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Effect of finishing diet and duration on the sensory quality and volatile profile of lamb meat

Vasiliki Gkarane[a] vasiliki.gkarane@ucdconnect.ie; Nigel P. Brunton[a] nigel.brunton@ucd.ie; Paul Allen[b] paul.allen@teagasc.ie; Rufielyn S. Gravador[a] rufielyn.gravador@ucd.ie; Noel A. Claffey[c] noel.claffey@teagasc.ie; Michael G. Diskin[c] michael.diskin@teagasc.ie; Alan G. Fahey[a] alan.fahey@ucd.ie; Linda J. Farmer[d] linda.farmer@afbini.gov.uk; Aidan P. Moloney[e] aidan.moloney@teagasc.ie; Maria J. Alcalde[f] aldea@us.es; Patrick Murphy[g] patrick.murphy@ucd.ie; Frank J. Monahan[a,*] frank.monahan@ucd.ie

[a]University College Dublin, School of Agriculture and Food Science, Dublin 4, Ireland
[b]Teagasc, Food Research Centre, Ashtown, Dublin 15, Ireland
[c]Teagasc, Animal & Grassland Research and Innovation Centre, Athenry, Co. Galway, Ireland
[d]Agri-Food and Biosciences Institute, Newforge Lane, Belfast, BT9 5PX; UK
[e]Teagasc, Animal & Grassland Research and Innovation Centre, Grange, Co. Meath, Ireland
[f]University of Seville, Department of Agroforestry Science, Agricultural Engineering College
[g]University College Dublin, School of Mathematics and Statistics, Dublin 4, Ireland

[*]Corresponding author.

Abstract

Animal production factors such as animal diet can affect the sensory quality of lamb meat. The study investigated the effect of diet composition and duration of consumption on the composition, volatile profile and sensory quality of lamb meat. Ninety-nine male Texel × Scottish Blackface lambs were raised at pasture for 10 months before being assigned in groups of 11 to one of the following treatments: 100% Silage (S) for 36 (S36), 54 (S54) or 72 (S72) days; 50% Silage 50% - 50% Concentrate (SC) for 36 (SC36), 54 (SC54) or 72 (SC72) days; 100% Concentrate (C) for 36 (C36) or 54 (C54) or 72 (C72) days. A trained sensory panel found *Intensity of Lamb Aroma*, *Dry Aftertaste* and *Astringent Aftertaste* to be higher in meat from lambs on the concentrate diet. Discriminant analysis showed that the volatile profile enabled discrimination of lamb based on dietary treatment but the volatile differences were insufficient to impact highly on sensory quality. Muscle from animals in the S54 group had higher *Manure/Faecal Aroma* and *Woolly Aroma* than the SC54 and C54 groups, possibly related to higher levels of indole and skatole. Further research is required to establish if these small differences would influence consumer acceptability.

Keywords: animal diet, silage, concentrate, finishing period, palatability, SPME/GC/MS

1. Introduction

The main feedstuffs consumed by sheep for meat production are derived from cereal grains and pasture (either grazed or ensiled grass), with combinations of both feed sources often in use over the lifetime of animal (Almela *et al.*, 2010). The growth rates of sheep receiving solely grass-based diets are lower and ultimate carcass weights may also be lower (Murphy, Loerch, McClure, & Solomon, 1994; Priolo, Micol, Agabriel, Prache, & Dransfield, 2002); thus, grain-based concentrates, which are more energy dense, are often used to shorten the time to slaughter, increase dressing percentage, and improve carcass quality (De Brito, Ponnampalam, & Hopkins, 2017; Jaborek, Zerby, Moeller, & Fluharty, 2017) .

