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Fatty acid, volatile and sensory characteristics of beef as affected by grass silage or pasture in the bovine diet

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Short (running) title: Fatty acid, volatile and sensory qualities of beef as affected by diet

Abstract

Fatty acid, volatile compounds and sensory attributes of beef from bulls fed concentrates to slaughter (C), grass silage for 120 days (GS) followed by C (GSC), or GS followed by 100 days at pasture and then C (GSPC) and slaughtered at 3 target carcass weights were determined. Total intramuscular fat (IMF) was lower for GSPC than for GSC and C. C18:3*n*-3 concentration and polyunsaturated fatty acid (PUFA) to saturated fatty acid (SFA) ratio were higher and C18:2*n*-6 and monounsaturated fatty acid concentrations and *n*-6:*n*-3 PUFA ratio lower for GSPC than C. C16:0, C18:0 and C18:1*c*9 increased with carcass weight when expressed quantitatively, but not when expressed proportionately. Hexanal concentration was higher and 2-methyl-1-butanol and toluene lower for C and GSC than for GSPC. Overall liking was negatively correlated with C20:5*n*-3 and PUFA/SFA ratio, but differences in sensory attributes (tenderness, flavour liking, overall liking) were most strongly correlated with IMF.

Key words: beef, intramuscular fat, fatty acids, volatile compounds, sensory

1. Introduction

Consumer acceptability of beef is related to their perception of its healthiness and its sensory ratings (Platter et al., 2003; Verbeke & Viaene, 1999). In this context, beef from grass based production systems is often leaner (Scerra et al., 2014) with a more desirable fatty acid composition, specifically higher levels of *n*-3 polyunsaturated fatty acids (PUFA) and some conjugated linoleic acids (CLAs), such as C18:2*c*9,*t*11 (Aldai et al., 2011). However, feeding grazed grass alone can lead to a reduction in intramuscular fat (IMF) content to a level that has a negative impact on consumer liking (juiciness, tenderness and flavour scores) of the beef (Hunt et al., 2016). In addition, a decrease in IMF content, combined with increased PUFA, can lead to changes in the flavour desirability of the beef since differences in fatty acid composition affect the volatile compounds produced in beef on cooking (Baublits et al., 2009; Wood et al., 2004). This problem is likely to be exacerbated in beef from male animals (bulls), which is inherently leaner than that of females or castrated males (steers).

To have sufficient IMF, beef cattle from pasture based production systems may require a finishing period on high energy cereal concentrate diets before slaughter (Aldai et al., 2011). On the other hand, the provision of cereal concentrate diets prior to slaughter could also undermine the benefits associated with grazed grass or grass silage consumed earlier by the animals. To date, little is known about the effect of inclusion of grass silage or grass silage followed by grazed grass in bovine diets on the fatty acid profiles and volatile compounds and ultimate sensory quality of muscle from animals finished on concentrates. Therefore, the objective of the study was to test the hypothesis that feeding bulls, to different target carcass weights, on grass silage, or grass silage followed by pasture, prior to finishing on cereal concentrates, would alter the IMF content, fatty acid composition, volatile profile and, ultimately, the sensory quality of the beef.

2. Materials and Methods

2.1. Animals and management

For this study, 54 animals were randomly selected from a larger study involving 126 weaned Charolais and Limousin sired suckler bulls, described in Mezgebo et al. (2017). The bulls were purchased at approximately 8 months of age during October/November, acclimatised to slatted floor accommodation and offered grass silage *ad libitum* plus 2 kg/head/day of a barley-based concentrate. In early December animals were assigned to a 3 production system (PS) × 3 carcass weight (CW) factorial arrangement of treatments (six animals per treatment). The three PS were: 1) *ad libitum* concentrates (860 g/kg rolled barley, 60 g/kg soya bean meal, 60 g/kg molasses and 20 g/kg minerals/vitamins) plus 1.5 kg grass silage dry matter (DM) daily until slaughter (C), 2) grass silage *ad libitum* plus 1.5 kg concentrate daily for 120 days followed by *ad libitum* concentrates until slaughter (GSC), or 3) grass silage *ad libitum* plus 1.5 kg concentrate daily for 120 days, followed by 100 days grazing at pasture and then *ad libitum* concentrates until slaughter (GSPC). The three target CW within each PS were 360, 410 and 460 kg. A 3-week period was allowed for animals to adjust to the concentrate diet and their weight was regularly recorded. The study was carried out under license from the Irish Government Department of Health and Children and all procedures used complied with national regulations concerning experimentation on farm animals (Health Research Board, 2001).

2.2. Animal slaughter, carcass grading and muscle sampling procedure

The bulls were slaughtered at a commercial slaughter plant (Kepak Group, Clonee, Co. Meath, Ireland) on reaching the treatment mean live weight to achieve the target CW. At 48 h post-mortem, samples of the *longissimus thoracis* (LT) muscle were excised (from the 10^{th} rib region), vacuum packed, aged for a further 15 days at 2ºC and finally stored frozen at -18ºC prior to proximate composition, sensory, fatty acid and volatile compound analyses.

2.3. Proximate composition and sensory analyses

Moisture, IMF and protein contents of the LT muscle were determined using the SMART System 5 microwave moisture drying oven, the NMR SMART Trac rapid fat analyser (CEM Corporation, USA) and the LECO FP328 (LECO Corp., MI, USA) protein analyser, respectively. Sensory analysis was carried out using a 10-person trained taste panel, using panellists selected for their sensory acuity. The LT samples were thawed overnight at 4°C, cut into 20 mm thick steaks and grilled on pre-coded foil-lined grill pans under preheated, domestic low level grills, turning every 3 min until the desired centre temperature of 74°C (measured by a thermocouple probe at the geometrical centre of the sample) was reached; a detailed procedure is given in Mezgebo et al. (2017).

2.4. Chemicals and reagents

All chemicals and reagents used for fatty acid and volatile compound analysis were obtained from Sigma-Aldrich, Ireland Ltd.

2.5. Fatty acid profiles analysis

Fatty acid analysis was undertaken following the method described in Noci et al. (2005), with minor modifications. The IMF was dissolved in 300 µl of toluene for preparation of fatty acid methyl esters (FAME). A sub-sample (100 µl) was transferred to 12 ml glass test tube with screw top. The methylation procedure involved a combination of alkaline and acidic *trans* esterification. The extracted fat was initially methylated with $NaOCH_3$ (2 ml, 0.5N), which was followed with a solution of HCl (4 ml, 4%) in methanol to avoid possible isomerization of conjugated dienes associated with the use of BF_3/CH_3OH. Both methylation procedures were carried out at 50°C for 20 min. Tricosanoic acid methyl ester was used as an internal standard for fatty acid quantification. Deionized water (2ml) saturated with hexane (95:5 water to hexane; vol/vol) was added to the tube containing the FAME, followed by 2 ml of

hexane. The tubes were centrifuged (2000g at 4°C) for 5 min and the top layer containing FAME in hexane was removed and transferred to a glass tube (12 mm × 75 mm). This step was repeated with a further 2 ml of deionized water saturated with hexane. The top layers were transferred to tubes containing approximately 0.5 g of Na_2SO_4 which were centrifuged (2000g at 4°C) for 5 min. An aliquot of the supernatant (1 ml) containing FAME was transferred into a 2 ml glass vial before injection.

The FAME were separated by gas chromatography using a Varian 3800 GC (Varian Instruments) equipped with a CP-Sil 88 capillary column (100 m length, 0.25 mm internal diameter, 0.2 µm film thickness; Chrompack, The Netherlands) and a Varian 8400 auto sampler. The injector and the flame ionization detector were kept at constant temperatures of 250 and 260°C, respectively, and the injector was in a splitless mode. The column oven temperature was held at 70°C for 4 min, increased at 8°C/min to 110°C, increased to 170°C at 5°C/min and held for 10 min, and finally to 240°C at 4°C/min and held for 10.50 min. The total run time was 59 min, and the carrier gas used was H_2 at a flow rate of 1 ml/min. For peak identification, a standard mix of 37 FAME (Supelco Inc., Bellefonte, PA) was used. Individual standards from Matreya (Matreya Inc., Pleasant Gap, PA) were used for identification of those FAME not contained in the mix.

For feed fatty acid analysis, concentrate (n = 10), silage (n = 10) and pasture (n = 16) samples were taken over the duration of the feeding trial. The feed FAME were extracted and prepared as described by Sukhija and Palmquist (1988) and analysed by GC following the GC conditions described above.

2.6. Volatile compounds analysis

The method of Vasta et al. (2011), with minor modifications, was used for analysis of volatile compounds. Frozen LT muscle was defrosted, trimmed of external visible fat and connective

tissue and finely sliced (slice thickness: 1 mm maximum) using a scalpel. Six grams of the sliced beef was placed in a 20 ml glass vial, capped with a polytetrafluoroethylene (PTFE) septum. For the extraction of head space volatile compounds a solid phase micro-extraction (SPME) technique was used. The vial containing the sample was placed in a water bath set at 70°C for 10 min; a 50/30μm DVB/CAR/PDMS fibre (Supelco, Bellefonte, PA; 57328-U) was then exposed to the headspace over the sample at 70°C for 30 min.

