Biochemical and organoleptic characteristics of muscle from early and late maturing bulls in different production systems

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Short title

Effect of breed type and diet on bull beef quality

Abstract

In grass based beef production systems (PS), early maturing breed types (EM) may be preferable to late maturing breed types (LM) in achieving adequate fat cover. Biochemical and organoleptic characteristics of muscle from suckler bulls were investigated in EM and LM (n = 28/breed) assigned to one of two PS [*ad libitum* concentrates and grass silage to slaughter (C) or *ad libitum* silage plus 2 kg concentrate daily during winter followed by 99 days at pasture and then an indoor finishing period on C (GSPC)] in a 2 breed type × 2 PS factorial arrangement of treatments. Bulls were managed to have a common target carcass weight of 380 kg. Intramuscular fat (IMF) content was higher ($P < 0.05$) for EM than LM, and for C than GSPC bulls. Collagen solubility was higher ($P < 0.05$) for C than GSPC bulls. Lactate dehydrogenase (LDH) and phosphofructokinase activities were higher ($P < 0.05$) for LM than EM. Isocitrate dehydrogenase activity and the Type I myosin heavy chain (MyHC) proportion were higher ($P < 0.05$) for EM than LM. The LDH activity and the Type IIX MyHC proportion were higher ($P < 0.05$) for C than GSPC bulls. Sensory ratings for tenderness and juiciness were higher ($P < 0.01$) for beef from EM than LM while sensory ratings for tenderness, flavour liking and overall liking were higher ($P < 0.001$) for C than for GSPC bulls. Differences in sensory quality were largely eliminated when adjusted for IMF. Overall, carcass fat scores, IMF and sensory scores were higher in EM than LM and in C than GSPC bulls but most differences in sensory quality could be attributed to differences in IMF.

Key words: beef, breed type, diet, sensory, intramuscular fat

Implications

In countries like Ireland, where grazed grass is abundantly available, inclusion of grass silage followed by a period of grazed grass, prior to finishing on a high energy concentrate diet, decreases production costs in late maturing suckler bull production systems but the bulls may not meet the market-specific requirements in terms of carcass fat cover. It may be more appropriate, therefore, to rear early maturing breed types in such production systems as the bulls have higher carcass fat scores and marbling fat, and yield a more tender and juicier beef.

Introduction

In Ireland, late maturing breed types (LM) account for 85% of the suckler beef herd while the remaining 15% are early maturing breed types (EM) (McGee, 2012). Traditionally, the male beef cattle population was dominated by steers, but more recently the proportion of bulls has increased as steers are less efficient in nutrient utilization than bulls when reared similarly (O'Riordan *et al.*, 2011). However, producing beef from suckler bulls, which usually involves provision of a high concentrate ration for a prolonged period, is usually less profitable because of the higher cost of concentrates compared to grass silage or grazed grass diets (Finneran *et al.*, 2011). Incorporating a grazing period prior to finishing on a concentrate diet has been shown to reduce the production costs of LM suckler bulls (O'Riordan *et al.*, 2011) with little impact on eating quality of the beef (Mezgebo *et al.*, 2016).

However, while it is economically viable to incorporate a grazing period in the LM suckler bull production system (PS), the bulls may not meet the market requirements in terms of adequate carcass fat cover at a particular carcass weight (O'Riordan *et al.*, 2011). Carcass fat cover and colour are important parameters for the beef industry as they influence the quality and consumer acceptability of beef (Moloney and Richardson, 2013). Even though LM predominate in the suckler herds in Ireland, EM may be more suitable for a grass-based PS because when managed to a particular slaughter weight and/or age, EM have a higher genetic potential to deposit fat than LM (Keane, 2011).

Recently, the influence, on beef quality characteristics, of incorporating a grazing period prior to indoor finishing on a concentrate diet in the LM suckler bull PS was evaluated

(Mezgebo *et al.*, 2016). However, to our knowledge, little is known about the effect of incorporating a grazing period in EM suckler bull PS on the quality of the beef. Therefore, the aim of this study was to determine the influences of breed maturity and inclusion of a period of grazed grass in a suckler bull PS on the compositional, biochemical and organoleptic characteristics of beef. It was hypothesised that LM could be replaced by EM, to achieve adequate fat cover and product quality specifications, in a suckler bull beef PS.

