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Running title: Muscle retail characteristics of cull cows**Muscle profiling of retail characteristics within the Canadian cull cow grades**

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Roberts, J., Rodas-González, A., Juárez, M., López- Campos, Ó., Larsen, I. L., and Aalhus, J. L. 2016. **Muscle profiling of retail characteristics within the Canadian cull cow grades**. Can. J. Anim. Sci. **XX**:00-00. Composition, drip loss, objective colour and measures of colour stability during three days of retail display were benchmarked for 11 muscles obtained from youthful beef and cow carcasses (n=120). Traits were compared between the muscles from cow carcasses, graded using the Canadian grading system (D1, D2, D3, D4; > 50% ossification), and muscles from A/AA youthful carcasses (identified as under 30 months of age based on dentition and < 50% ossification, UTM or over thirty months based on dentition, but <50% ossification, OTM). Muscles from D3 graded carcasses had a lower intramuscular fat content, aside from these carcasses, all other cow carcass grades had muscles with either equivalent or higher fat content. Most muscles from cow carcasses had consistently darker meat (lower L^* ; $P < 0.05$), yet the colour stability measures were similar between most muscles from cow graded carcasses and UTM over 3 d of retail display. Notably, the infraspinatus (flat iron) from cow carcasses did not differ in colour from UTM beef. In general, OTM carcasses had similar colour and composition attributes to the UTM beef. Given the retail performance of muscles from cow carcasses, opportunities may exist to better utilize specific muscles from these carcasses.

Key words: cull cows, muscle profiling, colour, proximate composition, colour stability

Abbreviations: UTM, under thirty months; OTM, over thirty months; RF, *rectus femoris*; GM, *gluteus medius*; ST, *semitendinosus*; SM, *semimembranosus*; BF, *biceps femoris*; LT, *longissimus thoracis*; LL, *longissimus lumborum*; PM, *psoas major*; IF, *infraspinatus*; TB, *triceps brachii*; TM, *teres major*; WHC, water holding capacity; DMB, deoxymyoglobin; OMB, oxymyoglobin; MMB, metmyoglobin

INTRODUCTION

The export of Canada mature graded carcasses (> 50% ossification) from Canada to the United States was disrupted from 2003 to 2007 due to a single case of BSE in May 2003. Since then, the Canadian beef industry has been investigating opportunities to expand domestic markets and improve the carcass value for mature cows. Potential opportunities for improving the value of mature carcasses have been explored in a recent study (Rodas-González et al. 2013), where cow carcass traits (including: lean yield, marbling at the grade site, and rib-eye area) were characterized from mature carcasses graded according to Canadian standards, in the *longissimus thoracis* muscle. Rodas-González et al. (2013) observed D1 and D4 Canada carcass grades had the most marbling and least yellow fat presence at the grade site compared to youthful carcasses (AA/A carcass grades over/under 30 months of age). Consumers use marbling as an indicator of quality and palatability (Killinger et al. 2004), therefore there may be some opportunities to improve the marketing of cow meat at retail. However, despite high levels of desirable marbling, cow meat, from some cuts tends to be darker in lean colour (Boccard et al. 1979; Rose et al. 2010).

To date, much of the research conducted on mature cow meat quality has focused on improving carcass traits, lean colour and palatability of mature cows through increasing the nutritional plane before slaughter (Boleman et al. 1996; Brown and Johnson 1991; Cranwell et al. 1996; Rider-Sell et al. 2004; Schnell et al. 1997; Stelzl et al. 2007; Weber et al. 2012). However, research has been conducted to profile quality attributes among the United States maturity grades C/D and E (Jones et al. 2004). Within the Canadian cow carcass grades however, there has been limited research completed to

identify muscles with characteristics similar to youthful beef. As such, there may be opportunities to improve cow carcass value if quality for traits associated with consumer purchase intent (e.g. colour) in muscles from cow carcasses are similar to those from youthful beef. This information is necessary in order to make improved decisions regarding the cow carcass grades and muscles used for merchandisable cuts or for manufacturing beef products (e.g. ground beef).

Currently, mature cow carcass grades (D1, D2, D3 or D4) in Canada are assigned based on the extent to which spinal processes and ribs have ossified (i.e. >50% ossification, a carcass receives a D grade) (Canada Gazette 2007; Canadian Beef Grading Agency 2016). These mature carcasses are further delineated: where D1 must have excellent muscling with white or amber fat; D2 have medium to excellent muscling, but are allowed yellow fat; D3 carcasses have poor muscling; and D4 carcasses are overfat, with >15mm of backfat. It is expected the differentiation between the mature grades results in differences in meat quality. In order to effectively market cow meat, processors need to ensure consistency in quality. As such, utilizing the mature grades may allow identification of cuts suitable for retail marketing.

In addition to mature D grades, carcasses are separated from youthful beef where more than two permanent incisors have erupted, regardless of ossification scores. In these carcasses (over thirty months: OTM, by dentition), specified risk materials must be removed from the carcass before further processing. It has been observed that dentition scores are not well correlated with ossification scores (Lawrence et al. 2001). As such, some carcasses determined to be OTM by dentition are considered youthful by

ossification. The meat quality attributes from these carcasses are currently unknown as well.

The objective of this research was to benchmark the physical, chemical and colour attributes under simulated retail conditions from a number of front, mid and hind muscles of cows (Canada D1, D2, D3, D4; > 50% ossification; OTM by dentition but <50% ossification) compared to youthful carcasses (Canada A/AA grades under 30 months of age based on dentition and < 50% ossification, UTM).

MATERIALS AND METHODS

Handling and slaughtering of animals at the commercial abattoirs followed the humane practices described in the Canadian Council of Animal Care Guidelines (2009).