In addition to the effects of diet on production parameters (De Brito *et al.*, 2017), dietary constituents may also have a considerable effect on meat quality (Kitessa *et al.*, 2009). There are differences in the consumer acceptability of meat from grain-fed and grass-fed sheep (Font i Furnols *et al.*, 2006; Sanudo *et al.*, 2007) attributable to, among other factors, variation in the level of intramuscular fat (IMF) and subcutaneous fat and their fatty acid composition (Howes, Bekhit, Burritt, & Campbell, 2015). Consumer assessment of lamb meat is influenced by the taste and/or aroma deriving from volatile compounds, which are known to be affected by the relative proportions of fatty acids in the meat (Ponnampalam, Sinclair, Egan, Ferrier, & Leury, 2002). With regard to flavour specifically, the extent to which flavour intensity is altered depends on the types of both forage and grain consumed (Duckett & Kuber, 2001). Meat from sheep receiving primarily grass-based diets (pasture or grass silage) is reported to have a pastoral (grassy) flavour (Young, Lane, Priolo, & Fraser, 2003). In this context, nutritional strategies may be used to modulate the sensory quality of lamb ultimately affecting consumer preference (Almela *et al.*, 2010); in this instance a modification to the diet might be useful in overcoming undesirable sensory attributes. There

are other instances too, in which nutritional interventions could be useful. For example, in a previous study (Gkarane *et al.*, 2017), we reported less favourable sensory attributes in lamb from rams compared to castrates. The objective of the current study was to test the hypothesis that different proportions and durations of feeding cereal concentrate and silage-based diets would affect the sensory quality and volatile profile of lamb meat from rams.

2. Materials and Methods

2.1 Animal husbandry, slaughter and sampling

All animal procedures used in this study were conducted under experimental license from the Irish Health Products Regulatory Authority (HPRA) in accordance with the European Union protection of animals used for scientific purposes regulations 2012 (S.I. No. 543 of 2012). Ninety-nine ram lambs (Texel × Scottish Blackface) were sourced from Irish farms in March 2015. Lambs were raised at pasture from birth (March 2015) and were weaned at 130 d of age after which they were transported to the Teagasc Sheep Research Centre, Athenry, Co. Galway, Ireland (Claffey *et al.*, 2018). Lambs were maintained at pasture until selected for commencement of an intensive indoor finishing period. Lambs were allocated to the following nine dietary treatments consisting of three grass silage:concentrate ratios (100:0 (S), 50:50 (DM basis) (SC), 0:100 (C)) with each diet being fed for three pre-slaughter feeding durations (36, 54 and 72 d) to give the following dietary treatments: S36, S54, S72, SC36, SC54, SC72, C36, C54, C72. The grass silage was predominantly *Lolium perenne L.* and the concentrate diet consisted of 30% maize, 30% barley, 16.5% soya hulls and 15.5% soybean meal. In line with commercial practice, lambs were selected for treatment based on initial live weight and predicted growth rate on the assigned diets to yield lambs with similar weights at slaughter. Thus, the lightest lambs were assigned to the C72 treatment and the heaviest to the S36 treatment. For the indoor finishing period (36, 54 or 72 d) lambs

were individually penned in metal floor feeding pens (182 cm × 122 cm). At the end of the finishing period, lambs were transported to a commercial abattoir (Gillivan's, Moate, Co. Westmeath, Ireland) for slaughter. The mean ages in days (±SD) of the animals at slaughter were 252 (±6.4), 260 (±3.7), 273 (±6.0), 248 (±3.8), 254 (±4.8), 271 (±5.3), 248 (±6.1), 258 (±5.0), 266 (±4.3) for the S36, S54, S72, SC36, SC54, SC72, C36, C54, C72 treatments, respectively. After slaughter, carcasses were chilled overnight and transported to Teagasc Food Research Centre, Ashtown, Dublin 15, Ireland, for dissection. Ultimate pH (pHu) of *M. longissimus thoracis et lumborum* (LTL) was measured at 25 h post slaughter at the 13th rib using a SympHony SP70P hand-held pH meter (VWR, Dublin, Ireland). Both LTL muscles were excised from each carcass, cut into 2.5 cm thick steaks, vacuum packed, aged for 8 d at 4 °C and frozen at -20 °C until required for analysis.

2.2 Compositional analysis

Samples of LTL were thawed overnight at 4 °C and homogenized using a Kenwood CH180 Compact Mini Chopper (Kenwood, Hampshire, UK). Moisture and intramuscular fat (IMF) contents were determined using the SMART Trac Rapid Fat Analyzer (CEM Corporation, NC, USA) according to AOAC Methods 985.14 and 985.26 (AOAC, 1990), respectively. Protein concentration was determined using a LECO FP328 (LECO Corp., MI, USA) protein analyzer based on the Dumas method and according to AOAC method 992.15 (AOAC, 1990). Ash was determined following incineration of samples overnight in a furnace at 540 °C.