Materials and methods

Animals and management

As part of a larger study described by Marren *et al.* (2013), 28 spring-born (mean birth date 30 March) EM (Aberdeen Angus and Hereford sired calves) and 28 spring-born (mean birth date 8 March) LM (Charolais and Limousin sired calves) weaned suckler bulls were purchased at livestock markets in Ireland at approximately 8 months of age, acclimatised to slatted floor accommodation and offered grass silage *ad libitum* plus 2 kg/head/day of a barley-based concentrate. Bulls were randomly assigned (1 December) within breed maturity to a two breed types (B) × two PS factorial arrangement of treatments, balanced for sire breed and initial weight. The two PS were: (1) *ad libitum* concentrates (870 g/kg rolled barley, 60 g/kg soya bean meal, 50 g/kg molasses and 20 g/kg minerals/vitamins) plus *ad libitum* grass silage (GS) (dry matter digestibility 700 g/kg) (C), and (2) GS plus 2 kg concentrate daily during the winter (123 day duration) followed by 99 days at pasture and then an indoor finishing period on C (GSPC). Bulls were slaughtered at a commercial slaughter plant (Kepak Group, Clonee, Co. Meath, Ireland) on reaching a mean live weight estimated to achieve a target carcass weight of 380 kg. The study was carried out under license from the Irish Government and with the approval of Teagasc, the Agricultural and Food Development Authority.

Carcass grading and muscle tissue collection

Post slaughter, carcasses were weighed and graded for conformation according to the EU Beef Carcass Classification Scheme as described in Mezgebo *et al.* (2016). At 1 h post-slaughter, a sample (*ca.* 20 g) of *longissimus thoracis* (LT) muscle tissue was taken (from 9th rib), snap frozen in liquid nitrogen and maintained at -80ºC for muscle metabolic enzyme activity and muscle typing analyses.

Muscle pH and temperature measurement

Muscle pH was measured at 2, 3.5, 5 and 48 h post-mortem by making a scalpel incision in the muscle at the 10th rib and inserting a glass electrode (Model EC-2010-06, Amagruss Electrodes Ltd., Westport, Co. Mayo, Ireland) attached to a portable pH meter (Model no. 250A, Orion Research Inc., Boston, MA) approximately 4.0 cm into

105 the muscle. The temperature was recorded simultaneously and used to make a
106 temperature compensated pH measurement.

107 *Fat and muscle colour measurements*

108 A detailed procedure is given in Mezgebo *et al.* (2016). Briefly, at 48 h post-mortem,
109 carcasses were cut at the 5/6th rib interface prior to subcutaneous fat and muscle colour
110 measurements. Subcutaneous fat colour (i.e. *L, a, b* colour coordinates) was measured
111 using a Miniscan XE Plus (Hunter Associates Laboratory Inc., Reston, VA, USA) at two
112 positions: (1) the lower round/rump region and (2) 13th rib region. Chroma/saturation (*C*)
113 and hue angle (*h*°) values were calculated form the '***a'*** and '***b'*** values. For muscle colour
114 measurement, the cut surface of the muscle was first allowed to bloom for 1 h. Muscle
115 colour grade was also subjectively assessed on the chilled carcass using Meat
116 Standards Australia colour sticks (Anon, 2005). A portion of LT muscle (13 cm in length,
117 from the 10th rib region) was excised, vacuum packed, aged for 14 days at 2ºC, and
118 finally frozen and stored at -18ºC prior to compositional, collagen and sensory analysis.

119 *Proximate composition, collagen content and sensory analyses*

120 Moisture, intramuscular fat (IMF) and protein contents of the LT muscle were
121 determined using the SMART System 5 microwave moisture drying oven, NMR SMART
122 Trac rapid fat analyser (CEM Corporation, Matthews, NC, USA) and LECO FP328
123 (LECO Corp., St. Joseph, MI, USA) protein analyser, respectively (AOAC, 1990).
124 Collagen content (i.e. total and soluble) was determined by quantitative determination of
125 hydroxyproline by a colorimetric reaction (Kolar, 1990). Sensory analysis was carried
126 out using a 10-person trained taste panel who had been selected for their sensory
127 acuity, a detailed procedure is given in Mezgebo *et al.* (2016).

128 *Muscle metabolic enzyme activity and muscle contractile and metabolic type*

129 Glycolytic enzyme activities (lactate dehydrogenase (LDH) and phosphofructokinase
130 (PFK)) and oxidative enzyme activities (isocitrate dehydrogenase (ICDH), citrate
131 synthase (CS) and cytochrome *c* oxidase (COX)) were quantified
132 spectrophotometrically according to Jurie *et al.* (2006). Muscle typing was assessed by
133 determination of relative proportions of myosin heavy chains (MyHC) isoforms types I,

IIA and IIX using high-resolution mini-gel electrophoresis as described by Picard *et al.* (2011).