After adsorption, the fibre was removed from the vial and immediately inserted into the Varian 3800 GC (Varian Instruments). The injector, operated in splitless mode, was set at 250°C and the desorption time was 4 min. Helium was used as carrier gas with a flow rate of 1.0 ml/min. Volatile compounds were separated using an Agilent DB-5 column (60 m length, 0.32 mm internal diameter, 1μm film thickness) (Agilent Technologies, Palo Alto, CA, USA). The GC oven temperature was programmed as follows: 40°C held for 5 min; increased to 230°C at 4°C/min and held at 230°C for 5 min, with a total acquisition program of 58 min. The GC/MS interface was heated at 280°C. The mass spectra of volatile compounds were generated by a MS equipped with an ion-trap (Polaris Q, Thermo-Finnigan, San Jose, CA); the acquisition was performed in electron impact (EI) mode (70 eV) by 10 microscans/s, scanning the mass range 33–230 m/z.

Compounds were tentatively identified by comparing their mass spectra with the National Institute of Standards and Technology (NIST) Mass Spectral Data Centre and confirmed by matching their linear retention indices (LRI) with Kondjoyan and Berdagué (1996), Mottram (2005) and NIST Mass Spectral Data Centre. Saturated *n*-alkanes (C_7-C_{30}) were run under the same conditions to obtain LRI values for the identified volatile compounds. A quantitative analysis of twenty nine volatile compounds, commonly identified in beef, was carried out. The concentration of the volatile compounds in beef was determined using a standard curve

prepared by running a series of known concentrations (0.00, 0.01, 0.03, 0.05, 0.07, 0.09 and 0.10 ppm) of standard compounds.

2.7. Statistical analysis

The data were analyzed using the SAS statistical package (Version 9.3, SAS Institute Inc., Cary, NC, USA). Data analysis involved a mixed model procedure whereby PS, CW and their interactions were treated as fixed effects and animal as a random effect. With regard to feed fatty acids, data were analysed using the GLM procedure of SAS where feed stuff was regarded as a fixed effect. Differences between means were considered significant at $P < 0.05$. Pearson correlation coefficients (r) between beef fatty acids, volatile compounds and sensory scores were also determined.

3. Results

3.1. Feed fatty acid composition

The fatty acid composition of the fat extracted from the feeds (i.e. concentrate, grass silage and pasture) is presented in Table 1. Total saturated fatty acid (SFA) proportion was higher ($P < 0.05$) for the fat extracted from the concentrate and grass silage (which did not differ) than from pasture. Of the SFA, the proportions of C14:0 and C20:0 were higher ($P < 0.001$) for the fat extracted from the grass silage than from concentrate and pasture, which did not differ; C16:0 was higher ($P < 0.001$) for the fat extracted from the concentrate than from grass silage and from pasture, which did not differ; C18:0 and C22:0 were higher ($P < 0.001$) for the fat extracted from the grass silage and from pasture (which did not differ) than from concentrate; and C24:0 was higher ($P < 0.001$) for the fat extracted from the grass silage than from pasture, which in turn was higher ($P < 0.001$) than for the fat extracted from the concentrate.

Total monounsaturated fatty acid (MUFA) proportion was higher ($P < 0.001$) for the fat extracted from the concentrate than from grass silage and from pasture, which did not differ. Of the MUFA, the proportion of C18:1*c*9 was higher ($P < 0.001$) for the fat extracted from the concentrate than from grass silage, which in turn was higher ($P < 0.001$) than for the fat extracted from the pasture; C20:1 (which was not detected in the fat extracted from the pasture) was higher ($P < 0.001$) for the fat extracted from the concentrate than from grass silage; C22:1*n*-9 was higher ($P < 0.001$) for the fat extracted from the pasture and from grass silage (which did not differ) than for the fat extracted from the concentrate; and C24:1 was higher ($P < 0.001$) for the fat extracted from the concentrate than from grass silage and from pasture, which did not differ.

Total polyunsaturated fatty acid (PUFA) proportion was higher ($P < 0.001$) for the fat extracted from the pasture and from grass silage (which did not differ) than from concentrate. Of the PUFA, the proportion of C18:2*n*-6 trans (which was not detected in the fat extracted from the concentrate) was higher ($P < 0.01$) for the fat extracted from the pasture than from grass silage; C18:2*n*-6 was higher ($P < 0.001$) for the fat extracted from the concentrate than from grass silage, which in turn was higher than for the fat extracted from the pasture; C18:3*n*-3 was higher ($P < 0.001$) for the fat extracted from the pasture than from grass silage, which in turn was higher than for the fat extracted from the concentrate. The proportion of *n*-6 PUFA and *n*-3 PUFA differed significantly ($P < 0.001$) in fat extracted from the feedstuff; *n*-6 PUFA increased from grass to grass silage to concentrate while the opposite was true for *n*-3 PUFA.

3.2. Proximate composition and sensory score data

Intramuscular fat content was lower ($P < 0.01$) and muscle moisture content was higher ($P < 0.01$) for GSPC than for GSC and C bulls, which did not differ (Table 2). Tenderness score

tended to be higher ($P < 0.058$) for C than for GSPC bulls but similar to GSC bulls, which in turn was similar to GSPC bulls; and it was higher ($P < 0.05$) for 410 kg CW than for 360 and 460 kg CW, which did not differ. There was an interaction ($P < 0.05$) between PS and CW with respect to abnormal flavour. Thus for 360 kg CW, abnormal flavour was higher for C and GSPC (which did not differ) than for GSC. For 410 and 460 kg CW, abnormal flavour was lower for C than for GSC and GSPC bulls, which did not differ. There was an interaction ($P < 0.058$) between PS and CW with respect to flavour liking. Thus, for 360 kg CW, flavour liking was higher for GSC than GSPC bulls but similar to C bulls, which in turn was similar to GSPC bulls. For 410 kg CW, flavour liking was higher for C and GSC bulls (which did not differ) than for GSPC bulls; for 460 kg CW, flavour liking was similar for all PS. Overall liking was higher ($P < 0.01$) for C and GSC (which did not differ) than for GSPC bulls.

3.3. Muscle fatty acid composition

The main effects of PS and CW on muscle fatty acid composition, expressed in mg/100 g muscle, are presented in Table 3. With respect to PS, the concentrations of C12:0, C14:0, C16:0, C18:1*c*9, C18:1*c*11, C18:2*t*10,*c*15, C18:2*t*12,*c*15, C20:1*c*11 and total MUFA were lower ($P < 0.05$) for GSPC than for C but similar to GSC, which in turn were similar to C. The concentrations of C16:1*c*13, C18:2*n*-6, C20:3*n*-6 and C24:1, and *n*-6:*n*-3 PUFA ratio were lower ($P < 0.05$) for GSPC than for GSC and C, which did not differ. The concentration of C16:2*c*9,*c*12 was lower ($P < 0.05$) for GSPC and C (which did not differ) than for GSC. The concentration of C18:3*n*-3 was higher ($P < 0.05$) for GSPC than for GSC, which in turn was higher than for C. The concentration of C22:1*n*-9 was lower ($P < 0.05$) for GSPC than for GSC but similar to C, which in turn was similar to GSC. The concentration of C20:4*n*-3 was higher ($P < 0.01$) for GSPC than for GSC and C, which did not differ. The concentration of total SFA was higher ($P < 0.05$) for C than for GSC and GSPC, which did not differ. The

concentration of total PUFA:SFA ratio was higher ($P < 0.05$) for GSPC than for C but similar to GSC, which in turn was similar to C.

With respect to CW, the concentrations of C14:0, C16:0, C17:0, C17:1*t*11, C18:0, C18:1*t*10, C18:1*c*9, C18:2*n*-6, C20:1*c*11, total SFA, MUFA and *n*-6 PUFA, and *n*-6:*n*-3 PUFA ratio were higher ($P < 0.05$) for 460 kg CW than for 360 kg CW but similar to 410 kg CW, which in turn was similar to 360 kg CW. The concentration of C16:1*c*13 was higher ($P < 0.01$) for 360 and 410 kg CW (which did not differ) than for 460 kg. The concentration of C16:2*c*10,*c*15 was lower ($P < 0.01$) for 360 and 410 kg CW (which did not differ) than for 460 kg. The concentration of C20:4*n*-3 was higher ($P < 0.05$) for 360 kg CW than for 460 kg CW but similar to 410 kg CW, which in turn was similar to 360 kg CW. The PUFA:SFA ratio was lower ($P < 0.05$) for 460 kg CW than for 410 and 360 kg CW, which did not differ.

The proportion of individual fatty acids in the total lipid fraction of the muscle, expressed as % of total fatty acids, is presented in Table 4. With respect to PS, the proportions of C15:1 and C17:0 were lower ($P < 0.05$) for C and GSC (which did not differ) than for GSPC. The proportions of C16:1 and C18:2*n*-6 *trans* were lower ($P < 0.05$) for GSPC than for GSC but similar to C, which in turn were similar to GSC. The proportion of C18:2*t*10,*c*15 was lower ($P < 0.05$) for GSPC than for GSC and C, which did not differ. The proportions of C20:2 and C20:4*n*-6 were higher ($P < 0.05$) for GSPC than for C but similar to GSC, which in turn were similar to C. The proportion of C20:3*n*-6 was lower ($P < 0.05$) for GSPC than for GSC but similar to C, which in turn was similar to GSC.

There were interactions ($P < 0.01$) between PS and CW with respect to C18:3*n*-3, C20:5*n*-3, C22:5, total PUFA, *n*-3 PUFA and PUFA/SFA whereby for 360 and 410 kg CW, the proportions of C18:3*n*-3, C20:5*n*-3, C22:5, total PUFA, *n*-3 PUFA and PUFA/SFA were higher for GSPC than for C and GSC, which did not differ, while for 460 kg CW, GSPC was

similar to C but lower than GSC where GSC and C did not differ. There was an interaction ($P < 0.05$) between PS and CW with respect to C22:6*n*-3 whereby for 360 and 410 kg CW, the proportion of C22:6*n*-3 was higher for GSPC than for C and GSC, which did not differ, while for 460 kg CW, GSPC was lower than C, which in turn was lower than GSC.