Carcass selection and fabrication

This experiment was conducted using 120 commercial carcass sides from the four Canadian mature cow grades (>50% ossification; D1, D2, D3, D4, n=21 of each grade) compared to Canadian youthful grades (<50% ossification with two or fewer permanent incisors, quality grade A/ AA, UTM; n=18). In addition, a group was included that were over thirty months of age by dentition, but youthful by ossification (<50% ossification with more than two permanent incisors, OTM; n=18). Full details of carcass selection, evaluation and fabrication procedures were described by Rodas-González et al. (2013).

Procurement of samples

Carcass sides were shipped to the AAFC Research and Development Centre (Lacombe, AB) by way of refrigerated truck. Following delivery, carcasses were weighed and kept in a carcass cooler at 2°C with a wind speed of 0.5 m·s⁻¹ until 6 - 7 d *post-mortem*. From the right carcass sides, 11 muscles were removed for evaluation of quality

characteristics from the hind [*rectus femoris* (RF; part of the knuckle), *gluteus medius* (GM; top butt), *semitendinosus* (ST; eye of round), *semimembranosus* (SM; part of the inside round), *biceps femoris* (BF; outside round)], mid [*longissimus thoracis* (LT; rib-eye), *longissimus lumborum* (LL; striploin), *psoas major* (PM; tenderloin)] and front [*infraspinatus* (IF; flat iron), *triceps brachii* (TB; part of the clod), *teres major* (TM; petite tender)]. The pH and temperature were measured (Visor Palm Pilot and a Fisher Scientific Accumet Module with handspring software installed and equipped with an Orion Ingold electrode, Udorf, Switzerland). Individual muscle weights were recorded (Sartorius CP1600IS, Fisher Scientific, Mississauga, ON), then muscles were vacuum packaged (Multivac AGW, Multivac Inc., Kansas City, MO) and kept in a cooler for 14 d of ageing at 2°C with wind speeds of $0.5\text{m}\cdot\text{s}^{-1}$. After the ageing period, the final weight of each muscle was measured for determination of purge loss during vacuum packaged storage.

Muscles were cut to a uniform shape and two steaks (2.5 cm thick) were obtained from each muscle perpendicular to the fibre grain; with the exception of the TM and IF. The first steak was designated for steak drip-loss and the second for retail colour evaluation. The remaining portions of all muscles were retained for proximate analyses. Due to the small size of the TM, one steak (5.0 cm) was cut out from the centre of the muscle and cut as a butterfly steak. One further (2.5 cm) steak was cut from the proximal end of the remaining muscle for drip-loss determinations. The IF was cut parallel to the fibre direction down the centre seam of connective tissue. The proximal end was used for retail evaluation. The superficial area of the muscle was cut into two portions with the

proximal portion used for drip-loss and the remainder of the distal portion used for proximate analyses.

Proximate analysis

Portions of all muscles not cut into steaks for retail and drip loss evaluation were polybagged and placed in a cooler overnight. The next day, samples were trimmed of all external fat and connective tissue then ground three times (Butcher Boy Meat Grinder Model TCA22 with a 1/8-inch grind plate; Lasar Manufacturing Co., Los Angeles, CA) before subsampling for proximate analyses. Moisture content was determined as the weight lost from 100g of ground tissue after heating at 102°C for 24-h in a gravity convection-drying oven (VWR Scientific Model 1370FM, Mississauga, ON). Dried sample was finely ground and analyzed for crude fat content (Method 960.39: Association of Official Analytical Chemists 1995) using petroleum ether extraction (Tecator Soxtec System HT-1043, Tecator Ltd., Hoganas, Sweden).

Colour evaluation and steaks drip loss

Steaks used for the determination of drip loss were weighed and placed into a polystyrene tray with a dri-loc pad and over-wrapped with oxygen permeable film (8000 ml m⁻² 24 h⁻¹ vitafile choice wrap, Goodyear Canada Inc.). Packages were stored for 3 d at an average temperature of 3.5°C in coffin-style retail display case (Hill Refrigeration of Canada Ltd., Barrie, ON, Canada). Following three days of retail display, a final weight of the steak was recorded and used to calculate drip loss.

Steaks used for retail evaluation were packaged and placed in retail display in the same manner as described above. Retail displays were under fluorescent room lighting for 12 h·d⁻¹ as described in Jeremiah and Gibson (2001). Samples were organized into the

display case to ensure known differences in temperature gradients were balanced amongst grades.

Objective colour measurements were obtained from the surface of meat using a Minolta[®] CM-2002 Spectrophotometer (Minolta Canada Inc., Mississauga, ON, Canada) with a 3 mm diameter measuring aperture, illuminant C, and 2° standard observer. Instrument calibrations were completed before use for each sampling period according to the manufacturer's instructions. Meat colour was measured at three different locations across the surface of steaks at 1 hour post-bloom (1 d) and following 3 d of the retail display. CIE L^* (lightness), a^* (redness) and b^* (yellowness) values were measured (CIE 1976). The a^* and b^* values were transformed to colour descriptor as hue angle ($H_{ab} = \arctan[b^*/a^*]$) and saturation as chroma ($C_{ab} = [a^{*2} + b^{*2}]^{0.5}$). Additionally, change in objective colour (ΔE) was calculated between colour measures obtained at 1 d and 3 d retail display (Luo et al. 2001).