2.3 Reagents and fibres for volatile analysis

Volatile standards, the alkane mixture (C7 - C30), methanol (for preparation of stock solutions of the standards), and sodium sulfate were supplied by Sigma-Aldrich Ireland Ltd

(Arklow, Co. Wicklow, Ireland). The volatile standards hexanoic acid and α-terpineol were supplied from VWR International Ltd (Blanchardstown, Dublin 15, Ireland) while 1-pentadecanol was supplied from Fisher Scientific Ireland Ltd (Blanchardstown, Dublin 15, Ireland). Solid phase microextraction (SPME) fibres (50/30 μm CAR/DVB/PDMS fiber; 1 cm length) were supplied by Agilent Technology (Part Number: SU57298U; Unit 3, Euro Business House, Cork, Ireland). All reagents and chemicals were of chromatographic quality.

2.4 Sample preparation and volatile analysis

Before analysis LTL samples were thawed by immersion of frozen vacuum packed samples in water at room temperature for 20 min. Thawed steaks were grilled with the fat attached, using a clamshell grill until an internal temperature of 70 °C was reached (monitored using a hand-held digital thermometer; Eurolec, Dublin, Ireland). Subcutaneous fat was removed and 7 g from the core was weighed and homogenised with 7 g Na_2SO_4 using a Kenwood CH180 Compact Mini Chopper (Kenwood, Hampshire, UK). A 5 ± 0.05 g sample of the mixture was placed in a 20 ml glass headspace vial sealed with a polytetrafluoroethylene (PTFE)-faced silicone septum (VWR, Dublin, Ireland). The vial containing the sample was equilibrated in a water bath set at 90 ± 2 ºC for 20 min and the fibre was exposed to the headspace over the sample for a further 20 min. These SPME conditions (adopted based on maximizing the number of compounds detected, the total peak area and the detection of BCFAs) were considered optimum as previously described in Gkarane *et al.* (2018). After adsorption, the fibre (50/30 μm CAR/DVB/PDMS) was removed from the vial and immediately inserted into the injection port of the GC. Analysis of the volatile compounds was carried out using a Varian 3800 GC coupled to a Varian Saturn 2000 ion trap mass spectrometer (Varian Chromatography Systems, Walnut Creek, CA, USA). Volatile extraction, adsorption and injection were performed manually. The injector,

operating in splitless mode, was set at 250 °C and the desorption time was 8 min. Helium was used as carrier gas with a constant flow rate of 1.0 ml/min. Volatile compounds were separated using an Agilent ZB-5MS column (30 m length, 0.25 mm internal diameter, 0.25 μm film thickness) (Agilent Technologies, Palo Alto, CA, USA). The GC oven temperature was programmed as follows: 40°C for 5 min, increasing to 230°C at 4°C/min and holding for 5 min, with a total acquisition time of 57.5 min. The GC/MS transfer line was heated at 280°C. Acquisition was performed in electron impact (EI) mode (70 eV) at 10 microscans/s, scanning the mass range 33–230 m/z. Saturated n-alkanes (C7 - C30) injected directly (1 μl) onto the column were run under the same GC-MS conditions (at split ratio of 1:50)) to obtain linear retention index (LRI) values for the volatile compounds detected. Compounds were identified by comparing their mass spectra with those of spectra from the NIST/EPA/NIH Mass Spectral Database (Version 2.0g, 2011), those of authenticated standards and linear retention indices matching those of published values (Gkarane *et al.*, 2018). Individual animals were considered as experimental units and one meat sample from each animal was subjected to analysis using a randomized block design to avoid experimental bias. Integration of the peak areas of the volatile compounds used specific ion identification for each molecule (to deal with co-elution of some compounds). An external standard (bromobenzene (10 ppm)) was run daily under the same SPME and GC-MS conditions as the samples. For volatile analysis, the peak area (PA) of each volatile was first normalised against bromobenzene before adding a constant (+1) and being logarithmically transformed to achieve a normal distribution. The amount of each volatile was expressed as logarithmically transformed PA for that compound

2.5 Lamb meat preparation.

The LTL muscle from the left side of each carcass was used for sensory analysis. On the day of sensory testing, packaged frozen steaks were thawed by immersion in water at room temperature for 45 min. Steaks were grilled, with subcutaneous fat attached, to an internal temperature of 70 °C, using a clamshell grill. On reaching 70 °C (monitored using a hand-held digital thermometer (Eurolec, Dublin, Ireland)) the steaks were removed from the grill, wrapped with aluminium foil and allowed to rest for 3 min. Each steak was unwrapped and following removal of the subcutaneous fat, cut into 8 pieces of approximately 2 cm^3. Samples were re-wrapped with foil, assigned a random three-digit code, held in an oven set at 60 °C and served to the panellists within 20 min.