Statistical analysis

Data were subjected to analysis of variance using the General Linear Model procedure of SPSS (IBM SPSS Statistics Version 20, International Business Machines (IBM) Corporation, Armonk, NY, USA) where the B, PS and their interaction were regarded as fixed factors. For data relating to sensory analysis, assessor and session effects were also included as fixed factors. The sensory data were also analysed using IMF as an overall linear covariate. Means were considered significant at $P < 0.05$.

Results

Production and carcass traits

Production, carcass and subcutaneous fat colour data are presented in Table 1. There was an interaction ($P < 0.001$) between B and PS with respect to age at slaughter. Thus for C bulls, age at slaughter was higher for EM than for LM, but for GSPC bulls, age at slaughter was similar for EM and LM. The ADG indoor (i.e. during finishing on the concentrate diet) was lower ($P < 0.001$) for C than for GSPC. There was an interaction ($P < 0.05$) between B and PS with respect to ADG overall. Thus for C bulls, ADG overall was lower for EM than for LM, but for GSPC bulls, ADG overall was similar for EM and LM. Conformation score was lower ($P < 0.001$) for EM than for LM. There was an interaction ($P < 0.001$) between B and PS with respect to fat score. Thus for C bulls, fat score was similar for EM and LM, but for GSPC bulls, fat score was higher for EM than for LM. Subcutaneous fat *'L'* and *'b'* values were higher ($P < 0.05$) for EM than for LM, and for C than for GSPC. *'h*^{o}*'* value was higher ($P < 0.05$) for C than for GSPC bulls.

Muscle pH, temperature, colour, proximate composition and collagen data

Muscle pH, temperature, colour, proximate composition and collagen data are presented in Table 2. At 2 h post-mortem, muscle pH was higher for EM than for LM ($P < 0.001$), and for C than for GSPC ($P < 0.01$). There was an interaction ($P < 0.05$) between B and PS with respect to pH at 3.5 h post-mortem. Thus for EM, pH at 3.5 h was higher for C than for GSPC, but for LM, pH at 3.5 h was similar for C and GSPC. There was an interaction ($P < 0.01$) between B and PS with respect to pH at 5 h post-mortem. Thus for C bulls, pH at 5 h was higher for EM than for LM, but for GSPC bulls, pH at 5 h was lower for EM than for LM. There was an interaction ($P < 0.05$) between B and PS with respect to ultimate pH (pH_u), i.e. 48 h post-mortem. Thus for C bulls, pH_u was similar for EM and LM, but for GSPC bulls, pH_u was higher for EM than for LM. There was an interaction ($P < 0.001$) between B and PS with respect to muscle temperature at 2 h post-mortem. Thus for C bulls, muscle temperature at 2 h was lower for EM than for LM, but for GSPC bulls, muscle temperature at 2 h was higher for EM than for LM. At 3.5 h post-mortem, muscle temperature was higher ($P < 0.001$) for EM than for LM. There was an interaction between B and PS with respect to muscle

temperature at 5 h post-mortem. Thus for C bulls, muscle temperature at 5 h post-mortem was similar for EM and LM, but for GSPC bulls, muscle temperature at 5 h post-mortem was higher ($P < 0.01$) for EM than for LM. At 48 h post-mortem, muscle temperature was higher ($P < 0.001$) for C than for GSPC.

For muscle colour, *'L'* value was higher ($P < 0.001$) for C than for GSPC, and *'a'* value was higher ($P < 0.001$) for GSPC than for C. There was an interaction ($P < 0.05$) between B and PS with respect to *'b'*, *'C'* and *'h°'* values. Thus for C bulls, *'b'*, *'C'* and *'h°'* values were lower for EM than for LM, but for GSPC bulls, *'b'*, *'C'* and *'h°'* values were similar for EM and LM. Muscle colour grade was higher ($P < 0.05$) for GSPC than for C. The IMF content was higher ($P < 0.001$) for EM than for LM, and for C than for GSPC. Moisture content was higher for LM than for EM ($P < 0.001$), and for GSPC than for C ($P < 0.05$). Total collagen was higher ($P < 0.05$) for EM than for LM. There was an interaction ($P < 0.05$) between B and PS with respect to percentage of soluble collagen. Thus for C bulls, percentage of soluble collagen was higher for EM than for LM, but for GSPC bulls, percentage of soluble collagen was similar for EM and LM.