In order to determine the calculated pigment content, the meat spectral reflectance readings were also collected and converted to reflex attenuance (Shibata 1966). Interpolation of isobestic points for 473, 525, 572, and 730nm were determined to calculate $a_1 = (A^{572} - A^{730}) / (A^{525} - A^{730})$ and $a_2 = (A^{473} - A^{730}) / (A^{525} - A^{730})$. These values were used to find relative contents of metmyoglobin (MMB) ($MMB = 1.395 - a_1$), deoxymyoglobin (DMB) ($DMB = 2.375 * [1 - a_2]$) and oxymyoglobin (OMB) ($1 - [MMB + DMB]$), according to Krzywicki (1979). Proportions of metmyoglobin after 3 d of retail display were used for analysis. Change in metmyoglobin and oxymyoglobin values (ΔMMB or ΔOMB ; respectively) were calculated as the difference between 1 and 3 d

retail display. Positive and higher values of Δ MMB or Δ OMB indicate lower MMB or OMB levels at 3 d than 1 d of the retail display.

Afterwards, steaks were subjectively evaluated for percent surface discolouration, lean colour score, and amount of marbling by 6 trained panellists. Panellists scored each factor according to descriptive scales developed using Munsell colour chips: lean colour (1 = white; 2 = pale pink; 3 = pink; 4 = pale red; 5 = bright cherry red; 6 = slightly dark red colour; 7 = moderately dark red; 8 extremely dark red), percentage surface discolouration (1 = 0%; 2 = 1 to 10%; 3 = 11 to 25%; 4 = 26 to 50%; 5 = 51 to 75%; 6 = 76 to 99 % and 7=100% discolouration), and amount of marbling (1 = devoid, 2 = slight; 3 = small, 4 = moderate and 5 = abundant).

Statistical analysis

Data were analyzed using the MIXED model procedures of SAS (Cary, NC) version 9.2 (SAS 2009). Measured variables related to purchase quality (muscle weight, moisture, fat, drip loss, L^* , chroma, hue, ΔE between 1 and 3 d retail display, subjective discolouration scores after 3 d retail display, and proportion of MMB at 3 d) from each muscle were compared between UTM and the cow carcass grades separately using orthogonal contrasts. When a trait measured from a cow carcass grade was significantly different from the UTM value ($P < 0.05$), the relative difference was presented in the results. Within the UTM animals, each trait was analyzed between the muscles, with individual carcass included as a random variable.

For all measured traits least squares means were separated between all grades (F test, $P < 0.05$) using least significant differences generated by the PDIFF option. Individual carcasses were included as a random factor. The denominator degrees of

freedom were adjusted using the Kenward-Roger procedure. The results for this analysis are presented in the supplementary tables.

RESULTS

The average quality traits and mean separation for the different muscles from the UTM youthful beef carcasses with AA/A marbling levels used in the present study are presented in Table 1. Statistical contrasts relative to the corresponding muscle from UTM carcasses were made for OTM carcasses and each of the mature grades (Tables 2-6). Orthogonal contrasts from the mature grades (OTM, D1, D2, D3 and D4) not mentioned in the results were not statistically different ($P > 0.05$) from the characteristics in UTM carcasses.

The IF of the UTM carcasses had the highest levels of fat, while the SM and ST had the lowest (Table 1). Drip loss was higher in the RF and TM than all other muscles ($P < 0.05$). The L^* and hue angle of the ST were higher than all other muscles measured ($P < 0.05$); however, the a^* was highest from the GM ($P < 0.05$). The chroma measured from the SM and the GM were highest among the UTM muscles ($P < 0.05$). For the measures of colour stability in retail display, ΔE was lowest from LT and LL, this was also reflected in lower subjective scores of discolouration and proportion of MMB after 3 d of retail display for these muscles ($P < 0.05$).

Muscles from OTM carcasses (Table 2) had similar characteristics to the muscles from UTM carcasses in many quality traits. Fat contents of the BF and IF muscles from OTM carcasses were higher than UTM carcasses ($P < 0.05$). Drip loss was lower in the RF of OTM carcasses ($P < 0.05$). For the measures of objective colour, L^* was lower in the RF and PM ($P < 0.05$), a^* was higher in the LT and LL ($P < 0.05$). Chroma was higher

in the LT; hue was lower in the RF, LT and LL ($P < 0.05$). Additionally, there were no significant differences between OTM and UTM carcass muscles in objective colour change (ΔE) over time in retail, nor in the MMB content measured after 3 d in retail ($P > 0.05$).

The GM, LL and IF of D1 cows (Table 3) were heavier than those from UTM carcasses ($P < 0.05$). Relative to UTM beef, the LT, LL and IF of D1 carcasses had lower moisture content ($P < 0.05$). The same muscles of the D1 carcasses were higher in fat content ($P < 0.05$). Drip losses were lower from D1 cows in the RF, GM and TB ($P < 0.05$). In terms of colour, all muscles, except the IF, from D1 carcasses had a lower L^* ($P < 0.05$). The ST, LT, and LL all had higher a^* ($P < 0.05$). The ST of D1 cows had a higher chroma ($P < 0.05$); all other muscles measured from D1 carcasses were not different from UTM carcasses ($P > 0.05$). The hue angles of all but the BF, PM and IF were lower in D1 cow carcasses than in UTM ($P < 0.05$). After three days of retail display, subjective surface discolouration scores and ΔE were not significantly different between D1 and UTM carcasses in any muscles measured ($P > 0.05$). The MMB after 3 d retail ageing were higher in the ST and LL of the D1 cow carcasses ($P < 0.05$).