2.6 Panel training

Staff at Teagasc Food Research Centre, Ashtown, participated as sensory panellists in 16 training sessions prior to participating in sensory testing. Training sessions included: lamb meat tasting to generate descriptors for aroma, flavour, texture/mouthfeel, taste and aftertaste; spiking sessions using lamb flavour/aroma compounds; and training using physical and chemical reference standards. A detailed procedure for the panel training is described in Gkarane *et al.* (2017).

2.7 Quantitative descriptive analysis

Quantitative descriptive analysis (QDA) was performed on one day per week over 8 weeks with two sensory sessions per day (morning and afternoon). In each session, six samples were assessed using a balanced and randomized design. Panellists were asked to rate 38 attributes (generated during the training) for each sample, by marking a point on a 100 mm unstructured line scale. Unsalted crackers and water at room temperature were given to

panellists to cleanse the palate between samples. The sensory attribute definitions, agreed during the training sessions (Gkarane *et al.*, 2017), were available to each panellist during tasting. Panellist evaluations were recorded using Compusense 5 (v4.4, Compusense Inc., Guelph, Ontario, Canada).

2.8 Statistical analyses

Proximate and sensory analysis data were tested for the normality of the residuals for each variable. In the case of non-normal distribution, data were transformed using the Box-Cox transformation. The data were analysed using a mixed model with diet, duration and diet x duration as fixed effects (SAS (v9.4)). For the sensory data, the sensory analysis session and carcass weight were considered as random effects. Data were presented as least square means for the sensory scores of each attribute and for proximate analysis. The volatile were analyzed using a mixed model with diet, duration and diet x duration as fixed effects. Analysis was conducted in the MIXED procedure of SAS (v9.4). Data were presented as least square means for each volatile.

Principal component analysis (PCA) of the sensory and volatile data for the nine treatments was performed using XLSTAT®statistical software (Version 19.01.41647; Addinsoft, Paris, France). Associations between sensory attributes and diets, and volatile compounds and diets were also investigated using Discriminant Analysis (DA) performed using XLSTAT®statistical software (Version 19.01.41647; Addinsoft, Paris, France).

3. Results and Discussion

3.1 Proximate analysis

There was no difference in muscle fat content among dietary treatments or finishing periods (Table 1). Other authors have reported that lambs receiving concentrate diets generally have higher growth rates (Fraser & Rowarth, 1996) and IMF than lambs receiving pasture-based diets (De Brito *et al.*, 2017). However, Crouse *et al.* (1978) found no difference in fat thickness or percentage carcass fat of lambs fed low, medium or high energy diets and slaughtered at constant weights. Similarly, Aurousseau *et al.* (2007) detected no differences in the lipid content of *M. longissimus thoracis* of lambs raised and finished on pasture only, raised on grass and finished in stalls for 22 or 41 d, or raised and finished indoors (in stalls) on concentrates and hay only. They attributed the lack of differences between treatments to similarity in energy expenditure between animals and a higher rate of gain from good quality grass.

For protein, there was a diet × duration interaction whereby the muscle from the S group had lower protein content than that of the SC and C groups at 54 d and 72 d, but there were no differences due to diets at 36 d (Supplementary Table S1). The lower protein content of the lamb muscle from the S group may be explained by the fact that concentrate diets have higher dry matter and crude protein content than silage-based diets (Warren *et al.*, 2008); however, this was more noticeable when the feeding duration increased to 54 and 72 days. In addition, there were differences due to duration in the C group, whereby the muscle of the 54 d and 72 d groups had higher protein content than the 36 d group. In general, concentrate-based diets favour the production of propionate leading to increased insulin secretion and stimulation of protein and fat synthesis in muscle (Weekes, 1986). Muscle from lambs receiving the experimental diets for 36 and 54 d duration had higher muscle ash content ($P < 0.05$) than lambs fed for the 72 day duration, although there was a diet × duration interaction whereby the SC group at 54 d had higher ash content than the S and C groups.