With respect to CW, the proportion of C10:0 was lower ($P < 0.05$) for 460 kg CW than for 410 kg CW but similar to 360 kg CW, which in turn was similar to 410 kg CW. The proportions of C16:1*c*13, C17:1*c*9 and C20:2 were lower ($P < 0.01$) for 460 kg CW than for 410 and 360 kg CW, which did not differ. The proportions of C18:2*n*-6 *trans*, C18:2*t*11,*c*15 and C18:2*c*9,*t*11 were lower ($P < 0.05$) for 460 kg CW than for 360 kg CW but similar to 410 kg CW, which in turn were similar to 360 kg CW. The proportion of C20:3*n*-6 was lower ($P < 0.05$) for 460 kg CW than for 410 kg CW but similar to 360 kg CW, which in turn was similar to 410 kg CW. The proportions of total SFA and *n*-6/*n*-3 were higher ($P < 0.05$) for 460 kg CW than for 410 and 360 kg CW, which did not differ.

3.4. Volatile compounds

Volatile compounds present in the LT muscle of bulls are available in Table S1 (Supplementary material). Seventy one volatile compounds were identified and classified according to their chemical nature. Of the volatiles identified, 18 were aldehydes, 15 were alcohols, 2 were organic acids, 8 were esters, 22 were hydrocarbons, 4 were ketones and the remaining 2 were a furan and a sulphur-containing compound. Quantitative analysis of the most common volatile compounds derived from bovine muscle is presented in Table 5.

Aldehydes

With respect to PS, the concentration of hexanal was lower ($P < 0.001$) for GSPC than for GSC and C, which did not differ (Table 5). The concentration of heptanal was higher ($P < 0.001$) for GSC than for GSPC and C, which did not differ. The concentration of decanal was

lower ($P < 0.001$) for GSPC than for C, which in turn was lower ($P < 0.001$) than for GSC. The concentration of 2-decenal was higher ($P < 0.001$) for GSC and GSPC (which did not differ) than for C.

With respect to CW, the concentration of hexanal was higher ($P < 0.05$) for 410 kg CW than for 360 kg CW but similar to 460 kg CW, which in turn was similar to 360 kg CW. The concentration of heptanal was higher ($P < 0.001$) for 460 and 360 kg CW (which did not differ) than for 410 kg CW. The concentration of benzaldehyde was higher ($P < 0.05$) for 460 kg CW than for 360 kg CW but similar to 410 kg CW which in turn was similar to 360 kg CW. The concentration of decanal was lower ($P < 0.001$) for 460 kg CW than for 360 kg CW, which in turn was lower ($P < 0.001$) than for 410 kg CW. The concentration of 2-decenal was higher ($P < 0.001$) for 460 kg CW than for 410 and 360 kg CW, which did not differ.

Alcohols and organic acids

With respect to PS, the concentration of 2-methyl-1-butanol was higher ($P < 0.001$) for GSPC than for C, which in turn was higher ($P < 0.001$) than for GSC. The concentration of nonanoic acid was higher ($P < 0.001$) for GSPC than for GSC, which in turn was higher ($P < 0.001$) than for C. With respect to CW, the concentration of nonanoic acid was lower ($P < 0.001$) for 460 and 410 kg CW (which did not differ) than for 360 kg CW.

Hydrocarbons and ketones

With respect to PS, the concentration of tridecane was lower ($P < 0.05$) for GSPC than for C but similar to GSC, which in turn was similar to C. The concentration of toluene was higher ($P < 0.001$) for GSPC than for GSC, which in turn was higher ($P < 0.001$) than for C. The concentration of 2-nonanone was lower ($P < 0.001$) for GSC than for GSPC and C, which did not differ.

With respect to CW, the concentration of decane was higher ($P < 0.001$) for 460 kg CW than for 410 and 360 kg CW, which did not differ. The concentration of tridecane was higher ($P < 0.001$) for 460 kg CW than for 360 kg CW, which in turn was higher than for 410 kg CW. The concentration of eicosane was higher ($P < 0.001$) for 460 and 410 kg CW (which did not differ) than for 360 kg CW. The concentration of 2-nonanone was lower ($P < 0.001$) for 410 kg CW than for 460 and 360 kg, which did not differ.

3.5. Correlations between total intramuscular fat (IMF), sensory scores, fatty acid concentration and volatile compounds of beef

The correlations between selected sensory scores, fatty acid concentration and volatile compounds of beef are summarised in Table 6 and discussed below. The full set of correlation data is available in Table S2 (Supplementary material).

4. Discussion

From a nutritional value and eating quality perspective, the inclusion of grass silage or grazed grass could enhance the proportion of desirable fatty acids in bovine muscle, while finishing on concentrates can increase the IMF which in turn enhances beef eating quality (Hunt et al., 2016). The effects of PS and CW on the carcass traits are described in detail in a companion paper involving a larger cohort of animals (Mezgebo et al., 2017). Thus, the discussion focuses on the impact of inclusion of grass silage, or grass silage followed by grazed grass, prior to a concentrate finishing period on muscle fatty acids (especially the nutritionally important fatty acids) and volatile compounds and on the ultimate quality of beef. The effects of CW on these components are also discussed.

4.1. Fatty acid composition

The feed fatty acid compositions are in agreement with previously published data for a barley-based concentrate, grass silage and pasture (Noci et al. 2005; French et al. 2000). Differences in the fatty acid composition of LT muscle reflected differences in the dietary fatty acid composition, as shown for the total SFA, MUFA and some PUFA (such as C18:2*n*-6 and C18:3*n*-3). The higher SFA (such as C12:0, C14:0 and C16:0) and MUFA (such as C18:1*c*9, C18:1*c*11 and C20:1*c*11) concentrations for the C bulls was expected since high energy cereal-based concentrate diets are often a major source of SFA and MUFA (Aldai et al., 2011), as shown in the feed fatty acid composition data. Similarly, the higher C18:3*n*-3 concentration for the GSPC bulls may be related to the inclusion of grazed grass as *n*-3 PUFA are associated with pasture based systems (Raes et al., 2001). A similar explanation may be offered for the higher C18:3*n*-3 concentration in GSC bulls compared to the C bulls. Thus, the variations in these fatty acids and other PUFA (such as C18:2*n*-6, C20:3*n*-6, C20:4*n*-3, PUFA:SFA ratio and *n*-6:*n*-3 PUFA ratio) between the PS can be explained by the inclusion of grass silage or grass silage followed by grazed grass prior to finishing on concentrates.

However, compared to the C group, the effect on SFA, MUFA and PUFA of the inclusion of grass silage or grass silage followed by grazed grass prior to the finishing period on concentrates differed, with the inclusion of grazed grass affecting some SFA (a decrease in C12:0, C14:0 and C16:0 concentrations), MUFA (a decrease in C18:1*c*9, C18:1*c*11, C20:1*c*11 and C24:1 concentrations) and PUFA (a decrease in C18:2*n*-6 and C20:3*n*-6 concentrations and *n*-6:*n*-3 PUFA ratio, and an increase in C20:4*n*-3 concentration and PUFA:SFA ratio) while the inclusion of grass silage did not. A possible explanation could be the duration of the concentrate finishing period since a longer period of concentrate feeding was required for the GSC bulls to achieve the target carcass weights (i.e. mean of 94 and 71 days for GSC and GSPC bulls, respectively). The shorter finishing period may have led to the retention of the residual effects of grazed grass on the fatty acid composition of muscle from the GSPC bulls. Similar findings were reported by Aldai et al. (2011) who studied the effect of different lengths of concentrate finishing period on fatty acids. Similarly, with regard to CW, the higher concentrations of C14:0, C16:0, C17:0, C17:1*t*11, C18:0, C18:1*t*10, C18:1*c*9, C18:2*n*-6, total SFA, MUFA, *n*-6 PUFA and *n*-6/*n*-3 PUFA ratio for 460 kg CW compared to 360 kg CW and lower PUFA:SFA ratio for 460 kg CW compared to 410 and 360 kg CW could be explained by the differences in the length of concentrate finishing period whereby on average days on *ad libitum* concentrates were 67, 112 and 150 for 360, 410 and 460 kg CW, respectively.

As reported by Raes et al. (2001), C18:3*n*-3 and C18:2*n*-6 can be used as indicators of grass and concentrate based production systems, respectively. Similarly, in our study, the higher C18:3*n*-3 and lower C18:2*n*-6 concentrations for the GSPC bulls compared to GSC and C bulls are indicative of inclusion of grazed grass in the diet of the bulls. This shows that finishing on concentrate diets, up to 71 days in our case, may not entirely eliminate the contribution to muscle fatty acids of grazed grass offered prior to the finishing period, which

was in agreement with Scerra et al. (2014) in a study conducted over a relatively shorter finishing period (60 days).

Many of the C18:1 *trans* isomers are often regarded as undesirable fatty acids as they are associated with increased atherogenicity and they are often present in higher quantities in beef from animals fed grain based diets or finished on concentrate rations than beef from grass based systems (Alfaia et al., 2009; Purchas et al., 2005). In agreement, in the present study, C18:1*t*10 (the dominant C18:1 *trans* isomer after C18:1*t*11) was significantly higher in the beef from 460 kg CW compared to the beef from 360 kg CW, reflecting longer pre-slaughter duration of dietary concentrate feeding. With regard to PS, although not significant, most of the C18:1 *trans* isomers (i.e. C18:1*t*6-8, C18:1*t*9, C18:1*t*10, C18:1*t*11, C18:1*t*12 + C18:1*t*13) were numerically higher in the C bulls compared to the other groups; they also increased numerically with increased CW.