Muscle metabolic enzyme activity and muscle contractile and metabolic type

Muscle metabolic enzyme activity and MyHC proportion data are presented in Table 3. When enzyme activity was expressed as µmol/min per g of tissue, LDH activity was higher for LM than for EM ($P < 0.001$), and for C than for GSPC bulls ($P < 0.05$); PFK activity was higher ($P < 0.05$) for LM than for EM; ICDH activity was higher ($P < 0.01$) for EM than for LM and COX activity tended to be higher ($P < 0.07$) for EM than for LM. When enzyme activity was expressed as µmol/min per g of protein, similar trends were observed although significance ($P < 0.05$) was only reached in the case of the breed type effects on LDH and ICDH activities. Type I MyHC proportion was higher ($P < 0.001$) for EM than for LM. Type IIX MyHC proportion was higher ($P < 0.05$) for C than for GSPC.

Sensory characteristics

Muscle sensory data are presented in Table 4. Tenderness, flavour liking and overall liking were higher ($P < 0.001$) for C than for GSPC. Tenderness and juiciness were higher ($P < 0.01$) for EM than for LM. Ease of cutting ($P < 0.001$) and cleanness of cut

204 ($P < 0.05$) were higher for C than for GSPC. Clean cut was higher ($P < 0.05$) for EM
205 than for LM. Toughness (both during in-bite and eating) was higher for GSPC than for C
206 ($P < 0.001$), and for LM than EM ($P < 0.05$). Juiciness (during in-bite) was higher for C
207 than for GSPC ($P < 0.01$), and for EM than for LM ($P < 0.001$). Sponginess was higher
208 ($P < 0.001$) for C than for GSPC. Moisture, greasiness and pulpiness (both during
209 eating and residual), dissolubility, ease of swallow and mouthfeel were higher ($P < 0.05$)
210 for C than GSPC, and for EM than LM. Chewiness, fibrousness and residual particles
211 were higher ($P < 0.05$) for GSPC than for C. When the sensory data were analysed
212 using IMF as a covariate, only beefy flavour was lower ($P < 0.05$) and moisture and
213 pulpiness (during eating) were higher ($P < 0.05$) for EM than for LM (mean values of
214 4.39 *vs* 4.59, 50.8 *vs* 46.9 and 55.8 *vs* 52.0 for beefy flavour, moisture and pulpiness
215 respectively). Ease of swallow was higher ($P < 0.05$) for C than GSPC (mean values of
216 60.0 *vs* 54.7).

Discussion

The bulls were slaughtered on reaching a mean group live weight estimated to achieve a target carcass weight of 380 kg which is required by some markets (Bord Bia, 2011). To reach the same target carcass weight, the LM bulls reared in the C PS grew faster generally (i.e. higher ADG overall), reached the desired live weight earlier and therefore were slaughtered at a younger age compared to that of EM bulls on the same PS. This confirms that LM are better converters of a high energy diet to carcass weight (Keane, 2011). However, when reared on the GSPC system, both breed types grew at a slower rate overall and took longer to reach the target live weight. Prior to slaughter (i.e. finishing period), the GSPC bulls grew faster compared to C bulls. The higher growth rate prior to slaughter for the GSPC bulls suggests compensatory growth during the indoor period as they had received a low energy diets (i.e. grass at pasture) prior to the finishing period compared to C bulls (Hornick *et al.*, 2000).

When managed to the same carcass weight, carcasses from LM are characterised by having relatively more muscle and less fat compared to carcasses from EM (O'Riordan *et al.*, 2011, Keane, 2011). In the present study, the better carcass conformation of the LM bulls compared to the EM bulls can be attributed to a higher degree of muscularity in the LM carcasses. Fat score, which is a measure of subcutaneous fat thickness or degree of finish, was similar between EM and LM in the C group possibly because of rapid growth due to the high energy diet of the C diet. However, in the GSPC bulls, carcasses of the LM were leaner even though both breed types were finished on the same concentrate diet. In this case, it appears that during the concentrate finishing period the LM were physiologically ‘younger’ and therefore were depositing less fat than the physiologically ‘older’ EM (Warriss, 2010). With regard to subcutaneous fat colour, the higher lightness of fat from EM compared to LM, and for C compared to GSPC bulls may be attributed to the higher fat scores (i.e. subcutaneous fat thickness over the muscle) of the carcasses of EM and C groups. Fat yellowness, often associated with grass diets due to accumulation of carotenoids (Dunne *et al.*, 2006), and reported to negatively influence consumer acceptability (Cornforth, 1994), was unexpectedly higher for C bulls compared to GSPC bulls. However, although differences in fat yellowness due to B and PS were significant ($P < 0.05$), values were numerically quite similar,

suggesting that these colour differences would probably not be perceived by consumers. In the case of PS this may be attributed to the similarity in diets in the immediate pre-slaughter period.