3.2 Effect of diet on sensory and volatile profiles of lamb meat

In general, a limited effect of the different dietary treatments on the 38 sensory descriptors was noted (only seven were significantly affected; P<0.05) (Table 2). For three of these (*Animal/Farm Smell, Woolly Aroma* and *Fattiness*) there were diet × duration interactions which are discussed in the next section (3.3). *Intensity of Lamb Aroma, Dry Aftertaste* and *Astringent Aftertaste* scored higher (P < 0.05) in the C group compared to the S and SC groups. *Farmyard Flavour* scored lower (P < 0.05) in the SC group compared to the C group, but was similar to S group. Although significant effects on sensory descriptors were few, lamb from animals fed the SC group received lower scores (P = 0.015 – 0.078) for attributes that may be considered hedonically negative by some consumers (i.e. *Animal/Farm Smell, Woolly Aroma, Manure/Faecal Aroma, Off-flavours*) (Table 2) although no consumer evaluation was performed in this study. Similar conclusions regarding lamb meat assessed by European consumers was reported by Font i Furnols *et al.* (2009) where meat from lambs fed concentrate or a mixture of pasture and concentrate was more acceptable compared to meat from lambs at pasture. Specifically, the meat from lambs fed a mixture of pasture (6% of live weight, LW) and concentrate (1.2% of LW) was the most acceptable. Arsenos *et al.* (2002) showed that meat from lambs fed lucerne hay with low and medium levels of concentrate was preferred more than meat from lambs fed high levels of concentrates. Other studies have reported bigger differences when comparing grass-based systems with concentrate-based system (Priolo *et al.*, 2002; Resconi, Campo, Furnols, Montossi, & Sanudo, 2009), with concentrate-fed lambs having more intense lamb odour and/or flavour than grass or forage-fed lambs but also higher acceptability (Borton, Loerch, McClure, & Wulf, 2005; Resconi *et al.*, 2009; Schreurs, Lane, Tavendale, Barry, & McNabb, 2008).

The volatile analysis showed that only ten volatile compounds were significantly (P<0.0.5) affected by diet (Table 3), seven of which showed diet × duration interactions

(described in section 3.3). The SC and C groups had higher ($P < 0.05$) values for dimethyl sulphide (formed through Strecker degradation of methionine (Bailey, Rourke, Gutheil, & Wang, 1992)), than the S diet. Levels of hexanal (a compound that derives from oxidation of linoleic acid in muscle (C18:2n-6) (Elmore *et al.*, 2005)), increased gradually with increasing dietary concentrate although only the C and S groups were significantly different from each other ($P < 0.05$). This could be due to the higher proportion (%) of C18:2n-6 in the C group compared to the other groups (Rowe, Macedo, Visentainer, Souza, & Matsushita, 1999). Muscle from lambs fed the S diet had higher values ($P < 0.05$) for skatole than the SC and C diets. Skatole (which has a "faecal/manure aroma") derives from the degradation of dietary tryptophan and since lush pasture is a source of more readily degradable protein than cereal concentrates, it is also a possible source of tryptophan (Tavendale, Lane, Schreurs, Fraser, & Meagher, 2006). In addition, pasture-based diets have a high ratio of protein to readily fermentable carbohydrate (Schreurs *et al.*, 2008; Young *et al.*, 2003). This may explain the higher levels of skatole in muscle from animals on the S group compared the other groups. Priolo *et al.* (2004) reported differences in p-cymene and eight sesquiterpenes among lambs fed either on grass or on concentrates for different periods while Resconi *et al.* (2010) found that lambs fed only on pasture had lower levels of carbonyl compounds (alkanals, alkadienals, ketones, strecker aldehydes) than those fed on grass with a concentrate supplement, or only with concentrate.