The C18:2*c*9,*t*11, a prominent conjugated linoleic acid (CLA) with positive health implications (Salter, 2013), has been linked to grass based production systems (Shantha et al., 1997). In the present study, its concentration was similar among all treatments. As shown by Scerra et al. (2014), a higher C18:2*c*9,*t*11 content was reported from LT muscle of bulls fed on pasture prior to finishing on concentrate diet compared to bulls raised on concentrate diet only. However, compared to our study, the pasture feeding period was longer (200 *vs* 100 days) and the concentrate finishing period was shorter (60 *vs* 71 days) in the study of Scerra et al. (2014) which may have contributed to a greater effect of the pasture diet on this particular isomer. Dannenberger et al. (2005) reported that not all CLA isomers were associated with grass-based diets as some CLA isomers such as C18:2*t*9,*c*11 and C18:2*t*10,*c*12 were abundant in muscle from animals fed concentrate based diets while others such as C18:2*t*11,*c*13 and C18:2*c*9,*t*11 were abundant in muscles of animals finished on

grass. In addition, Fukuda et al. (2009) reported that C18:3*n*-3 was linked to the formation of the isomer C18:2*t*9,*c*11 which in turn was linked for the isomerization of C18:2*t*11,*c*15. In our study, despite differences in diet prior to finishing period and higher C18:3*n*-3 concentrations in the GSPC bulls, the CLA isomers we detected (C18:2*c*9,*t*11 and C18:2*t*10,*c*12) had similar concentrations, which could possibly be because of feeding the same concentrate finishing diet.

In many cases the PUFA:SFA ratio is higher in beef from grass based systems than from concentrate based systems (Baublits et al., 2009). In the present study, the higher PUFA:SFA ratio in the GSPC bulls compared to the C bulls was mainly because of the lower SFA concentration of GSPC bulls which in turn could be related to the inclusion of grazed grass prior to the finishing period. A similar increase in PUFA:SFA ratio was reported by French et al. (2000) in beef from steers raised on grass based diets. With regard to CW, the higher PUFA:SFA ratio in the 360 and 410 kg CW bulls compared to the 460 kg CW bulls could be due to the lower total SFA content of the 360 and 410 kg CW bulls which in turn could be related to the shorter concentrate finishing period. In general, beef from concentrate based production systems was reported to have higher *n*-6:*n*-3 PUFA ratio than beef from pasture based systems, with values of 9.2 and 4.1 reported by Enser et al. (1998) and French et al. (2000), respectively. In the present study, the inclusion of grazed grass resulted in a lower *n*-6:*n*-3 PUFA ratio, in agreement with Aldai et al. (2011) (3.3) and French et al. (2000) (2.3) who studied beef muscle from grass fed animals.

Overall, in discussing the significant differences in fatty acid concentration due to PS and CW, differences in the IMF content should also be considered. Thus, for example, while there were significant treatment differences in the concentration of C14:0, C16:0, C18:0, C18:1*c*9, C18:2*n*-6, C20:1*c*11, C22:1*n*-9 and C20:4*n*-3, these were not apparent when fatty acid

composition was expressed on a proportion basis (Tables 3 and 4). However, for some fatty acids (for example, C18:3*n*-3 and C20:3*n*-6) the effects of PS and/or CW on fatty acid composition were evident whether or not fatty acids were expressed on a concentration or proportion basis. From a human nutrition perspective expression on a proportion, as opposed to a concentration, basis is particular useful in presenting a profile of the bovine fat consumed.

4.2. Volatile compounds

Aldehydes, one of the main categories of meat volatile compounds, are primarily produced by thermal oxidation of fatty acids during cooking (Descalzo et al., 2005) and their concentration was reported to be related to the levels of C18:2*n*-6 and C18:3*n*-3 (Elmore et al., 2005). In the present study, the higher concentration of hexanal in the C and GSC bulls could be due to the higher levels of C18:2*n*-6 in the muscle of these bulls. The positive relationship ($r = 0.28$, $P < 0.05$) between hexanal and C18:2*n*-6 concentrations supported this observation. Similarly, hexanal was also positively correlated ($r = 0.27$, $P < 0.05$) with C18:1*c*9 content which was similarly higher in C and GSC bulls, and when thermally oxidized can give rise to aldehydes, including hexanal (Elmore et al., 1999). Although it was reported that oxidation of C18:2*n*-6 results in higher concentrations of 2-nonenal and pentanal while C18:3*n*-3 results in higher concentration of benzaldehyde (Descalzo et al., 2005; Elmore et al., 2005), in our study, the concentrations of these volatiles were similar between the PS despite variations in C18:2*n*-6 and C18:3*n*-3 concentrations.

Alcohols also originate from oxidation of fatty acids (Dransfield, 2008). Beef from grass based systems is more susceptible to autoxidation due to higher levels of PUFA, particularly of *n*-3 PUFA, but the rate of oxidation could be reduced by naturally synthesized anti-oxidants in the pasture-based systems (Aurousseau et al., 2004). The concentration of 1-

octen-3-ol was similar between the treatments even though GSPC bulls had elevated levels of C18:3*n*-3 which is believed to be source of this alcohol mainly because of its third double bond. However, in our study, even though not significant, C18:3*n*-3 and 1-octen-3-ol concentrations were positively correlated (r = 0.22, $P < 0.09$).

Like alcohols and organic acids, the volatile hydrocarbons did not show clear trends, i.e. some volatiles were detected in higher concentrations on GSPC bulls while others on GSC and/or C bulls. This might be explained by the finishing period as provision of the same finishing diet could diminish the effects of different diets prior to the finishing period. However, toluene, a compound reported to be an indicator of feeding lambs on pasture (Sivadier et al., 2010), was detected in higher concentration in the GSPC bulls. A similar finding was reported by Vasta et al. (2011).

Ketones originate mainly from oxidation of lipids (Mottram, 1998). Oxidation of lipids was also reported to be associated with formation of furans (Grosch, 1987), even though furans are primarily linked with Maillard reactions (Raes et al., 2003). A similar concentration of 2-pentyl-furan was detected in all treatments even though the C and GSC bulls had higher concentration of C18:2*n*-6 which, as reported by Grosch (1987), could also give rise to 2-pentyl-furan upon oxidation. However, in our study, the positive but weak association between C18:2*n*-6 and 2-pentyl-furan (r = 0.17) concurs somewhat with Grosch (1987). It may be suggested that the similar concentration of 2-pentyl-furan across the treatments could be attributed to feeding the same concentrate finishing diet.

4.3 Correlations between total intramuscular fat (IMF), sensory scores, fatty acid concentration and volatile compounds of beef

The correlations between selected sensory scores, fatty acid concentration and volatile compounds of beef are summarised in Table 6. A more detailed analysis on the relationships

between IMF (and other muscle chemical constituents) and sensory quality of beef is given in a companion study (Mezgebo et al., 2017). In brief, there were positive correlations between IMF content and many of the sensory scores (tenderness, beefy flavour, flavour liking and overall liking; $r \geq 0.36$, $P < 0.01$). These associations, which indicate that eating quality of beef is greatly influenced by IMF, were in agreement with other studies (Corbin et al., 2015; O'Quinn et al., 2012). In the present study, juiciness was poorly correlated with total IMF content and many of the individual fatty acid concentrations in contrast to other reports (Hunt et al., 2016).

The positive correlations between overall IMF content and many of the fatty acid concentrations, even though not all strong, were in line with Hunt et al. (2016) and this indicates that the total IMF deposition is associated with the increase in the concentration of individual fatty acids, as reported by Wood et al. (2008). An increase in total IMF can have a diluting effect on PUFA content since SFA and MUFA are often deposited at a faster rate than PUFA (De Smet et al., 2004). The negative correlations between total IMF content and PUFA:SFA ratio ($r = - 0.35$, $P < 0.05$) and total IMF content and C20:5*n*-3 ($r = - 0.39$, $P < 0.01$), and relatively weaker and negative correlations with some PUFA (such as C18:3*n*-3 and C22:5) support this observation.

Some individual fatty acids were also correlated with the sensory scores even though not as strong and consistent as the correlations between the total IMF content and sensory scores. Of these, the correlations, even though not all significant, between some of the fatty acids (for example, C20:1*c*11 and C22:0) and tenderness, beefy flavour, flavour liking and overall liking scores were partly in agreement with Hunt et al. (2016). Overall it appears that the sensory scores were mainly influenced by the total IMF content as the relationships between sensory scores and total IMF were stronger and more consistent than the relationships

between sensory scores and individual fatty acids. In other studies PUFA were associated with a decrease in desirable flavour (such as beefy flavour) and an increase in undesirable flavour (such as grassy and milky-oily) characteristics of beef (Baublits et al., 2006, 2009). In the present study, the positive correlations between C20:5*n*-3 and abnormal flavour (r = 0.28, $P < 0.05$), between C18:3*n*-3 and PUFA/SFA ratio and abnormal flavour (although not significant), and the negative correlations between C20:5*n*-3 and overall liking (r = - 0.34, $P < 0.05$) and between PUFA/SFA ratio and overall liking (r = - 0.36, $P < 0.01$) support this observation.