From the contrasts between the D2 and UTM carcasses (Table 4), the SM and BF weighed less from D2 carcasses ($P < 0.05$). There was lower moisture content in the LT and IF of D2 carcasses compared to UTM carcass muscles ($P < 0.05$). The LT, LL, PM, TB and IF of D2 cow carcasses had higher fat content than UTM carcasses ($P < 0.05$). Drip losses relative to UTM carcasses were lower in the ST, RF, GM, TB, IF and TM of D2 graded carcasses ($P < 0.05$). Similar to the D1, contrasts with L^* , all muscles of D2 carcasses except the IF were darker ($P < 0.05$). The ST, LL from D2 carcasses had higher

a^* ($P < 0.05$); while a^* from the PM was lower. For chroma of muscles from D2 carcasses, the SM, RF, GM and PM were lower than those of UTM carcasses ($P < 0.05$). The hue for the SM, ST, RF, GM, LT, LL, TB and TM muscles from D2 carcasses was lower than in UTM carcasses ($P < 0.05$). Subjective surface discolouration scores and changes in objective colour after three days under retail conditions were not significantly different between D2 and UTM carcasses in any of the muscles measured ($P > 0.05$). MMB in the LT and LL of D2 cows was higher than in the UTM carcasses ($P < 0.05$).

D3 carcasses (Table 5) had a higher weight for the GM muscle than UTM carcasses ($P < 0.05$). Moisture content of all muscles measured from D3 carcasses was higher than the muscles of UTM carcasses ($P < 0.05$), whereas the fat content for D3 muscles was lower than UTM carcasses in all but the SM and ST muscles ($P < 0.05$). The drip losses from all the muscles of the D3 cows except in the SM, were lower than UTM muscles ($P < 0.05$). The L^* of D3 muscles were lower than UTM muscles in all but the IF. The same muscles from D3 cows except for the ST had a lower a^* ($P < 0.05$), the chroma for all of these muscles and the ST was lower than UTM muscles ($P < 0.05$). With the hue, the SM, ST, RF, GM, LT and LL were lower in the muscles of the D3 carcasses ($P < 0.05$). Objective colour change over 3 days in retail display was higher in the LL ($P < 0.05$), but lower in the TM of D3 carcasses compared to UTM carcasses ($P < 0.05$). For subjective surface discolouration scores the LT and LL of D3 carcasses following 3 days of retail ageing were higher than the same muscles in the UTM carcasses ($P < 0.05$).

D4 carcasses (Table 6) had lighter weights in the SM and BF muscles ($P < 0.05$). Moisture content of the ST, LT, LL, PM and IF from the D4 carcasses were lower than in

UTM carcasses ($P < 0.05$). All muscles from D4 carcasses had higher fat content ($P < 0.05$). Drip losses were lower in the RF and the TB ($P < 0.05$). Except for the IF, all muscles from D4 carcasses had lower L^* ($P < 0.05$). The ST and LT had a higher a^* ($P < 0.05$). The chroma of the RF was lower in D4 carcasses than in UTM carcasses ($P < 0.05$). Hue angle was lower in all but the BF, PM and IF of D4 carcass muscles ($P < 0.05$). MMB was higher in the LT and LL after 3 days of retail ageing ($P < 0.05$). There was a higher change in objective colour in the LL from D4 carcasses over the retail ageing ($P < 0.05$); while no subjective colour scores were significantly different from UTM carcasses ($P > 0.05$).

DISCUSSION

UTM muscle profiling

Extensive muscle profiling research has been conducted on various aspects of meat quality and muscle properties from youthful carcasses (Calkins 2001; Kirchofer et al. 2002; Von Seggern et al. 2005). This area of research has characterized aspects of quality in different cuts of meat, particularly from the chuck and round to improve carcass value. In agreement with the present study, McKenna et al. (2005) found among the 17 muscles they surveyed, the ST and SM are among the most red at 1 d retail display.

The L^* , a^* , chroma and hue varied between the muscles in UTM carcasses. This can likely be attributed in part to the oxidative state and concentration of myoglobin in the different muscles (Mancini and Hunt 2005). These differences between muscles in turn are associated with fibre type composition within muscles (Aalhus et al. 2009).

Muscle weights

D2 carcasses are graded as such, in part due to minor deficiencies in muscling; the required muscling in D2 carcasses as stipulated by the grade regulations is “medium to excellent” (Canadian Beef Grading Agency 2016). In the present study this deficiency in muscling appears to be reflected in the lower muscle weights in the SM and BF, as individual muscle weights have a strong relationship with carcass weight ($r = 0.83$) (Greiner et al. 2003). However, the muscle weights were not lower in D3 carcasses. D3 carcasses would be expected to have more deficient muscling than D2 carcasses given the lower muscling requirements for receiving a D3 grade. Thus, deficiencies in carcass muscling did not result in lower weights of muscles. Instead the emaciated appearance of D3 carcasses likely reflects lower intermuscular and subcutaneous fat deposition. Cold carcass weights for the carcasses used in the present study have been published previously; these results showed D3 carcasses were lighter than other cow grades, but were not significantly different from UTM carcass weights (Rodas-González et al. 2013). Overall however, most muscle weights were not different between cow grades and UTM carcasses.

Fat and moisture content

The higher fat content measured from muscles of the D4 grades matched expectations as D4 grades are assigned to carcasses from overfat cows (Canadian Beef Grading Agency 2016). Conversely, D3 carcasses were lower in fat content; as expected (Canada Gazette 2007; Canadian Beef Grading Agency 2016). Intramuscular fat content of the LT is well correlated with marbling score at the grade site (Li et al. 2006; Mello et al. 2012). The pattern of intramuscular fat content in the muscles was similar to the marbling score differences observed at the grade site in the same animals (Rodas-

González et al. 2013), where the D4 grade obtained the highest marbling scores (543), followed by D1 (517), D2 (491), and OTM (448), next by UTM (424) and finally D3 with the lowest marbling score (272).

Under Canadian law, grading of carcasses is optional. While youthful grades (A's and B's) may allow packers to better market beef at retail, the benefit to grading cow carcasses may not be immediately obvious. The present results suggest compositional differences exist between the different D grades; as such, segregating carcasses among the D grades may allow better utilization of the different grades to meet processing needs (different value-added products).