Multivariate analysis techniques were applied to investigate potential differences between groups and associations with the sensory and volatile data. Following discriminant analysis of the sensory data, the first component (F1) explained 58.87 % of the variation and the second component (F2) explained 41.13% of the variation (Figure 1). The centroids of the dietary treatments were placed in different quadrants (Figure 1a), revealing some associations with some sensory attributes (Figure 1b). The factor loadings of the sensory attributes that

were considered significant were higher than 0.30. In general, the overlapping of the groups confirmed that the sensory profile of the lambs fed on different diets was similar. Also, the P values from Wilk's Lambda test, Pillai's trace test and Roy's greatest root test showed that the mean vectors only approached significance (range P = 0.06-0.10). Nevertheless, the C group (centroid located in the upper right quadrant) was more associated with *Dry Aftertaste* and *Astringent Aftertaste.* The S group (centroid located in the upper left quadrant) was more associated with *Fattiness.* For the SC group (centroid in the bottom left quadrant), although visually it was associated with *Juiciness, Intensity of Roast Meat Aroma* and *Intensity of Roast Meat Flavour,* the factor loadings of these attributes were less than 0.30. However, it is clear that the SC group was not associated with attributes that may be viewed as undesirable (i.e. *Manure/Faecal Aroma, Animal/Farm Smell, Off-flavours, Farmyard Flavour;* factor loadings > 0.30 for F2).

The discriminant analysis plot of the volatile data (Figure 2) showed that the three groups (S, SC and C) were clearly separated. The first component (F1) explained 73.04% of the variation and the second component (F2) explained 26.96 % of the variation. The factor loadings of the volatile compounds that were considered significant were equal or higher than 0.30. The P values from Wilk's Lambda test, Pillai's trace test and Roy's greatest root test (P < 0.001) indicate that at least one of the groups was different from another, whereby according to the Fisher distances test the C group differed from the S group (P < 0.001) and from the SC group (P = 0.001). For F1, the S and SC groups (both placed on the left side of the plot) were separated from the C group. The compounds that contributed to this separation were 2,5-dimethylpyrazine, 2,6-dimethylpyrazine, 2-ethyl-3,6-dimethylpyrazine, (*E,Z*)-2,6-nonadienal, pentadecane, hexadecane, and pentadecanol (factor loadings ≥ 0.3 for F1, data not shown). The slight overlap of the S and SC groups indicated that their volatile profile had some similarities. The results are in accordance with Vasta *et al.* (2011) who, through

discriminant analysis, showed that the volatile profile of meat from animals fed silage-based diets was different from those on a concentrate-based diet suggesting that this could be due to the presence of compounds in silage-based diets arising from bacterial fermentation of herbage that makes the "volatile fingerprint" different. The second component separated the SC from the C and S groups and the compounds that contributed to the variation were dimethyl sulfide and indole (factor loadings ≥ 0.3 for F2). The differences in the volatile profile (Figure 2) show that both S and SC groups differed from the C group; however, the differences were not reflected in the sensory quality to a large extent as few differences were detected (Table 2). The explanation could be that, while the volatile analysis showed 10 compounds to be significantly affected, only seven (dimethylsulfide, hexanal, 2,6-nonadienal, indole, skatole, 2,5-dimethylpyrazine and 2-ethyl-3,6-dimethylpyrazine) have low odour threshold and have been reported to be odour-active in previous lamb meat flavour studies (Gkarane *et al.*, 2018). Furthermore, only three out of the seven compounds (dimethylsulfide, hexanal and skatole) had a "clear" diet effect since the others had an interaction with duration. These compounds, even if they have concentration above the odour threshold, may not be adequate to elicit significant sensory differences among diets which could explain the similarity in the sensory profiles of the lambs on different diets. Another hypothesis is that the panellist's sensitivity was insufficient to detect the differences in the aroma or that even if they detected them they didn't score them very differently on the magnitude scale of 0-100. Thus, while the discriminant analysis separated the lamb based on diets, it seems that there are limitations that should be considered regarding the compounds that could ultimately influence flavour.

The fact that only few effects of dietary treatment on the volatile and sensory profiles of lamb were noted in the present study is surprising given that differences in the fatty acid profile of the lambs due to the different dietary treatments were present (unpublished results).

