*	8.13	146*b*	13.9	201*a*	3.92	162*b*	24.9	<0.001	0.872	0.242
	IM fat	60.6	3.86	59.3	4.39	64.1	8.00	67.3	2.07	49.3	14.5	0.155	0.575	0.542
Flank	Lean	484*a*	13.2	468*ab*	14.1	414*b*c	20.6	440*c*	10.0	466*ab*c	33.7	0.007	0.262	0.428
	Bone	8.20*a*	0.49	7.66*ab*	0.54	5.66*ab*c	0.97	6.24*c*	0.33	5.64*b*c	1.64	0.004	0.837	0.353
	IM fat	508c	13.0	524*b*c	13.9	581*ab*	20.7	554*a*	9.97	529*ab*c	33.8	0.004	0.278	0.390
Chuck	Lean	626*a*	9.58	614*a*	10.4	602*ab*	14.9	588*b*	5.22	610*ab*	25.4	0.012	0.951	0.334
	Bone	136*a*	2.49	136*a*	2.72	132*ab*	5.11	127*b*	1.65	126*ab*	8.96	0.008	0.144	0.514
	BC fat	11.4	0.93	12.1	0.91	8.8	2.18	12.1	0.54	13.0	3.91	0.852	0.476	0.588
	SQ fat	59.1*b*	3.47	64.1*b*	3.80	69.2*ab*	6.02	77.8*a*	1.88	63.6*b*	10.6	<0.001	0.576	0.470
	IM fat	168*b*	7.22	174*b*	7.91	186*ab*	11.7	195*a*	3.88	188*ab*	20.3	0.025	0.767	0.231
Rib	Lean	524*a*	10.1	510*a*	11.3	485*ab*	19.5	470*b*	5.54	504*ab*	33.1	<0.001	0.857	0.833
	Bone	173	5.32	177	6.32	178	12.3	165	3.13	174	21.4	0.438	0.834	0.721
	BC fat	28.3	1.63	29.2	1.86	29.3	3.03	29.9	0.91	28.2	5.37	0.911	0.875	0.622
	SQ fat	108c	5.59	115*b*c	6.13	122*ab*c	9.53	149*a*	2.97	132*ab*	16.8	<0.001	0.657	0.303
	IM fat	164*b*	4.86	168*b*	5.32	184*ab*	10.4	185*a*	2.82	163*b*	18.6	0.004	0.795	0.506
Plate	Lean	457*a*	11.9	444*ab*	13.0	423*ab*	19.2	417*b*	6.59	450*ab*	33.0	0.037	0.935	0.427
	Bone	116*a*	2.55	113*a*	2.49	111*ab*	6.06	100*b*	1.43	109*ab*	10.9	<0.001	0.519	0.494
	BC fat	101	4.49	103	4.92	100	8.30	106	2.77	100	14.4	0.796	0.968	0.211
	SQ fat	53.6*b*	3.26	60.2*ab*	3.62	70.3*ab*	6.45	68.1*a*	1.94	68.5*a*	11.3	0.004	0.132	0.015
	IM fat	275*b*	8.62	280*b*	9.56	293*ab*	15.4	310*a*	5.17	272*b*	26.7	0.004	0.509	0.680
Brisket	Lean	458*a*	8.00	440*a*	8.85	430*ab*	15.4	414*b*	4.20	434*ab*	27.6	<0.001	0.902	0.645
	Bone	148	5.07	144	5.63	135	8.87	134	2.91	149	15.0	0.107	0.407	0.050
	BC fat	25.4	2.58	27.0	2.84	40.7	4.95	27.5	1.46	20.0	8.75	0.311	0.649	0.722
	SQ fat	147	10.3	156	11.19	184	16.7	173	6.78	162	28.3	0.140	0.189	0.199
	IM fat	221*b*	8.35	233*ab*	9.14	213*ab*	14.4	251*a*	4.68	231*ab*	25.0	0.019	0.393	0.128
Shank	Lean	472*ab*	7.83	471*ab*	8.50	477*ab*	11.8	454*b*	4.46	488*a*	19.6	0.026	0.136	0.069
	Bone	377	7.00	368	7.66	353	12.4	358	4.24	355	20.8	0.135	0.217	0.776
	IM fat	150*b*	8.56	163*b*	8.99	175*ab*	12.5	188*a*	7.24	155*b*	19.8	<0.001	0.707	0.734

[z]Ps, production system; Imp, implant strategy; Cn, continental; Br, British.
BC, body cavity; SQ, subcutaneous; IM, intermuscular.
a–c Values in the same row with different letters are significantly different ($P < 0.05$).
Only interactions with at least one trend ($P < 0.1$) or significant effect ($P < 0.05$) for any of the traits were presented in the table.