The positive correlations between total IMF content and some volatile compounds (such as 2-nonenal and decane) were expected as the volatile compounds detected are primarily derived from thermal oxidation of lipids (Larick et al., 1987; Mottram, 1998). However, some volatile compounds (such as 2-decenal, 2-methyl-1-butanol, nonanoic acid and dimethyl sulfide) were negatively correlated with the total IMF content.

In the present study, the positive correlations (although not significant) between hexanal concentration and overall liking, flavour liking and beefy flavour scores were not in agreement with other studies (Hunt et al., 2016). As reported by Melton (1983) hexanal, produced mainly during a thermal oxidation of fatty acids, affects the flavour of beef positively but also added that at higher concentrations it could produce undesirable flavours. A similar conclusion was drawn by Brunton et al. (2000) in a study of flavour development in turkey. In our study, the positive relationship between hexanal and sensory scores suggests that the hexanal concentration was within an acceptable level/range or its effect could have been counterbalanced by other volatile compounds. In general, aldehydes are mainly reported to have negative correlations with sensory scores (Legako et al., 2016), even though, in the present study, some aldehydes (such as heptanal and 2-nonenal) were positively correlated

(although not all significant) with beefy flavour, flavour liking and overall liking. The negative correlations between dimethyl sulphide and flavour liking and overall liking scores and positive relationships between nonane and flavour liking and overall liking scores were in agreement with Legako et al. (2016).

5. Conclusion

The study showed that the inclusion of grass silage followed by grazed grass prior to finishing on a concentrate diet changed the fatty acid composition of the bovine muscle while inclusion of grass silage alone had an intermediate effect. Thus, the inclusion of grazed grass resulted in higher C18:3*n*-3 concentration and PUFA:SFA ratio and lower total IMF content, C18:2*n*-6, total SFA and MUFA concentrations and *n*-6:*n*-3 PUFA ratio. Concentrations of the major fatty acids in muscle (C:16:0, C18:0 and C18:1*c*9) increased with increasing CW when expressed in quantitative terms but not when expressed as a proportion of total fatty acids. With respect to volatile compounds, while the inclusion of grass silage followed by grazed grass resulted in lower concentrations of hexanal, decanal and tridecane and higher concentrations of 2-decenal, 2-methyl-1-butanol, nonanoic acid and toluene, the inclusion of grass silage alone resulted in a higher concentrations of heptanal and decanal and lower concentrations of 2-methyl-1-butanol and 2-nonanone. There was no consistent effect of CW on individual volatile concentrations. The differences in sensory scores in beef (for example, tenderness, flavour liking and overall liking) most likely reflect differences in IMF, with which they show strongest correlations. The data support a negative impact of some long-chain PUFA on flavour attributes although the absolute differences were small and may not be detectable by an untrained sensory panel.

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7. References

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Table 1. The proportion (expressed as % of total fatty acids) of fatty acids in the fat extracted from feedstuffs (concentrate, grass silage and pasture) fed to bulls.

	Concentrate (n=10)		Grass-silage (n=10)		Pasture (n=16)		Significance
	Mean	SD	Mean	SD	Mean	SD	
Fatty acids (%)							
C14:0	0.40[a]	0.152	0.95[b]	0.370	0.33[a]	0.324	.000
C16:0	27.12[b]	1.661	21.98[a]	2.955	21.73[a]	2.320	.000
C16:1	[n.d.]-	-	0.45	0.949	0.29	0.808	
C17:1	0.03	0.097	0.23	0.590	0.09	0.256	
C18:0	1.82[a]	0.159	2.42[b]	0.726	2.78[b]	0.432	.000
C18:1*t*9	0.31	0.273	0.34	0.604	0.39	0.549	
C18:1*c*9	15.18[c]	0.988	3.38[b]	0.550	2.84[a]	0.485	.000
C18:2*n*-6 *trans*	-	-	0.14[a]	0.295	1.54[b]	1.632	.002
C18:2*n*-6	48.73[c]	1.127	15.55[b]	1.200	12.00[a]	0.789	.000
C20:0	0.11[a]	0.204	0.93[b]	0.422	0.30[a]	0.358	.000
C18:3*n*-6	-	-	0.04	0.129	0.02	0.081	
C20:1	0.84[b]	0.057	0.05[a]	0.144	-	-	.000
C18:3*n*-3	3.88[a]	0.202	48.06[b]	6.282	53.52[c]	4.717	.000
C21:0	0.09	0.291	0.42	0.784	0.04	0.146	
C20:2	0.04	0.080	0.05	0.150	-	-	
C22:0	0.24[a]	0.243	1.79[b]	0.566	1.56[b]	0.341	.000
C20:3*n*-6	0.22	0.294	0.30	0.627	-	-	
C22:1*n*-9	0.50[a]	0.120	0.86[b]	0.376	1.03[b]	0.372	.001
C24:0	0.12[a]	0.153	2.01[c]	0.572	1.50[b]	0.340	.000
C24:1	0.37[b]	0.266	0.04[a]	0.131	0.04[a]	0.113	.000
SFA	29.89[b]	1.607	30.51[b]	4.980	28.23[a]	3.238	.041
MUFA	17.23[b]	0.765	5.36[a]	2.053	4.69[a]	1.024	.000
PUFA	52.87[a]	1.010	64.13[b]	5.819	67.08[b]	3.695	.000

n-6 PUFA	48.99[c]	0.983	16.08[b]	1.333	13.56[a]	1.694	.000
n-3 PUFA	3.88[a]	0.202	48.06[b]	6.282	53.52[c]	4.717	.000

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids

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

[n.d.] not detected

SD: standard deviation

Table 2. Proximate composition and sensory panel evaluation of *longissimus thoracis* muscle of bulls from three production systems (PS) (C = concentrate, GSC = grass silage followed by concentrate, GSPC = grass silage followed by pasture and then concentrate) and carcass weights (CW) (360, 410 and 460 kg)

Treatment	PS			CW			s.e.m.	Significance		
	C	GSC	GSPC	360	410	460		PS	CW	PS x CW
Proximate composition (g/kg)										
Intramuscular fat (IMF)	26.3[b]	21.9[b]	9.3[a]	18.1	19.9	19.4	3.12	.001		
Moisture	732.8[a]	734.1[a]	746.0[b]	741.9	739.1	731.9	3.07	.007		
Protein	235.0	234.8	229.7	231.1	234.2	234.2	2.93			
Ash	11.0	10.8	10.9	11.1	11.0	10.6	0.17			
Sensory panel test[m]										
Tenderness	4.39[b]	4.28[ab]	3.88[a]	4.28[d]	4.47[e]	3.80[d]	0.154	.058	.011	
Juiciness	4.86	4.98	5.00	4.87	5.07	4.92	0.084			
Beefy flavour	4.43	4.39	4.26	4.39	4.40	4.29	0.066			
Abnormal flavour	2.41	2.60	2.57	2.50	2.49	2.59	0.075			.044[x]
Flavour liking	5.03[a]	5.29[b]	4.84[a]	5.13	5.10	4.93	0.079	.001		.058[y]
Overall liking	4.56[b]	4.76[b]	4.14[a]	4.56	4.63	4.27	0.120	.002		

[x] Mean values = 2.61, 2.31 and 2.54 for 360 kg CW, 2.33, 2.81 and 2.62 for 410 kg CW, and 2.30, 2.67 and 2.55 for 460 kg CW of C, GSC and GSPC, respectively

[y] Mean values = 4.92, 5.59 and 4.80 for 360 kg CW, 5.09, 5.02 and 4.69 for 410 kg CW and 5.07, 5.26 and 5.04 for 460 kg CW of C, GSC and GSPC, respectively

[m] Category scale: one to eight, where 8 is extremely tender/juicy/intense flavour/liked

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

[d,e,f] means of CW within rows assigned different superscripts differ significantly ($P < 0.05$)

s.e.m. = standard error of the mean for comparison of main effects

Table 3. Fatty acid concentration in the total lipid fraction of intramuscular fat from *longissimus thoracis* muscle of bulls from three production systems (PS) (C = concentrate, GSC = grass silage followed by concentrate, GSPC = grass silage followed by pasture and then concentrate) and carcass weights (CW) (360, 410 and 460 kg).

	PS			CW			s.e.m.	Significance		
	C	GSC	GSPC	360	410	460		PS	CW	PS x CW
Fatty acids (mg/100 g muscle)										
C10:0	4.80	5.01	3.72	3.80	4.94	4.80	0.689			
C11:0	0.04	0.07	0.06	0.03	0.11	0.03	0.041			
C12:0	1.38^{b}	1.19^{ab}	0.76^{a}	0.91	1.1	1.31	0.227	.035		
C14:0	70.39^{b}	55.69^{ab}	48.22^{a}	46.56^{d}	55.45^{de}	72.27^{e}	8.787	.044	.044	
C15:0 *iso*	2.30	1.99	1.68	1.77	1.91	2.28	0.421			
C15:0 *anteiso*	4.00	3.71	3.13	3.05	3.63	4.16	0.669			
C14:1	12.74	11.07	8.98	8.97	10.31	13.5	2.011			
C15:0	11.97	10.6	8.42	8.82	10.37	11.8	1.514			
C15:1	24.21	27.35	22.56	23.12	24.96	26.03	2.225			
C16:0 *iso*	2.83	2.51	2.07	2.24	2.46	2.71	0.488			
C16:0	605.5^{b}	500.3^{ab}	433.7^{a}	421.3^{d}	487.6^{de}	630.6^{e}	69.89	.049	.040	
C17:0 *iso* + C16:1*t*9	7.55	6.54	6.17	5.98	6.42	7.87	1.113			
C16:1*t*10-12	3.70	3.03	2.59	2.78	2.98	3.56	0.662			
C16:1	79.02	68.05	54.82	56.46	64.84	80.58	10.292			
C16:1*c*13	11.41^{b}	11.02^{b}	4.80^{a}	12.51^{e}	10.24^{e}	4.47^{d}	2.156	.035	.011	
C17:0	25.41	21.9	21.88	16.75^{d}	22.10^{de}	30.34^{e}	4.24		.028	
C17:1*t*11	10.53	10.40	9.52	7.17^{d}	9.58^{de}	13.70^{e}	2.045		.029	
C16:2*c*10,*c*15	6.52	6.39	8.12	3.26^{d}	6.39^{d}	11.38^{e}	1.647		.000	
C17:1*c*9	20.10	18.93	15.23	16.07	20.31	17.88	2.346			
C16:2*c*9,*c*12	13.26^{a}	16.74^{b}	12.99^{a}	14.65	15.87	12.46	1.33	.049		
C18:0	351.8	300.1	273.2	258.9^{d}	291.0^{de}	375.2^{e}	44.25		.047	
C18:1*t*4	0.28	0.51	0.30	0.36	0.33	0.41	0.181			