In addition to the overall high fat content in muscles from D4 carcasses, fat content was higher in some muscles from D1, D2 and OTM carcasses. Intramuscular fat tends to accumulate in cattle over a longer period than lean and bone (Berg and Butterfield 1968; Robelin 1986). This might indicate why aside from D3 carcasses, fat content was higher in some mature carcass muscles. Among the cow graded carcasses in the present study the IF consistently appeared to accumulate the highest levels of fat. Consistent with the present results, Hawrysh and Price (1981) found LL intramuscular fat levels from cull cows segregated in three maturity classes (physiological age of youthful, intermediate and mature; based on the extent of ossification) were higher from intermediate and mature animals (2.98 and 2.79% respectively), but lower in youthful animals (2.36%). Higher fat content in meat can result in improved flavour (Killinger et al. 2004). Additionally, fat content and composition contributes to the species specific flavour intensity (Kerth and Miller 2015). As such, aside from the muscles from D3 carcasses, the components of flavour associated with higher fat content should be

equivalent to, or improved in meat from cows relative to youthful beef. If other eating quality attributes (e.g. tenderness) are maintained in some muscles of cull cow carcasses, these could be sold as a differentiated product with more intense flavour. This has been done elsewhere, for example, steaks from Galician Blonde breed cows are being sold as a specialty product (after extended dry-ageing) in some high end restaurants (Cumming 2015).

Drip loss

The drip losses from cow meat were either lower or not different than muscles from UTM carcasses. High drip loss in packaging tends to be avoided by consumers (Apple and Yancey 2013). Therefore, at least in this respect, meat from cow carcasses would likely not have lower consumer acceptability. Drip losses are an indication of water holding capacity (WHC) in meat (Apple and Yancey 2013). Patten et al. (2008) observed no differences in WHC between cull cows and youthful carcasses for most muscles examined. In contrast, Hawrysh and Price (1981) demonstrated that WHC for roasts from physiological youthful and intermediate carcasses were higher than roasts from mature carcasses. The inconsistency between the present results and previous research suggests the relationships between WHC and carcass maturity are somewhat unclear. The carcasses used in the present study represent a wide range of compositions from very lean to overfat, which could have a greater effect on WHC than maturity alone. Additionally, differences between studies may in part reflect the different methods of evaluating WHC. Drip loss measured in the present study, only considers moisture loss of fully-fabricated retail cuts in packaging but does not consider moisture loss through the chilling and ageing prior to this point.

Colour and retail display

Some colour deficiencies were present across all mature cow carcass (D) grades. Most evidently, the meat from nearly all muscles from the cow carcass grades is darker (reflected in a lower L^*). Darker meat from mature cows has been observed previously (Boccard et al. 1979; Rose et al. 2010). Although, meat from cow carcasses does not appear to darken further with increased chronological ages, Xiong et al. (2007) found no differences in lean colour between meat from carcasses of animals of chronological ages from 3-12 years old. The shift from anaerobic to oxidative fibre types, resulting in higher concentration of muscle myoglobin with advancing maturity (Maltin et al. 1998; Moon et al. 2006) has been suggested as the mechanism for darker beef in older animals. Generally, light beef is preferred by consumers (Font-i-Furnols and Guerrero 2014), which indicates that cow meat from most muscles measured here may have lower acceptability in a retail setting, without utilizing a packaging intervention (Hunt et al. 2004; Yang et al. 2016). In addition to darker meat, D3 carcasses had a lower chroma in all muscles but the IF; losses in saturation were less evident from the other grades. The cause of lower chroma in meat from D3 cows is unclear from the present results but may be due to the lower intramuscular fat and higher moisture content.

Many muscles of D graded carcasses also had a lower hue and higher a^* (more red) than UTM meat, although the difference was not as consistently observed across muscles as in the lightness (L^*). Among the D grade carcasses the SM, ST, GM, RF, LT and LL had a lower hue. However, among the D3 carcasses, almost all muscles had a lower a^* indicating the change in hue for these muscle was associated with a change in b^* . As pigment content and oxidation state of myoglobin are the major contributing

factors to hue and a^* (Mancini and Hunt 2005); the lower hue and higher a^* observed in these muscles may be reflected in a higher myoglobin content. Moon et al. (2006) observed the LL of mature carcasses (>2 years) had a higher myoglobin content than in youthful carcasses (<2 years) (Moon et al. 2006). While a more red meat indicated by the lower hue angle and higher a^* may not be an obvious quality deficit, consumer preference for meat colour is in part based on experience (Font-i-Furnols and Guerrero 2014), therefore a different red hue may not be as acceptable at retail in North American markets.

The colour deficiencies found in many of the mature carcass muscles suggests this meat may not be suitable for retail display. However, as discussed above, compositional differences could contribute to unique flavour for a differentiated product in the restaurant industry where raw lean colour is less important. Despite most muscles showing colour deficiencies, across all cow carcass grades the IF did not appear to have any colour deficiencies. This may indicate the IF from all cow carcasses would be well suited for merchandising rather than used for further processing or value-added products. Previous research has shown, the *infraspinatus* when cut along the seam of connective tissue is a highly tender cut of meat (Calkins 2001).

The OTM carcasses did not appear to have as many quality deficiencies in the measured colour attributes, with darker lean only in the RF and PM. These carcasses were from animals which were determined to be under 30 mo of age by ossification (<50%), but were deemed mature by having more than two permanent incisors. The present results indicate this dentition breakpoint used as a cut off for maturity does not have a strong relationship to quality among carcasses deemed youthful by ossification

scores. Under Canadian regulations, carcasses determined to be OTM by dentition are identified/segregated in the plant and specified risk materials (SRM) are removed prior to further processing. As the OTM carcasses with <50% ossification show similar quality attributes to UTM carcasses, processors could potentially better utilize meat from these carcasses by further differentiating OTM carcasses by skeletal age as well. With the exception of the RF or PM other muscles from OTM carcasses have similar colour attributes to UTM carcasses; hence steaks from these carcasses may be suitable for retail sale.