Therefore, it seems clear that, besides the enhanced performance and the potential increase in REA, the effects of β-adrenergic agonists on beef carcass traits are minimal, especially regarding fatness and marbling scores due to its lack of effect on adipose tissue. Moreover, the combination of β-adrenergic agonists with different breed-crosses, production systems or hormonal implants did not modify any of these effects.

Several authors have reported differences in carcass traits among breeds and breed-crosses (Wheeler et al. 1997; Albertí et al. 2008; Goonewardene et al. 2009; Navajas et al. 2010; Prieto et al. 2010). In the past, the percentage of Continental breeds used in North America was higher due to their greater performance values, large rib eye areas and high lean to fat ratio (Amer et al. 1992). Nowadays, the percentage of British breeds has increased in the commercial feedlots due to their better maternal traits and high carcass quality (Amer et al. 1992). In the present study, increasing the percentage of British breeds in the breed-cross led to an increase in grade fat and a decrease in estimated yield, although REA was higher in carcasses from steers with $>75\%$ Continental influence compared with carcasses from steers with 50–75% British influence. Other studies have also reported greater carcass fatness from crosses with high Angus (British) percentage compared with Charolais or Limousin (Continental) breeds (Wheeler et al. 1997; Prieto et al. 2010). The optimal slaughter weight varies widely among cattle breeds depending on how rapidly they mature, which influences the fat deposition during the finishing period (Albertí et al. 2008). Goonewardene (2009) observed that, in the Continental breed cross, the growth rate for muscle was much higher than the growth rate for fat, while in British breed-cross the effect was opposite. Thus, these authors suggested that British breeds could be slaughtered $\sim$30 d earlier than the Continental in order to increase the proportion of muscle and decrease the proportion of fat in the carcass. In the present study, the slaughter weight was similar for all the breed-cross combinations. Under these conditions, another important attribute for carcass merit, marbling score, was also affected by the breed-cross. A contribution of British breeds $\geq 50\%$ increased the carcass marbling score values up to 37% compared with carcasses from steers with a larger contribution of Continental breeds. This is one of the reasons for the wide use of a high percentage of British breeds in the commercial breed-crosses in Canada. However, in the present study, this difference disappeared when animals were treated with hormonal implants. An interactive effect between breed-cross and implant strategy was observed, since no effect was observed for carcasses from mainly Continental steers. Therefore, the higher marbling advantage from using British breeds seems to be exclusive to non-implanted production systems, while implanted steers from any of the breed-crosses used in this study would produce carcasses with similar marbling scores.

Carcass Composition

The main effect observed in the dissection of the whole carcass from calf-fed and yearling-fed steers was a decrease in the proportion of bone. That same effect was observed in different primal cuts. Most studies comparing these two production systems report information regarding carcass grading or composition of longissimus dorsi muscle (Brewer et al. 2007; Griffin et al. 2007; Winterholler et al. 2008). However, fewer studies have reported differences in carcass cut-out and dissection between calf-fed and yearling-fed production systems. Compared with bone, muscle and fat are later developing tissues. Therefore, older animals (yearling-fed steers) will present a lower relative content of bone. However, a higher proportion of lean accompanying the decrease in proportion of bone was only observed in two carcass primals, the chuck and shank, from yearling-fed steers. Moreover, the few effects observed on fat depots showed a slight decrease in the relative content of adipose tissue of carcasses from yearling-fed steers. Kean and Allen (1998) did not find any difference in dissection values of carcasses from bulls produced using different production systems (age $\times$ diet). Dolezal et al. (1993) also reported a lack of effect on muscle percentage when calf-, yearling- and long-yearling-fed steers were compared. They only reported differences for fat and bone percentages, an increase and decrease, respectively, in carcasses from long-yearling-fed steers. The maturity type of the animal, which is influenced by the breed, is also closely related to the development of the different tissues (Butterfield 1966). However, no interaction was observed between the production system and the breed-cross or any other factor (implant or β-agonist strategies) in the present study. Thus, the results suggest that the production of calf-fed steers, although resulting in lighter carcasses, would produce similar proportions of primals and lean meat compared to yearling-fed steers.