The extent of post-mortem pH decline in a muscle depends on the glycogen concentration at slaughter which in turn depends on the animal's physical activity, nutrition and/or stress prior to slaughter (Klont and Lambooy, 1995; Warriss, 2010). In the present study, the influence of pre-slaughter physical activity and stress on muscle glycogen level would likely be minimal as the bulls were finished indoors and therefore were familiar with pre-slaughter handling; in addition the animals were carefully managed during transport and lairage. However, early post-mortem (i.e. 2, 3.5 and 5 h), a lower pH was recorded in the muscle from GSPC bulls compared to C bulls. This may be related to the higher growth rate of GSPC bulls during the finishing period compared to C bulls, whereby muscle is believed to become more glycolytic during periods of compensatory growth (Brandstetter et al., 1998). Similarly, a higher pH_u (i.e. pH at 48 h post-mortem) was recorded in the muscle from EM breed types than LM breed types; however, there was an interaction between B and PS whereby the difference was observed in GSPC bulls and not in C bulls. The lower pH_u for LM GSPC bulls could possibly reflect a higher muscle glycolytic potential as LM breed types are often characterised by an accelerated lean tissue growth compared to EM breed types when reared similarly (Hocquette *et al.*, 1998), in this case to a similar carcass weight. In agreement, glycolytic enzyme activity (LDH and PFK) were higher in muscle from LM breed types, as discussed further below. The higher muscle temperature at 3.5 h post-mortem for EM than LM bulls, and at 5 and 48 h post-mortem for C than GSPC bulls is most probably related to the carcass fat score as carcasses from EM and C groups had higher fatness scores than LM and GSPC groups, respectively. This is due to the fact that carcasses with a thicker fat cover cool more slowly than carcasses with a thinner fat cover (Warriss, 2010).

With regard to muscle colour, the lower lightness, higher redness, colour saturation and muscle colour grade (i.e. the higher the value, the darker the muscle) for the GSPC bulls could be explained by the higher age at slaughter (15.9 *vs* 18.5 months for C vs GSPC, respectively) as muscle tissue becomes darker and redder with increasing

279 slaughter age (Dunne *et al.*, 2006). The lower proportion of Type IIX MyHC, a
280 characteristic of white muscles, for the GSPC bulls could also be responsible for the
281 lower lightness of their LT muscle (Henckel *et al.*, 1997). The darker muscle from GSPC
282 compared to C bulls could also be related to the physical activity during the pasture
283 feeding period (Priolo *et al.*, 2001). However, it should be mentioned that the post-
284 mortem pH profile of each muscle was within an acceptable pH range (Warriss, 2010),
285 and thus meat from either group could not be considered to have experienced the 'dark
286 cutting beef' condition.

287 The higher IMF content for EM compared to LM may be related to the intrinsic variations
288 in the physiology of the animals (Oddy *et al.*, 2001) whereby at a similar live weight, the
289 EM bulls were physiologically 'older' and therefore were depositing more IMF than the
290 LM bulls, which were 'younger' physiologically, and therefore were depositing less IMF.
291 The higher IMF content for C bulls reflects the higher energy content of the concentrate
292 diet through out their life (Oddy *et al.*, 2001). The lower collagen solubility for GSPC
293 bulls may be related to the greater age at slaughter (Blanco *et al.*, 2013) and lower IMF
294 content (Nishimura, 2015) as an increase in slaughter age increases the proportion of
295 mature collagen crosslinks which in turn leads to a decrease in solubility of the collagen
296 (McCormick, 1994).

297 The higher glycolytic enzyme activities (LDH and PFK) for LM could be related to the
298 higher overall growth rate of these bulls as an increase in growth rate early in life (i.e.
299 period of rapid growth from one to 12 months) and further growing stage until sexual
300 maturity is associated with an increase in muscle LDH activity (i.e. glycolytic
301 metabolism) and a decrease in ICDH activity (i.e. oxidative metabolism) (Jurie *et al.*,
302 1995). A similar explanation could be offered for the tendency towards lower oxidative
303 enzyme activities ($P < 0.07$) of ICDH and COX, marker enzymes for tricarboxylic acid
304 cycle and mitochondrial electron transport respectively, and lower proportion of slow
305 twitch Type I oxidative MyHC in the muscle from LM. The higher LDH activity (per g of
306 tissue) and proportion of Type IIX (fast twitch glycolytic) MyHC for C bulls could be
307 explained by the higher overall growth rate which is mainly attributed to the continued
308 provision of concentrate diet which in turn results in a more glycolytic muscular
309 metabolism (Brandstetter *et al.*, 1998, Cassar-Malek *et al.*, 2004). In addition, such