From D1, D2, D4, and OTM carcasses, meat from most muscles showed similar colour stability to UTM in terms of discolouration, MMB levels and overall change in colour after 3 d of retail display. It has been shown previously that chronological cow age does not appear to have a large influence over colour stability (Xiong et al. 2007). However, in the D3 carcasses five muscles had higher MMB levels after 3 d of retail display. This was only reflected in higher subjective discolouration scores for the *longissimus* (LL and LT) which showed the greatest increases in MMB from D3 carcasses after 3 d. As discussed above, the LL and LT of UTM appear to have relatively high colour stability (Table 1). Thus a large increase in MMB in some surface regions of the LL and LT from D3 carcasses may have crossed a perceptible threshold, resulting in higher surface discolouration scoring. When 60% of myoglobin in a region of meat is in the MMB oxidation state, that area has a brown appearance (Seideman et al. 1984). The lower MMB concentrations than this perceptible threshold in the present study may represent the collection of instrumental colour measures over heterochromatic meat surface. Since the MMB concentrations were calculated based on triplicate samples

across the meat surface, discoloured regions could have >60% MMB, while regions of meat with acceptable colour had a lower proportion of MMB leading to averages below the perceptible threshold. In any case, both MMB and surface discoloration after 3 days retail ageing from the LL and LT of D3 suggest reduced colour stability.

Conclusions

Meat from Canada D grade carcasses is generally darker than youthful beef of A/AA marbling levels in most muscles. However, the IF from the D grade carcasses did not appear to have any colour deficiencies in any of the cow grades. As such, there may be further opportunities for packers to merchandize this cut from cow carcasses. Despite darker lean, many muscles from D grade carcasses had higher intramuscular fat content than in the youthful A/AA carcasses. These carcasses as a result may have an improved palatability. The unsuitable colour for retail display in North American markets without utilizing a packaging intervention, but higher fat content in these muscles may make this meat suitable for value added products. Additionally, muscles from OTM carcasses were similar in appearance and composition to most muscles in the UTM carcasses. While OTM carcasses will have lower value due to the cost of removal of SRM, there may be opportunities to better utilize meat from these carcasses.

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For Review Only

Table 1. Muscle characteristics from UTM beef.

	muscle	weight (kg)	moisture (mg·g ⁻¹)	fat (mg·g ⁻¹)	drip loss (mg·g ⁻¹)	<i>L</i> *	<i>a</i> *	chroma (%)	hue angle (°)	ΔE	subjective discolouration ^a	MMB ^b
hind	SM	4.72 <i>b</i>	749 <i>bcd</i>	13.5 <i>g</i>	32.8 <i>bc</i>	39.48 <i>cde</i>	20.84 <i>bc</i>	25.81 <i>ab</i>	36.06 <i>b</i>	5.21 <i>bc</i>	4.96 <i>a</i>	0.36 <i>cd</i>
	BF	5.58 <i>a</i>	746 <i>cde</i>	21.6 <i>e</i>	25.7 <i>d</i>	39.31 <i>cde</i>	20.71 <i>bc</i>	25.02 <i>bcd</i>	34.04 <i>cdef</i>	6.28 <i>a</i>	4.96 <i>a</i>	0.40 <i>ab</i>
	ST	2.40 <i>f</i>	753 <i>ab</i>	17.3 <i>fg</i>	35.5 <i>b</i>	43.84 <i>a</i>	19.09 <i>e</i>	25.02 <i>bcd</i>	40.24 <i>a</i>	3.65 <i>d</i>	4.27 <i>a</i>	0.29 <i>f</i>
	RF	1.94 <i>h</i>	751 <i>bcd</i>	23.9 <i>de</i>	47.3 <i>a</i>	41.16 <i>b</i>	19.96 <i>cde</i>	24.79 <i>bcd</i>	36.29 <i>b</i>	4.58 <i>cd</i>	4.53 <i>a</i>	0.32 <i>ef</i>
	GM	3.65 <i>c</i>	748 <i>bcd</i>	20.5 <i>ef</i>	35.1 <i>b</i>	40.03 <i>bc</i>	22.11 <i>a</i>	26.82 <i>a</i>	34.36 <i>cd</i>	5.69 <i>ab</i>	4.66 <i>a</i>	0.36 <i>bcd</i>
mid	LT	2.73 <i>e</i>	742 <i>ef</i>	29.2 <i>bc</i>	29.0 <i>cd</i>	38.48 <i>def</i>	19.97 <i>cde</i>	24.11 <i>def</i>	34.11 <i>cde</i>	1.57 <i>e</i>	2.03 <i>b</i>	0.19 <i>g</i>
	LL	3.62 <i>c</i>	740 <i>f</i>	27.4 <i>cd</i>	27.5 <i>d</i>	38.01 <i>f</i>	19.98 <i>cde</i>	24.16 <i>def</i>	34.16 <i>cde</i>	0.98 <i>e</i>	2.22 <i>b</i>	0.19 <i>g</i>
	PM	2.06 <i>gh</i>	746 <i>de</i>	32.8 <i>b</i>	35.4 <i>b</i>	39.65 <i>cd</i>	20.27 <i>bcd</i>	24.30 <i>cdef</i>	33.36 <i>ef</i>	5.87 <i>ab</i>	4.54 <i>a</i>	0.37 <i>bc</i>
front	TB	3.26 <i>d</i>	753 <i>ab</i>	24.2 <i>de</i>	34.1 <i>b</i>	38.31 <i>ef</i>	21.06 <i>b</i>	25.40 <i>bc</i>	33.93 <i>def</i>	4.27 <i>cd</i>	4.73 <i>a</i>	0.33 <i>def</i>
	IF	2.18 <i>fg</i>	752 <i>abc</i>	41.2 <i>a</i>	18.0 <i>e</i>	38.56 <i>def</i>	19.43 <i>de</i>	23.22 <i>f</i>	33.17 <i>f</i>	4.28 <i>cd</i>	4.69 <i>a</i>	0.34 <i>cde</i>
	TM	5.03 <i>i</i>	757 <i>a</i>	20.6 <i>ef</i>	48.2 <i>a</i>	39.88 <i>c</i>	19.43 <i>de</i>	23.74 <i>ef</i>	34.87 <i>c</i>	6.24 <i>ab</i>	4.88 <i>a</i>	0.41 <i>a</i>
average standard error		0.12	2	2.3	1.6	0.54	0.41	0.48	0.42	0.50	0.32	0.02