Steroidal implants lead to gene expression of growth-enhancing protein hormones (Gorski et al. 1990). As a result, carcass lean increases, as previously reported by several authors (Bruns et al. 2005; Reinhardt 2007). However, these same authors, as previously commented, have suggested that the increase in total lean may also result in a decrease in adipose tissue deposition. These two effects were observed for total lean, body-cavity and intermuscular fat in the present study. In other studies (Duckett and Andrae 2001; Smith et al. 2007), no effect was observed in the fat content in longissimus muscle when absolute values were analyzed. Thus, it was suggested that the lower marbling reported by many studies when using hormonal implants could be due to a dilution effect of the same amount of fat in a larger REA (Duckett et al. 1999). In the present study, hormonal implants resulted in heavier carcasses. Nevertheless, no effect was observed for REA. Furthermore, when the relative weights of the different primals were compared, no implant effect was observed. Another interesting finding was that, for important primals such as sirloin butt and short-loin, a decrease in body-cavity and intermuscular fat occurred while the lean content was not modified by the hormonal implants. As reported by Juárez et al. (2012) with additional data from the present study, absolute intramuscular fat content was also lower in muscle from implanted animals. This finding does not support the ‘‘fat dilution effect’’ theory and would be more supportive of the ‘‘decoupling’’ theory proposed by Bruns (2005) and Reinhardt (2007). In the chuck and the flank, however, the lean content increased while the intermuscular content decreased, as suggested by previous studies. All these effects were similar for calf-fed and yearling-fed steers, as indicated by the lack of interaction between production system and implant effects.

The use of ractopamine during the finishing period had no effect on cut-out and dissection values. In previous studies (Bryant et al. 2010), a lack of effect from ractopamine supplementation on fat thickness and lean maturity has been reported. Moreover, minimal interactions between β-adrenergic agonist and production system, implant strategy or breed-cross have been reported previously for carcass merit traits (Gruber et al. 2007; Winterholler et al. 2007; Scramlin et al. 2010).

In a large study with 888 carcasses analyzed, Wheeler et al. (1997) found significant differences for carcass composition among different genotypes (sire breeds). Continental breeds had greater lean and lower fat content than British breeds. Continental breeds also produced carcasses with higher percentages of total retail product. In the same study, cut-out percentages were also affected by the breed. For instance, Continental breeds had heavier rounds than British breeds, as also observed in the present study. In the same way, using both traditional dissection and computed tomography, Navajas et al. (2010) and Prieto et al. (2010) reported a higher percentage of lean and a lower percentage of fat in carcasses and retail cuts, respectively, from Continental (Limousin) compared with British (Angus) cross-bred steers. In a different study comparing 15 European breeds (Albertí et al. 2008), similar differences were observed between Continental and British breeds for dissection values, and Continental breeds were found to have longer carcasses with a greater blockiness index (kg cm^{-1}), even if no difference was reported for conformation scores. When the primal cuts from different Canadian composites were compared, Goonewardene et al. (2009) reported greater growth rates for the adipose tissue of the flank, chuck, rib, plate, brisket and shank from Continental compared to British breed-crosses. Many years ago, Berg and Butterfield (1976) already stated that, although some authors may find differences on muscle growth patterns among breeds, these are usually due to differences in breed maturity. In the present study, the greater differences in carcass composition (lean, bone and fat content) have been observed between >75% Continental and 50–75% British and, sometimes, 50:50 Continental:British steers. Hybrid vigor could explain, to certain extent, why the differences were not greater between the two purest populations (>75% Continental vs. >75% British). Cow size and individual bull performance could also have influenced carcass composition.

In conclusion, in addition to the expected reduction in live and carcass weight, reducing age at slaughter would not have a negative impact on Canadian beef carcass merit traits, such as marbling, carcass cut-out or cutability. The use of aggressive implant strategies appears to decrease the advantage in carcass quality (i.e., higher intramuscular fat) obtained by using a high percentage of British breeds in commercial breed-crosses. Furthermore, hormonal implants also had a negative effect on the carcass quality grade frequencies of yearling-fed steers. On the contrary, neither these factors nor the use of β-adrenergic agonists had any interactive effect on the calf-fed production system.

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