C18:1*t*5	0.80	0.08	0.18	0.22	0.25	0.6	0.31		
C18:1*t*6-8	2.73	2.23	1.81	1.7	2.3	2.77	0.508		
C18:1*t*9	5.06	4.50	3.52	5.15	3.46	4.46	1.243		
C18:1*t*10	14.25	11.6	9.8	7.81^{d}	11.62^{de}	16.22^{e}	2.179		.009
C18:1*t*11	20.75	18.93	17.11	18.35	19.73	18.71	3.536		
C18:1*t*12 + C18:1*t*13	9.47	7.26	3.05	5.63	4.61	9.54	2.683		
C18:1*c*9	789.6^{b}	674.4^{ab}	563.6^{a}	568.2^{d}	635.8^{de}	823.6^{e}	97.42	.048	.037
C18:1*c*11	33.18^{b}	26.93^{ab}	21.61^{a}	21.73	29.03	30.97	4.337	.026	
C18:1*c*12	2.43	1.53	1.39	1.19	2.19	1.97	0.64		
C18:1*c*13	6.26	5.39	4.11	4.3	5.09	6.37	0.936		
C18:1*t*16	3.61	2.82	2.47	2.53	3.01	3.35	0.607		
C19:0 + C18:1*c*15	3.77	3.22	2.54	2.72	3.32	3.5	0.569		
C18:2*n*-6 *trans*	3.43	3.31	2.31	2.96	2.95	3.15	0.549		
C18:1*c*16	2.51	2.2	1.61	1.76	2.11	2.44	0.381		
C18:2*t*10,*c*15	2.57^{b}	2.11^{ab}	1.44^{a}	1.72	2.18	2.21	0.438	.047	
C18:2*t*11,*c*15	2.26	2.3	1.65	2.12	2.01	2.07	0.418		
C18:2*n*-6	85.54^{b}	90.03^{b}	65.67^{a}	66.17^{d}	81.87^{de}	93.20^{e}	8.553	.049	.030
C18:2*t*12,*c*15	2.19^{b}	1.94^{ab}	1.30^{a}	1.55	1.78	2.11	0.314	.045	
C20:0	2.33	1.97	1.70	1.7	1.89	2.41	0.316		
C18:3*n*-6	0.17	0.93	0.08	0.83	0.12	0.23	0.407		
C20:1	1.34	1.15	0.85	0.98	1.12	1.25	0.24		
C20:1*c*11	3.14^{b}	2.80^{ab}	2.01^{a}	2.28^{d}	2.41^{de}	3.26^{e}	0.383	.042	.048
C18:3*n*-3	11.96^{a}	12.96^{b}	13.94^{c}	12.69	13.24	12.94	1.359	.039	
C18:2*c*9,*t*11	9.28	7.72	6.97	7.49	7.70	8.78	1.535		
C18:2*t*10,*c*12	1.22	1.92	0.66	1.71	0.91	1.18	0.601		
C21:0	0.8	0.87	0.56	0.63	0.82	0.78	0.13		
C20:2	1.46	1.75	1.34	1.47	1.54	1.54	0.173		
C22:0	0.44	0.33	0.19	0.21	0.33	0.42	0.125		

C20:3*n*-6	0.55[b]	0.75[b]	0.25[a]	0.43	0.61	0.51	0.080	.000		
C22:1*n*-9	4.17[ab]	5.39[b]	3.53[a]	4.51	3.98	4.61	0.623	.041		
C20:3*n*-3	0.06	0.14	0.09	0.08	0.12	0.08	0.052			
C20:4*n*-6	16.77	18.99	14.7	15.43	16.26	18.77	1.593			
C22:2	0.12	1.07	0.43	0.94	0.46	0.22	0.424			
C20:4*n*-3	0.46[a]	0.60[a]	0.95[b]	0.89[e]	0.63[de]	0.49[d]	0.105	.002	.030	
C24:0	0.6	0.56	0.5	0.4	0.5	0.75	0.161			
C20:5*n*-3	5.15	5.75	6.58	6.16	5.74	5.59	0.552			
C22:4	0.21	0.61	0	0.44	0.14	0.24	0.28			
C24:1	1.55[b]	1.92[b]	1.11[a]	1.44	1.5	1.65	0.182	.011		
C22:5	8.3	9.84	9.33	9.16	9.15	9.16	0.817			
C22:6*n*-3	4.19	4.86	3.7	4.48	5.07	3.2	0.552			
Others	46.53	34.69	19.69	28.39	27.89	44.62	8.612			
SFA	1092.2[b]	913.3[a]	805.9[a]	773.1[d]	890.7[de]	1147.7[e]	131.02	.034	.049	
MUFA	1066.6[b]	922.8[ab]	759.0[a]	778.0[d]	875.0[de]	1095.4[e]	127.28	.042	.035	
PUFA	175.7	190.8	152.5	154.6	174.7	189.5	16.78			
PUFA/SFA	0.17[a]	0.22[ab]	0.25[b]	0.23[e]	0.24[e]	0.17[d]	0.017	.010	.019	.018
n-6 PUFA	109.5	119.4	85.4	90.4[d]	104.9[de]	119.0[e]	10.95		.037	
n-3 PUFA	37.13	40.52	38.98	38.86	39.91	37.85	3.494			
n-6/*n*-3 PUFA	2.78[b]	2.91[b]	2.28[a]	2.34[d]	2.61[de]	3.01[e]	0.157	0.006	.015	
Total fatty acids	2381.0[b]	2061.5[b]	1737.2[a]	1734.1[d]	1968.3[de]	2477.2[e]	272.39	.041	.039	

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.
n-6 PUFA = sum of C18:2*n*-6 *trans*, C18:2*n*-6, C18:3*n*-6, C18:2*t*10,*c*12, C20:2, C20:3*n*-6, C20:4*n*-6, C22:2, C22:4.
n-3 PUFA = sum of C18:2*t*10,*c*15, C18:2*t*11,*c*15, C18:2*t*12,*c*15, C18:3*n*-3, C20:3*n*-3, C20:4*n*-3, C20:5*n*-3, C22:5, C22:6*n*-3.
[a,b,c] means of PS within rows assigned different superscripts differ significantly ($P < 0.05$)
[d,e,f] means of CW within rows assigned different superscripts differ significantly ($P < 0.05$)
s.e.m. = standard error of the mean for comparison of main effects

Table 4. The proportion (expressed as % of total fatty acids) of individual fatty acids in the total lipid fraction of intramuscular fat from *longissimus thoracis* muscle of bulls from three production systems (PS) (C = concentrate, GSC = grass silage followed by concentrate, GSPC = grass silage followed by pasture and then concentrate) and carcass weights (CW) (360, 410 and 460 kg).

	PS			CW			s.e.m.	Significance		
	C	GSC	GSPC	360	410	460		PS	CW	PS x CW
Fatty acids (%)										
C10:0	0.21	0.25	0.27	0.24^{de}	0.29^{e}	0.20^{d}	0.024		.035	
C11:0	0.00	0.00	0.01	0.00	0.01	0.00	0.002			
C12:0	0.05	0.06	0.05	0.05	0.05	0.06	0.013			
C14:0	3.01	2.70	2.72	2.59	2.61	3.23	0.247			
C15:0 *iso*	0.08	0.10	0.15	0.09	0.08	0.15	0.046			
C15:0 *anteiso*	0.15	0.18	0.17	0.16	0.17	0.16	0.013			
C14:1	0.46	0.53	0.41	0.49	0.45	0.47	0.039			
C15:0	0.50	0.51	0.46	0.49	0.51	0.48	0.016			
C15:1	1.22^{a}	1.45^{a}	1.92^{b}	1.68	1.67	1.24	0.144	.005		
C16:0 *iso*	0.11	0.12	0.10	0.12	0.11	0.09	0.009			
C16:0	25.70	24.22	24.03	24.03	24.11	25.81	0.721			
C17:0 *iso* + C16:1*t*9	0.30	0.32	0.35	0.35	0.32	0.29	0.014			
C16:1*t*10-12	0.14	0.14	0.12	0.15	0.13	0.12	0.010			
C16:1	3.13^{ab}	3.30^{b}	2.87^{a}	3.19	3.05	3.07	0.118	.043		
C16:1*c*13	0.58	0.67	0.48	0.78^{e}	0.71^{e}	0.24^{d}	0.125		.007	
C17:0	1.02^{a}	1.01^{a}	1.30^{b}	1.04	1.11	1.19	0.088	.041		
C17:1*t*11	0.49	0.47	0.58	0.38	0.51	0.64	0.113			
C16:2*c*10,*c*15	0.32	0.32	0.50	0.24	0.43	0.46	0.071			
C17:1*c*9	0.87	0.96	1.09	1.00^{e}	1.18^{e}	0.75^{d}	0.087		.004	
C16:2*c*9,*c*12	0.66	0.88	1.14	1.06	1.07	0.55	0.088			
C18:0	14.12	14.48	15.31	14.67	14.63	14.61	0.594			
C18:1*t*4	0.02	0.02	0.04	0.02	0.04	0.02	0.013			