Note: Least squares means within a column not sharing a common lowercase italic letter were significantly different (*P* < 0.05).

^aSeven point descriptive indicating the approximate percent of meat surface which was discoloured (1 = 0%; 2 = 1 to 10%; 3 = 11 to 25%; 4 = 26 to 50%; 5 = 51 to 75%; 6 = 76 to 99 % and 7=100% discolouration) following 3 d of retail display.

^bProportion of myoglobin in the metmyoglobin oxidative state after 3 d of retail display.

Table 2. Muscle characteristics from OTM carcasses significantly different from the same muscle as UTM beef.

	muscle	muscle weight (kg)	moisture (mg·g ⁻¹)	fat (mg·g ⁻¹)	drip loss (mg·g ⁻¹)	<i>L</i> *	<i>a</i> *	chroma (%)	hue angle (°)	ΔE	subjective discolouration ^a	MMB ^b
hind	SM	-	-	-	-	-	-	-	-	-	-	-
	BF	-	-	+9.4	-	-	-	-	-	-	-	-
	ST	-	-	-	-	-	-	-	-	-	-	-
	RF	-	-	-	-5.6	-2.27	-	-	-1.85	-	-	-
	GM	-	-	-	-	-	-	-	-	-	-	-
mid	LT	-	-	-	-	-	+1.74	+1.55	-1.93	-	-	-
	LL	-	-	-	-	-	+1.58	-	-1.61	-	-	-
	PM	-	-	-	-	-1.57	-	-	-	-	-	-
front	TB	-	-	-	-	-	-	-	-	-	-	-
	IF	-	-	+9.5	-	-	-	-	-	-	-	-
	TM	-	-	-	-	-	-	-	-	-	-	-

Note: The “-” symbol indicates difference between trait in UTM and OTM carcasses are not significantly different ($P \geq 0.05$)

^aSeven point descriptive indicating the approximate percent of meat surface which was discoloured (1 = 0%; 2 = 1 to 10%; 3 = 11 to 25%; 4 = 26 to 50%; 5 = 51 to 75%; 6 = 76 to 99 % and 7=100% discolouration) following 3 d of retail display.

^bProportion of myoglobin in the metmyoglobin oxidative state after 3 d of retail display.

Table 3. Muscle characteristics from D1 carcasses significantly different from the same muscle as UTM beef.

	muscle	muscle weight (kg)	moisture (mg·g ⁻¹)	fat (mg·g ⁻¹)	drip loss (mg·g ⁻¹)	<i>L</i> *	<i>a</i> *	chroma (%)	hue angle (°)	ΔE	subjective discolouration ^a	MMB ^b
hind	SM	-	-	-	-	-3.16	-	-	-2.42	-	-	-
	BF	-	-	-	-	-1.45	-	-	-	-	-	-
	ST	-	-	-	-	-2.64	+2.42	+2.01	-3.02	-	-	+0.06
	RF	-	-	-	-9.8	-2.98	-	-	-3	-	-	-
	GM	+0.35	-	-	-4.7	-2.72	-	-	-1.62	-	-	-
mid	LT	-	-14.9	+16.4	-	-2.73	+1.71	-	-3.10	-	-	-
	LL	+0.36	-9.6	+11.6	-	-2.8	+1.88	-	-2.99	-	-	+0.06
	PM	-	-	-	-	-2.04	-	-	-	-	-	-
front	TB	-	-	-	-5.9	-2.26	-	-	-1.76	-	-	-
	IF	+0.33	-12.7	+18.8	-	-	-	-	-	-	-	-
	TM	-	-	-	-	-1.5	-	-	-1.41	-	-	-

Note: The “-” symbol indicates difference between trait in UTM and OTM carcasses are not significantly different (*P* ≥ 0.05)

^aSeven point descriptive indicating the approximate percent of meat surface which was discoloured (1 = 0%; 2 = 1 to 10%; 3 = 11 to 25%; 4 = 26 to 50%; 5 = 51 to 75%; 6 = 76 to 99 % and 7=100% discolouration) following 3 d of retail display.

^bProportion of myoglobin in the metmyoglobin oxidative state after 3 d of retail display.