higher glycolytic metabolism in muscle could also be associated with the longer concentrate finishing period of the C group compared to GSPC group (i.e. concentrate finishing period of 98 and 71 d for GSPC and 258 and 201 d for C bulls of EM and LM respectively). Even though grazing on pasture is associated with an increase in oxidative metabolism of muscle mainly due to higher physical activity (Therkildsen *et al.*, 1998), the C and GSPC groups had similar oxidative enzyme activities. However, this was not unexpected as all bulls were finished indoors on the same concentrate diets for at least 71 days. In the present study, the fast twitch Type IIB glycolytic muscle MyHC was expressed in only 6 bulls (1 in EM of C, none in EM of GSPC, 1 in LM of C and 4 in LM of GSPC bulls, data not shown) in contrast to a study by Picard and Cassar-Malek (2009) in a Blonde d'Aquitaine (a French beef breed) in which Type IIB MyHC was usually identified.

The effect of PS on sensory characteristics was in agreement with Mezgebo *et al.* (2016). The higher tenderness scores for C bulls may be related to their younger age at slaughter (Bures and Barton, 2012), higher IMF (Thompson, 2004) and collagen solubility (Cross *et al.*, 1973). A similar explanation could be given for the higher sensory ratings for ease of cutting, cleanness of cut, juiciness (in-bite), sponginess, moisture, greasiness, pulpiness, dissolubility, ease of swallow and mouthfeel, and lower ratings in toughness, chewiness, fibrousness and residual particles for C bulls compared to GSPC bulls. The contribution of IMF to these differences was shown by the lack of significant differences in sensory ratings (except for ease of swallow) between PS when the data were adjusted for IMF. In addition, the higher LDH activity for the C bulls compared to GSPC bulls could also be linked to the higher tenderness ratings of the C bulls, as an increase in glycolytic characteristics of a muscle often leads to an increase in eating quality of meat mainly by accelerating the post-mortem tenderization process of the muscle (Maltin *et al.*, 2001). The sensory analysis also showed that the sensory data ratings were internally consistent, especially for tenderness, i.e. higher tenderness score (during the basic taste) was consistent with the lower toughness scores (both during in-bite and eating). Even though all bulls were finished indoors, the lower flavour liking and overall liking ratings of beef from GSPC bulls could possibly be associated with the inclusion of grass diet prior to the finishing

341 period as beef from pasture based systems is often reported to be less preferred by
342 consumers (Griebenow *et al.*, 1997).

343 The higher sensory ratings in tenderness and juiciness, and associated higher scores in
344 cleanness of cut, moisture, greasiness, pulpiness, dissolubility, ease of swallow and
345 mouthfeel, and lower scores in toughness for EM could be related to their higher
346 carcass fat cover and IMF content compared to LM. Similar findings were reported by
347 Sinclair *et al.* (2001) in beef from Aberdeen-Angus and Charolais breeds. In the current
348 study, beef from LM was rated to be lower in tenderness, juiciness and related sensory
349 quality attributes compared to beef from EM even though the LM were younger at
350 slaughter. In addition, LM muscle had higher glycolytic (LDH and PFK) and lower
351 oxidative (ICDH and COX) metabolic enzyme activities and lower Type I MyHC
352 proportion than EM, and an increase in glycolytic (Maltin *et al.*, 2001) and decrease in
353 oxidative (Monin and Ouali, 1991) characteristics of a muscle can lead to superior
354 eating quality in meat. When IMF was included as a covariate in the sensory data
355 analysis, most of the observed differences disappeared, confirming that IMF content
356 was the major contributor to differences in meat tenderness and juiciness between EM
357 and LM breeds (Sinclair *et al.*, 2001).

Conclusion

When managed to a similar carcass weight EM were older at slaughter, had higher carcass fat scores and IMF content and produced beef that was rated more tender and juicier by trained sensory panellists than LM. Furthermore, C bulls were younger at slaughter, had higher carcass fat scores, IMF and soluble collagen content and produced beef rated more highly by a trained sensory panel than GSPC bulls. While variations in sensory characteristics due to breed maturity and dietary inclusion of grass silage followed by pasture exist, IMF contributed to much of the variation and it remains to be established whether or not the differences would be perceptible to untrained consumers.