C18:1*t*5	0.04	0.00	0.03	0.02	0.02	0.03	0.018			
C18:1*t*6-8	0.10	0.10	0.09	0.09	0.11	0.10	0.012			
C18:1*t*9	0.20	0.21	0.17	0.24	0.16	0.18	0.046			
C18:1*t*10	0.58	0.51	0.48	0.40	0.58	0.60	0.070			
C18:1*t*11	0.82	0.93	0.98	1.02	1.05	0.66	0.092			
C18:1*t*12 + C18:1*t*13	0.75	0.36	0.15	0.29	0.21	0.76	0.310			
C18:1*c*9	31.47	32.24	30.10	31.72	31.04	31.05	1.243			
C18:1*c*11	1.30	1.34	1.24	1.27	1.39	1.23	0.066			
C18:1*c*12	0.07	0.07	0.06	0.06	0.08	0.06	0.008			
C18:1*c*13	0.23	0.26	0.20	0.24	0.23	0.23	0.017			
C18:1*t*16	0.13	0.13	0.12	0.14	0.13	0.12	0.009			
C19:0 + C18:1*c*15	0.14	0.15	0.13	0.14	0.16	0.13	0.008			
C18:2*n*-6 *trans*	0.13^{ab}	0.15^{b}	0.12^{a}	0.16^{e}	0.14^{de}	0.11^{d}	0.011	.040	.014	
C18:1*c*16	0.09	0.10	0.08	0.09	0.10	0.09	0.007			
C18:2*t*10,*c*15	0.10^{b}	0.10^{b}	0.06^{a}	0.09	0.10	0.07	0.009	.003		
C18:2*t*11,*c*15	0.08	0.10	0.08	0.11^{e}	0.09^{de}	0.07^{d}	0.010		.026	
C18:2*n*-6	3.91	4.56	4.76	4.19	4.92	4.12	0.329			
C18:2*t*12,*c*15	0.08	0.09	0.06	0.08	0.08	0.07	0.008			
C20:0	0.10	0.10	0.10	0.10	0.10	0.10	0.008			
C18:3*n*-6	0.01	0.04	0.00	0.03	0.00	0.01	0.016			
C20:1	0.05	0.05	0.04	0.05	0.05	0.04	0.005			
C20:1*c*11	0.13	0.14	0.11	0.13	0.12	0.12	0.009			
C18:3*n*-3	0.56^{a}	0.65^{a}	1.15^{b}	0.93^{e}	0.87^{e}	0.57^{d}	0.074	.000	.002	.000^{t}
C18:2*c*9,*t*11	0.35	0.38	0.34	0.41^{e}	0.35^{de}	0.30^{d}	0.024		.011	
C18:2*t*10,*c*12	0.04	0.08	0.02	0.07	0.03	0.04	0.022			
C21:0	0.03	0.04	0.04	0.04	0.05	0.03	0.005			
C20:2	0.07^{a}	0.09^{ab}	0.11^{b}	0.10^{e}	0.10^{e}	0.07^{d}	0.008	.003	.006	
C22:0	0.02	0.01	0.01	0.01	0.02	0.02	0.006			

C20:3*n*-6	0.03[ab]	0.04[b]	0.02[a]	0.03[de]	0.04[e]	0.02[d]	0.005	.035	.022	
C22:1*n*-9	0.20	0.27	0.28	0.29	0.26	0.21	0.025			
C20:3*n*-3	0.00	0.01	0.00	0.00	0.01	0.00	0.002			
C20:4*n*-6	0.84[a]	1.00[ab]	1.23[b]	1.10	1.09	0.88	0.091	.014		
C22:2	0.01	0.05	0.06	0.05	0.04	0.02	0.018			
C20:4*n*-3	0.02	0.03	0.09	0.08	0.05	0.02	0.008			
C24:0	0.02	0.03	0.03	0.02	0.03	0.03	0.007			
C20:5*n*-3	0.27[a]	0.31[a]	0.61[b]	0.49[e]	0.42[e]	0.27[d]	0.042	.000	.002	.000[u]
C22:4	0.01	0.02	0.00	0.02	0.00	0.02	0.012			
C24:1	0.07	0.10	0.09	0.09	0.10	0.07	0.008			
C22:5	0.42[a]	0.52[a]	0.83[b]	0.69[e]	0.64[e]	0.44[d]	0.052	.000	.003	.000[v]
C22:6*n*-3	0.21[a]	0.27[ab]	0.38[b]	0.36[e]	0.34[e]	0.15[d]	0.041	.020	.000	.010[w]
SFA	45.43	44.12	45.11	44.00[d]	44.18[d]	46.47[e]	0.641		.015	
MUFA	43.31	44.53	41.86	43.98	43.49	42.22	1.236			
PUFA	8.11[a]	9.69[a]	11.56[b]	10.28[e]	10.81[e]	8.26[d]	0.655	.002	.021	.008[x]
PUFA/SFA	0.18[a]	0.22[ab]	0.26[b]	0.24[e]	0.25[e]	0.18[d]	0.017	.005	.017	.007[y]
n-6 PUFA	5.04	6.04	6.32	5.75	6.36	5.29	0.420			
n-3 PUFA	1.74[a]	2.08[a]	3.26[b]	2.82[e]	2.60[e]	1.66[d]	0.185	.000	.000	.000[z]
n-6/*n*-3 PUFA	2.80[b]	2.92[b]	2.21[a]	2.31[d]	2.59[d]	3.02[e]	0.161	.007	.012	

[t] Mean values (%) = 0.57, 0.59 and 1.63 for 360 kg CW, 0.66, 0.67 and 1.27 for 410 kg CW and 0.43, 0.71 and 0.56 for 460 kg CW of C, GSC and GSPC, respectively

[u] Mean values (%) = 0.29, 0.24 and 0.94 for 360 kg CW, 0.29, 0.33 and 0.65 for 410 kg CW and 0.22, 0.36 and 0.24 for 460 kg CW of C, GSC and GSPC, respectively

[v] Mean values (%) = 0.42, 0.46 and 1.18 for 360 kg CW, 0.49, 0.53 and 0.90 for 410 kg CW and 0.36, 0.56 and 0.39 for 460 kg CW of C, GSC and GSPC, respectively

[w] Mean values (%) = 0.22, 0.25 and 0.62 for 360 kg CW, 0.27, 0.34 and 0.42 for 410 kg CW and 0.14, 0.22 and 0.09 for 460 kg CW of C, GSC and GSPC, respectively

[x] Mean values (%) = 7.81, 8.76 and 14.28 for 360 kg CW, 9.25, 10.10 and 13.09 for 410 kg CW and 7.27, 10.21 and 7.30 for 460 kg CW of C, GSC and GSPC, respectively

[y] Mean values (%) = 0.17, 0.20 and 0.33 for 360 kg CW, 0.21, 0.23 and 0.30 for 410 kg CW and 0.16, 0.23 and 0.15 for 460 kg CW of C, GSC and GSPC, respectively
[z] Mean values (%) = 1.86, 1.93 and 4.69 for 360 kg CW, 2.04, 2.20 and 3.55 for 410 kg CW and 1.33, 2.10 and 1.54 for 460 kg CW of C, GSC and GSPC, respectively
SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.
n-6 PUFA = sum of C18:2*n*-6 *trans*, C18:2*n*-6, C18:3*n*-6, C18:2*t*10,*c*12, C20:2, C20:3*n*-6, C20:4*n*-6, C22:2, C22:4.
n-3 PUFA = sum of C18:2*t*10,*c*15, C18:2*t*11,*c*15, C18:2*t*12,*c*15, C18:3*n*-3, C20:3*n*-3, C20:4*n*-3, C20:5*n*-3, C22:5, C22:6*n*-3.
[a,b,c] means of PS within rows assigned different superscripts differ significantly ($P < 0.05$)
[d,e,f] means of CW within rows assigned different superscripts differ significantly ($P < 0.05$)
s.e.m. = standard error of the mean for comparison of main effects

Table 5. Quantitative analysis[m] of the most common volatile compounds derived from *longissimus thoracis* muscle of bulls from three production systems (PS) (C = concentrate, GSC = grass silage followed by concentrate, GSPC = grass silage followed by pasture and then concentrate) and carcass weights (CW) (360, 410 and 460 kg).