For example, the C18:3 content was higher ($P < 0.001$) and the C18:2 content lower ($P < 0.001$) in LTL from the S treatment compared to the C treatment while LTL from the SC treatment had intermediate values (unpublished results). However, the lack of differences in IMF in this study could explain the lack of differences in the volatile profile of the diets. According to Vasta, D'Alessandro, Priolo, Petrotos, and Martemucci (2012) andFrank, Kaczmarska, Paterson, Piyasiri, and Warner (2017) most of the odour-impact volatiles in meat systems are lypophilic and their accumulation in animal tissue is correlated to the level of intramuscular fat deposition. Furthermore, differences in flavour volatiles and/or fatty acid composition following diet modification do not always have a major effect on sensory quality as reported by Kitessa *et al.* (2009) and Muir, Deaker, and Bown (1998). It is also important to recognise that the volatiles extracted by a static method headspace such as SPME may not be representative of the headspace volatiles (considering that many factors (Jelen, Majcher, & Dziadas, 2012) influence the extracted compounds). Finally, the compounds detected by SPME may not be perceived by trained panellists and the perception of trained panellists can't be equated to the perception of consumers (Munoz, 1998).

3.3 Effect of finishing duration on the sensory and volatile profiles of lamb meat

Sensory analysis showed that only two attributes (*Animal/Farm Smell* and *Woolly Aroma*) were affected by finishing duration, both of which had a diet × duration interaction which will be described later in this section (Table 2). A recent study (Guerrero *et al.*, 2018) also reported that feeding duration (30, 50 or 70 days) had a minor impact on sensory attributes of dry cured ham from culled ewes.

The volatile analysis showed that seven volatile compounds were affected ($P < 0.05$) by the finishing duration, regardless of the finishing diet (Table 3). For four compounds

(octanal, nonanal, 1-octanol, and nonanoic acid) the 54 day group had higher levels ($P < 0.05$) than the other two groups (36 d and 72 d) which did not differ from each other. For two compounds (dodecanal and tridecanal) the 54 day group was higher ($P < 0.05$) than the 72 day group but both were similar to the 36 day group. For one compound (2-pentylfuran) values for the 54 and 72 day groups were both higher ($P < 0.05$) than the 36 day group. This quadratic pattern (i.e. an increase to 54 d and a decrease thereafter) could be attributed to a number of factors including the different average daily gains and feed conversion efficiencies of the lambs. In the current study the average live weights (and ages) of lambs assigned to the experimental diets (S, SC and C) were 41.9 ± 2.4 kg (214 ± 5 d), 39.0 ±5.2 kg (204 ± 5d) and 38.9 ± 5.9 kg (197 ± 8 d) for the 36, 54 and 72 day groups, respectively. These differences in maturity and associated differences in average daily gain (ADG) and feed conversion efficiency (FCE), on assignment to the experimental diets, may have contributed to the minor differences in sensory character and volatiles. Similarly Arsenos *et al.* (2002) reported that lambs slaughtered at similar target slaughter weights may have differences in degree of maturity which may impact on meat quality and consumer acceptability.

Studies indicate that regardless of diet there is a limit to daily intake in ruminants (Allison, 1985; Caton & Dhuyvetter, 1997) after a defined period on a diet. A multitude of factors can affect feed palatability in ruminants and, thus, voluntary feed intake and rate of passage through the gut, including interactions between environmental conditions, animal requirements (physiological or metabolic demands), physical characteristics of the diet (composition, digestibility, energy density) and amount of protein which bypasses the rumen, efficiency of microbial growth and extent of methane loss (Baumont, 1996; Caton & Dhuyvetter, 1997; Decruyenaere, Buldgen, & Stilmant, 2009; Okine, Mathison, Kaske, Kennelly, & Christopherson, 1998). These factors may in turn be influenced by feeding duration with an ultimate effect on the lamb's metabolism and meat quality.

There were some interactions between diet and duration with respect to their effects on sensory and volatile profiles. The sensory analysis showed differences among groups at 54 d, whereby *Manure/Faecal Aroma* scores from the S group were higher ($P < 0.05$) than the scores from SC and C groups, but there were no differences among groups at the other two feeding durations (Supplementary Table S2). In the S group specifically, scores of *Manure/Faecal Aroma* and *Woolly Aroma* for 54 d were higher ($P < 0.05$) than for 36 d and 72 d ($P < 0.05$) whereas for *Animal /Farm Smell* scores for 54 d were higher ($P < 0.05$) than 36 d but similar ($P > 0.05$) to 72 d. For *Fattiness/Greasiness*, scores from the S group were higher ($P < 0.05$) than the scores of SC and C groups only at 72 d.