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Table 1 *Production, carcass and subcutaneous fat colour data of bulls from two breed types (B) (EM = early maturing, LM = late maturing), raised on two production systems (PS) (C = concentrate, GSPC = grass silage followed by pasture and then concentrate)*

B	EM		LM			Significance		
PS	C	GSPC	C	GSPC	s.e.m	B	PS	B x PS
Finishing period (days)[1]	258	98	201	71				
Age at slaughter (months)	16.7^{b}	18.6^{c}	15.0^{a}	18.3^{c}	0.25	***	***	**
ADG[2] finishing (kg/day)	1.35	2.09	1.50	2.06	0.081		***	
ADG overall (kg/day)	1.38^{b}	1.09^{a}	1.58^{c}	1.10^{a}	0.042	*	***	*
Slaughter weight (kg)	681	704	667	693	14.1			
Carcass weight (kg)	375	385	379	387	9.1			
Conformation score[3]	8.3	8.7	9.9	9.7	0.36	***		
Fat score[4]	8.3^{b}	8.3^{b}	8.4^{b}	6.6^{a}	0.26	***	***	***
Fat colour[5]								
'L'	72.4	68.9	68.6	64.5	0.66	***	***	
'a'	9.1	9.5	8.8	9.3	0.50			
'b'	16.9	15.6	15.6	15.4	0.32	*	*	
'C'	19.3	18.3	17.9	18.0	0.46			
'h°'	62.0	58.9	61.1	58.9	1.16		*	

[1] Days on *ad libitum* concentrates prior to slaughter
[2]Average daily live weight gain
[3]Conformation classes E^{+} (highest) to P^{-} (lowest), (E^{+} is 15)
[4]Fat score classes 5^{+} (highest) to 1^{-} (lowest), (5^{+} is 15)
[5]Subcutaneous fat colour: *'L'* = lightness, 0 (black) to 100 (white); *'a'* = redness, +a (red) to –a (green); *'b'* = yellowness, +b (yellow) to –b (blue); '*C'* = chroma, higher *'C'* values higher colour saturation; *'h°'* = hue, 0/360º is red, 90º is yellow, 180º is green and 270º is blue colour
[a, b, c] means within rows (where interaction exists), assigned different superscripts differ significantly ($P < 0.05$)
*$P < 0{\cdot}05$, **$P < 0{\cdot}01$, ***$P < 0{\cdot}001$

Table 2 *Post-mortem pH and temperature, colour, proximate composition and collagen content of longissimus thoracis muscle from bulls from two breed types (B) (EM = early maturing, LM = late maturing), raised on two production systems (PS) (C = concentrate, GSPC = grass silage followed by pasture and then concentrate)*

B	EM		LM			Significance		
PS	C	GSPC	C	GSPC	s.e.m	B	PS	B x PS
pH, post-mortem (h)								
2	6.59	6.47	6.45	6.28	0.054	***	**	
3.5	6.21^{c}	5.84^{a}	6.11^{bc}	5.97^{ab}	0.054		***	*
5	6.03^{c}	5.67^{a}	5.87^{b}	5.85^{b}	0.056		***	**
48	5.69^{ab}	5.74^{b}	5.68^{ab}	5.62^{a}	0.026	**		*
Temperature, post-mortem (h)								
2	33.1^{a}	35.1^{b}	35.3^{b}	32.4^{a}	0.55			***
3.5	29.1	29.5	28.1	27.3	0.48	***		
5	23.9^{b}	24.1^{b}	24.4^{b}	21.9^{a}	0.47		*	**
48	3.90	3.25	3.66	3.09	0.154		***	
Muscle colour[1]								
'L'	31.1	28.1	32.8	28.3	0.80		***	
'a'	19.8	21.6	20.5	21.2	0.30		***	
'b'	12.2^{a}	12.9^{a}	13.9^{b}	12.9^{a}	0.24	***		***
'C'	23.3^{a}	25.1^{b}	24.8^{b}	24.8^{b}	0.32		**	**
*'h*º*'*	31.7^{a}	30.8^{a}	34.2^{b}	31.4^{a}	0.50	***	***	*
Muscle colour grade[2]	3.07	3.29	2.57	3.21	0.172		*	
Proximate composition (g/kg)								
Intramuscular fat	55.2	27.7	26.2	10.2	3.94	***	***	
Moisture	720	738	747	749	4.8	***	*	
Protein	229	233	229	231	2.7			
Ash	10.5	12.0	11.2	11.3	0.59			
Collagen content								
Total collagen (mg/g)	4.06	4.21	3.86	3.87	0.126	*		
Soluble collagen (%)	13.4^{b}	8.3^{a}	9.4^{a}	9.4^{a}	0.79		***	***

[1]Muscle colour: *'L'* = lightness, 0 (black) to 100 (white); *'a'* = redness, +a (red) to –a (green); *'b'* = yellowness, +b (yellow) to –b (blue); '*C'* = chroma, higher *'C'* values higher colour saturation; *'h*º*'* = hue, 0/360º is red, 90º is yellow, 180º is green and 270º is blue colour

[2]Muscle colour grades: 1 (extremely bright red) to 9 (extremely dark red)