Volatile compounds	PS			CW			s.e.m.	Significance		
	C	GSC	GSPC	360	410	460		PS	CW	PS x CW
Aldehydes										
Hexanal	1824[b]	1759[b]	1115[a]	1341[d]	1833[e]	1524[de]	124	.000	.025	
Heptanal	360[a]	969[b]	318[a]	636[e]	356[d]	657[e]	20	.000	.000	
Benzaldehyde	326	281	336	199[d]	346[de]	398[e]	59		.049	
Octanal	964	948	1026	1013	912	1012	115			
Nonanal	8193	8861	10040	9744	8233	9116	1364			
(*E*)-2-Nonenal	68	65	54	64	54	69	5			
Decanal	737[b]	1063[c]	522[a]	775[e]	1031[f]	517[d]	48	.000	.000	
(*E*)-2-Decenal	537[a]	1563[b]	1558[b]	1034[d]	1049[d]	1576[e]	22	.000	.000	
Pentanal	2080	2295	2173	2384	1958	2207	170			
Alcohols										
1-Hexanol	606	629	344	748	385	447	139			
1-Heptanol	495	978	-[n.d.]	982	491	-	12			
1-Octen-3-ol	912	875	831	853	888	878	31			
1-Octanol	1439	1431	1438	1478	1382	1447	67			
2-methyl-1-butanol	949[b]	613[a]	2152[c]	2494	1220	-	121	.000		
Organic acids										
Hexanoic acid	2646	2688	2184	2913	2525	2081	437			
Nonanoic acid	3875[a]	11200[b]	16020[c]	17040[e]	7173[d]	6887[d]	1079	.000	.000	
Hydrocarbons										
Nonane	-	4594	-	4594	-	-	110			
Decane	3680	1794	-	1365[d]	942[d]	3166[e]	159		.000	
Undecane	-	-	124	-	-	124	16			
Dodecane	-	-	146	-	-	146	4			
Tridecane	136[b]	116[ab]	80[a]	121[e]	31[d]	181[f]	18	.036	.000	
Tetradecane	225	224	213	222	208	232	11			

Pentadecane	287	288	281	283	282	292	4		
Hexadecane	217	224	219	221	215	224	4		
Eicosane	-	954	642	327[d]	636[e]	633[e]	8		.000
Toluene	519[a]	567[b]	1050[c]	1078	-	1057	5	.000	
Ketones									
2-Nonanone	936[b]	630[a]	891[b]	920[e]	590[d]	947[e]	17	.000	.000
Furans									
2-Pentyl-furan	7194	6967	6288	7507	5536	7406	1055		
Sulphur-containing compounds									
Dimethyl sulfide	-	-	1761	-	1761	-	28		

[m] Concentration of volatile compounds expressed in ng/100 g of muscle
[a,b,c] means of PS within rows assigned different superscripts differ significantly ($P < 0.05$)
[d,e,f] means of CW within rows assigned different superscripts differ significantly ($P < 0.05$)
[n.d.] not detected
s.e.m. = standard error of the mean for comparison of main effects

Table 6. Pearson correlation coefficients (r) between total intramuscular fat, sensory scores, fatty acids and volatile compounds of beef

Traits[a]	IMF	Tend	Juic	BeFL	AbFL	FlLK	OvLK	C16:0	C18:0	C18:1*c*9	C18:2*n*6	C20:1*c*11	C18:3*n*3	C22:0	C20:5*n*3	C22:5	SFA	MUFA	PUFA	P/S	Hex	2-Dec	Hept	2Non	1-Oct	2-Met	N'acid	DiS	2Pen	D'ane
Tend	.393**																													
Juic	0.141	0.192																												
BeFL	.358**	.546**	-0.12																											
AbFL	-0.252	-.334*	0.266	-.63**																										
FlLK	.375**	.521**	-0.11	.782**	-.68**																									
OvLK	.480**	.852**	0.09	.705**	-.52**	.816**																								
C16:0	0.178	0.184	0.031	0.171	0.055	0.104	0.195																							
C18:0	0.062	0.159	0.068	0.109	0.122	0.053	0.133	.97**																						
C18:1*c*9	0.195	0.212	0.079	0.204	0.051	0.127	0.222	.976**	.969**																					
C18:2*n*6	-0.008	0.031	0.008	0.034	0.246	0.033	0.069	.784**	.835**	.807**																				
C20:1*c*11	0.197	.269*	0.032	.281*	-0.044	0.241	.325*	.887**	.888**	.936**	.771**																			
C18:3*n*3	-0.215	-0.144	0.154	-0.077	0.244	-0.133	-0.147	.635**	.713**	.646**	.764**	.564**																		
C22:0	0.149	0.234	-0.1	0.218	-0.206	0.245	.300*	.381**	.359**	.372**	.335*	.386**	0.2																	
C20:5*n*3	-.39**	-.338*	0.005	-0.198	.281*	-0.263	-.341*	0.005	0.112	0.037	.359**	0.046	.646**	-0.017																
C22:5	-0.248	-0.231	0.047	-0.103	0.24	-0.105	-0.179	0.163	0.255	0.205	.565**	0.213	.710**	0.101	.919**															
SFA	0.134	0.171	0.04	0.146	0.081	0.084	0.171	.996**	.987**	.978**	.807**	.890**	.669**	.377**	0.041	0.194														
MUFA	0.2	0.204	0.082	0.201	0.051	0.129	0.223	.979**	.968**	.999**	.815**	.935**	.653**	.370**	0.043	0.213	.980**													
PUFA	-0.045	-0.016	0.034	0.048	0.226	0.033	0.037	.778**	.834**	.814**	.964**	.791**	.854**	.339*	.489**	.664**	.802**	.822**												
P/S	-.347*	-.36**	0.035	-0.255	0.108	-0.193	-.37**	-.57**	-.48**	-.510**	-0.199	-.443**	0.057	-0.211	.417**	.272*	-.54**	-.506**	-0.143											
Hex	0.266	0.129	-0.02	0.164	-0.09	0.198	0.249	0.247	0.224	.270*	.283*	.326*	-0.019	0.005	-0.209	-0.081	0.239	.282*	0.209	-0.225										
2-Dec	-.344*	-0.144	-0.07	-0.105	0.072	0.078	-0.027	-0.151	-0.154	-0.147	-0.042	-0.102	0.014	0.053	0.13	0.133	-0.15	-0.155	-0.023	0.168	-0.221									
Hept	0.14	0.131	0.188	0.047	0.226	.290*	0.208	0.115	0.153	0.151	0.127	0.155	-0.039	-0.022	-0.111	-0.017	0.127	0.144	0.122	-0.249	0.173	0.003								
2Non	.320*	0.194	-0.08	0.142	-0.204	0.206	0.248	-0.003	-0.04	0.018	0.019	0.086	-0.161	-0.035	-0.173	-0.113	-0.016	0.018	-0.033	-0.16	.376**	0.057	0.011							
1-Oct	0.023	0.051	0.101	-0.035	-0.037	-0.029	0.017	0.189	0.221	0.211	.306*	0.198	0.229	-0.096	-0.024	0.038	0.204	0.217	0.251	-0.027	.478**	-0.136	-0.004	.430**						
2-Met	-.272*	-0.022	0.223	-0.094	0.025	-0.245	-0.161	-.344*	-.289*	-.318*	-.345*	-.310*	0.074	-0.222	.327*	0.145	-.325*	-.317*	-0.233	.400**	-0.096	-0.075	-0.22	-0.193	-0.122					
N'acid	-.327*	0.105	0.186	-0.109	0.092	-0.05	-0.047	-.36**	-.289*	-.337*	-.335*	-.365**	0.001	-0.159	0.244	0.101	-.333*	-.345*	-0.236	.425**	-.57**	0.266	0.065	-0.227	-.38**	.449**				
DiS	-.299*	-0.25	0.067	-0.214	0.093	-.34*	-.294*	-0.226	-0.191	-0.221	-0.163	-0.202	0.061	-0.161	0.183	0.094	-0.213	-0.221	-0.119	.327*	0.181	0.19	-.39**	-0.196	0.012	.563**	0.024			
2Pen	-0.151	0.174	0.153	-0.108	0.075	-0.077	0.09	0.006	0.008	-0.013	0.173	0.046	0.025	0.163	0.027	0.081	0.005	-0.003	0.103	0.041	0.12	0.077	-0.082	0.22	0.135	-0.048	0.028	-0.03		
D'ane	.282*	.295*	-0.04	0.144	-0.039	0.062	0.194	0.159	0.13	0.151	0.194	0.185	-0.058	0.006	-0.041	0.003	0.143	0.15	0.135	-0.236	0.182	-.38**	0.096	.300*	0.169	-.31*	-.329*	-.29*	0.223	
N'ane	0.112	.291*	0.101	0.245	-0.232	.487**	.465**	-0.046	-0.061	-0.006	0	0.113	-0.089	-0.043	-0.193	-0.053	-0.051	0.007	0.006	-0.039	.275*	0.172	0.194	0.208	0.058	0.136	0.038	-0.124	0.189	-.29*

[a] IMF: Intramuscular fat; Tend: Tenderness; Juic: Juiciness; BeFL: Beefy flavour; AbFL: Abnormal flavour; FlLK: Flavour liking; OvLK: Overall liking

Fatty acids of C16:0; C18:0; C18:1*c*9; C18:2*n*6: C18:2*n*-6; C20:1*c*11; C18:3*n*3: C18:3*n*-3; C22:0; C20:5*n*3: C20:5*n*-3; C22:5; SFA: total saturated fatty acids; MUFA: total monounsaturated fatty acids; PUFA: total polyunsaturated fatty acids; P/S: PUFA to SFA ratio

Volatile compounds of Hex: Hexanal; 2-Dec: (*E*)-2-Decenal; Hept: Heptanal; 2Non: (*E*)-2-Nonenal; 1-Oct: 1-Octen-3-ol; 2-Met: 2-methyl-1-butanol; N'acid: Nonanoic acid; DiS: Dimethyl sulphide; 2Pen: 2-Pentyl-furan; D'ane: Decane; N'ane: Nonane

*: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$