Table 4. Muscle characteristics from D2 carcasses significantly different from the same muscle as UTM beef.

	muscle	muscle weight (kg)	moisture (mg·g ⁻¹)	fat (mg·g ⁻¹)	drip loss (mg·g ⁻¹)	<i>L</i> *	<i>a</i> *	chroma (%)	hue angle (°)	ΔE	subjective discolouration ^a	MMB ^b
hind	SM	-0.35	-	-	-	-4.22	-	-1.54	-3.22	-	-	-
	BF	-0.49	-	-	-	-1.93	-	-	-	-	-	-
	ST	-	-	-	-4.7	-4.35	+2.34	-	-5.06	-	-	-
	RF	-	-	-	-14.9	-5.21	-	-2.46	-4.45	-	-	-
	GM	-	-	-	-5.2	-4.51	-	-2.02	-2.11	-	-	-
mid	LT	-	-12.9	+14.6	-	-3.87	-	-	-3.94	-	-	+0.06
	LL	-	-	+11.4	-	-3.44	+1.32	-	-3.79	-	-	+0.08
	PM	-	-	+15.3	-	-3.21	-1.23	-1.64	-	-	-	-
front	TB	-	-	+7.8	-6.3	-2.91	-	-	-2.38	-	-	-
	IF	-	-12.4	+17.7	-5.0	-	-	-	-	-	-	-
	TM	-	-	-	-9.0	-3.34	-	-	-2.43	-	-	-

Note: The “-” symbol indicates difference between trait in UTM and OTM carcasses are not significantly different ($P \geq 0.05$)

^aSeven point descriptive indicating the approximate percent of meat surface which was discoloured (1 = 0%; 2 = 1 to 10%; 3 = 11 to 25%; 4 = 26 to 50%; 5 = 51 to 75%; 6 = 76 to 99 % and 7=100% discolouration) following 3 d of retail display.

^bProportion of myoglobin in the metmyoglobin oxidative state after 3 d of retail display.

Table 5. Muscle characteristics from D3 carcasses significantly different from the same muscle as UTM beef.

	muscle	muscle weight (kg)	moisture (mg·g ⁻¹)	fat (mg·g ⁻¹)	drip loss (mg·g ⁻¹)	<i>L</i> *	<i>a</i> *	chroma (%)	hue angle (°)	ΔE	subjective discolouration ^a	MMB ^b
hind	SM	- ^c	+9.2	-	-	-3.91	-2.83	-3.99	-1.88	-	-	-
	BF	-	+13.0	-10.9	-5.4	-2.29	-2.52	-2.86	-	-	-	+0.06
	ST	-	+8.6	-	-7.8	-4.34	-	-1.99	-3.43	-	-	+0.07
	RF	-	+12.1	-10.3	-21.2	-4.7	-2.98	-4.26	-2.50	-	-	-
	GM	+0.46	+9.8	-8.8	-8.7	-5.17	-3.98	-5.19	-1.40	-	-	-
mid	LT	-	+14.3	-12.9	-8.4	-2.67	-1.58	-2.27	-1.60	-	+1.24	+0.09
	LL	-	+14.4	-14.0	-8.1	-2.21	-1.5	-2.17	-1.40	+2.71	+1.99	+0.13
	PM	-	+18.1	-10.3	-4.6	-2.07	-1.9	-1.98	-	-	-	-
front	TB	-	+12.2	-9.8	-9.0	-2.43	-2.51	-3.22	-	-	-	-
	IF	-	+11.3	-11.3	-5.1	-	-	-	-	-	-	-
	TM	-	+17.2	-8.6	-14.2	-2.94	-1.74	-2.44	-	-1.84	-	-0.05

Note: The “-” symbol indicates difference between trait in UTM and OTM carcasses are not significantly different (*P* ≥ 0.05)

^aSeven point descriptive indicating the approximate percent of meat surface which was discoloured (1 = 0%; 2 = 1 to 10%; 3 = 11 to 25%; 4 = 26 to 50%; 5 = 51 to 75%; 6 = 76 to 99 % and 7=100% discolouration) following 3 d of retail display.

^bProportion of myoglobin in the metmyoglobin oxidative state after 3 d of retail display.

Table 6. Muscle characteristics from D4 carcasses significantly different from the same muscle as UTM beef.

	muscle	muscle weight (kg)	moisture (mg·g ⁻¹)	fat (mg·g ⁻¹)	drip loss (mg·g ⁻¹)	<i>L</i> *	<i>a</i> *	chroma (%)	hue angle (°)	ΔE	subjective discolouration ^a	MMB ^b
hind	SM	-0.41	-	+8.1	-	-3.8	-	-	-2.8	-	-	-
	BF	-0.71	-	+12.0	-	-2.24	-	-	-	-	-	-
	ST	-	-8.6	+10.1	-	-3.69	+2.2	-	-4.38	-	-	-
	RF	-	-	+7.9	-12.4	-5.69	-	-1.83	-4.9	-	-	-
	GM	-	-	+7.8	-	-2.8	-	-	-1.42	-	-	-
mid	LT	-	-23.3	+29.4	-	-3.41	+1.36	-	-3.43	-	-	+0.07
	LL	-	-13.1	+21.3	-	-3.57	-	-	-3.52	+1.35	-	+0.08
	PM	-	-10.9	+17.8	-	-3.1	-	-	-	-	-	-
front	TB	-	-	+10.3	-4.77	-3.69	-	-	-2.78	-	-	-
	IF	-	-25.6	+33.0	-	-	-	-	-	-	-	-
	TM	-	-	+8.1	-	-2.55	-	-	-2.11	-	-	-

Note: The “-” symbol indicates difference between trait in UTM and OTM carcasses are not significantly different ($P \geq 0.05$)

^aSeven point descriptive indicating the approximate percent of meat surface which was discoloured (1 = 0%; 2 = 1 to 10%; 3 = 11 to 25%; 4 = 26 to 50%; 5 = 51 to 75%; 6 = 76 to 99 % and 7=100% discolouration) following 3 d of retail display.

^bProportion of myoglobin in the metmyoglobin oxidative state after 3 d of retail display.