[a, b, c]means within rows (where interaction exists), assigned different superscripts differ significantly ($P < 0.05$)

*$P < 0{\cdot}05$, **$P < 0{\cdot}01$, ***$P < 0{\cdot}001$

Table 3 *Metabolic enzyme activity and myosin heavy chains (MyHC) proportion of longissimus thoracis muscle from bulls from two breed types (B) (EM = early maturing, LM = late maturing), raised on two production systems (PS) (C = concentrate, GSPC = grass silage followed by pasture and then concentrate)*

B	EM		LM			Significance		
PS	C	GSPC	C	GSPC	s.e.m	B	PS	B x PS
Metabolic enzyme activity[1]								
µmol/min per g of tissue								
LDH	936	838	999	969	26.5	***	*	
PFK	101	96	112	112	6.8	*		
ICDH	1.17	1.33	1.01	1.02	0.085	**		
COX	17.0	18.3	15.1	15.2	1.33	0.07		
CS	5.27	5.37	5.34	4.58	0.463			
µmol/min per g of protein								
LDH	4908	4350	5007	5478	275.9	*		
PFK	527	498	559	636	45.0	0.06		
ICDH	6.14	6.90	5.12	5.68	0.483	*		
COX	89.3	94.7	75.7	87.1	8.14			
CS	27.7	27.9	27.1	26.2	2.86			
Protein (mg/g of tissue)	191	193	200	186	4.7			
MyHC[2] proportion (%)								
I	22.5	23.2	18.5	17.1	1.64	***		
IIA	45.1	48.8	38.6	46.8	3.35			
IIX	35.3	32.7	44.1	29.8	3.44		*	

[1]LDH: lactate dehydrogenase; PFK: phosphofructokinase; ICDH: isocitrate dehydrogenase; COX: cytochrome *c* oxidase; CS: citrate synthase

[2]I: oxidative, IIA: oxido-glycolytic, IIX: glycolytic

*P < 0·05, **P < 0·01, ***P < 0·001

505 **Table 4** *Sensory characteristics of of longissimus thoracis muscle from bulls from two*
506 *breed types (B) (EM = early maturing, LM = late maturing), raised on two production*
507 *systems (PS) (C = concentrate, GSPC = grass silage followed by pasture and then*
508 *concentrate)*

B	EM		LM			Significance		
PS	C	GSPC	C	GSPC	s.e.m.	B	PS	B x PS
Basic tastes, scale 1 (least) - 8 (most)								
Tenderness	4.81	4.50	4.63	4.20	0.093	**	***	
Juiciness	5.10	4.90	4.83	4.81	0.068	**		
Beefy flavour	4.54	4.41	4.55	4.51	0.060			
Abnormal flavour	2.30	2.50	2.30	2.42	0.074			
Flavour liking	5.45	5.02	5.46	5.10	0.081		***	
Overall liking	5.15	4.71	5.03	4.59	0.081		***	
Specific sensory indicators, scale 0 (nil) - 100 (extreme)								
On-cut								
Ease of cutting	55.7	49.6	53.5	46.7	1.34		***	
Cleanness of cut	59.2	56.8	56.6	53.9	1.20	*	*	
In-bite								
Toughness	43.1	48.8	45.5	54.9	1.35	**	***	
Crispness	25.3	26.1	24.3	25.6	1.08			
Juiciness	51.1	47.5	46.7	44.2	1.03	***	**	
Sponginess	29.9	26.9	28.6	25.5	0.87		***	
Eating								
Toughness	43.1	48.7	44.9	53.5	1.33	*	***	
Moisture	52.2	49.6	48.1	45.0	1.05	***	**	
Chewiness	40.9	47.1	42.6	49.0	1.42		***	
Greasiness	21.5	17.9	19.1	15.7	0.88	**	***	
Fibres	42.1	43.2	42.6	46.1	1.05		*	
Gristle	5.5	6.2	6.4	6.2	0.68			
Pulpy	57.5	54.9	52.7	50.2	1.08	***	**	
Dissolubility	51.5	46.3	49.6	43.0	1.31	*	***	
Residual								
Greasiness	21.5	18.2	18.4	15.4	0.93	**	***	
Ease of swallow	62.1	55.3	59.5	52.5	1.21	*	***	
Pulpy	56.7	54.4	51.9	48.2	1.12	***	**	
Particles	49.6	50.3	48.9	52.5	0.99		*	
Mouthfeel	57.0	54.5	52.2	49.8	0.99	***	*	

509 *$P < 0{\cdot}05$, **$P < 0{\cdot}01$, ***$P < 0{\cdot}001$