There were ten significant ($P < 0.05$) diet × duration interactions in the volatile analysis (Supplementary Table S3). For (*Z*)-4-heptenal there were no differences due to duration in the S group; however, in the SC group the 54 day value was higher ($P < 0.05$) than the 72 day value, neither of which differed ($P > 0.05$) from the 36 day value, while in the C group the 36 day value was higher ($P < 0.05$) than both the 54 and 72 day values. In addition, there were differences due to diet in the 72 day period, with S group having higher values than the C group and similar to the values of the SC group. For (*E,Z*)-2,6-nonadienal there were differences due to duration only in the SC and C groups, whereby the 36 and 54 day values, which did not differ, were higher ($P < 0.05$) than the 72 day values. A difference due to diet was found only for the 72 day group, whereby the S group had higher ($P < 0.05$) values than both the SC and C groups which did not differ. These two aldehydes derive from linolenic acid (C18:3n-3) (Elmore *et al.*, 2005), associated with grass-based diets (Enser *et al.*, 1998), which could explain why levels were lower with inclusion of concentrates for the longer (i.e. 72 d) finishing duration.

For 1-pentadecanol, the S and SC groups had higher ($P < 0.05$) values at 36 and 54 d, which did not differ, compared to the C group; at 72 d values decreased ($P < 0.05$) from S to

SC to C group. Long-chain fatty alcohols, like pentadecanol, derive from wax ester hydrolysis and are considered as diet biomarkers; notable differences in the alcohol content of wax are found mainly among grasses and legumes (Kelman, Bugalho, & Dove, 2003), which could explain the higher levels in muscle from the S and SC groups compared with the C group, regardless of the finishing duration. For 2-heptanone, differences due to diet were observed; thus, at 36 d values were lower ($P < 0.05$) in the S group than either the SC or C groups, which did not differ. This compound was generally present at higher levels (although not significant) in muscle from the SC and C groups at all finishing durations, probably because it derives from C18:2n-6 (Elmore *et al.*, 2005), which is associated with grain-based diets (Enser *et al.*, 1998). Differences in 2-heptanone due to feeding duration were significant only in the S group, whereby values at 36 d were lower ($P < 0.05$) than either 54 or 72 days, which did not differ.

Indole was detected at each duration of feeding in the S group, but only detected at 54 d in the SC group and at 72 days in the C group (Supplementary Table S3). The frequency of detection was higher in muscles from the S group since it derives from tryptophan degradation in the rumen mainly of grass-fed lambs and has been identified with pastoral flavours (Schreurs *et al.*, 2008). The higher scores for *Woolly Aroma* and *Manure/Faecal Aroma* in muscle from the S54 group could be due to the higher levels of indole and skatole (faecal, mothball-like aroma) compared to SC54 and C54 groups (although for skatole the diet × duration effect approached significance ($P < 0.1$)).

For 2,5-dimethyl pyrazine, values at 36 d in the S group were higher ($P < 0.0.5$) than in the C group, neither of which differed from the SC group; there were no statistical significant differences ($P > 0.05$) due to dietary treatment at the other durations of feeding despite the fact that the trend was similar (Supplementary Table S3). Differences due to feeding duration were significant only in the S group, whereby values at 36 d were higher (P

< 0.05) than at 72 d, neither of which differed from 54 d. For 2-ethyl-3,6-dimethylpyrazine, values at 54 d in the S group and SC groups were higher (P < 0.0.5) than those of the C group, while there were no differences (P > 0.05) due to dietary treatment at the other durations of feeding (although a similar trend was observed). Similar to 2,5-dimethylpyrazine, the S group, had higher (P < 0.05) values at 36 d than 72 d, neither of which differed from values at 54 d. Muscle from animals fed the S and SC diets had numerically higher levels for some pyrazines than the C diet. This could be due to a possibly higher content of specific amino acids (e.g. cysteine, glycine), that contribute to the Maillard reaction, in muscle from animals fed silage-based diets as reported by other authors (Farmer, 1994). Koutsidis *et al.* (2008) reported a significant effect of the diet (grass silage *vs* concentrate) on the concentration of free amino acids (which can participate in the Maillard reaction) in bovine muscle, with animals fed grass silage having higher levels than animals fed a concentrate diet. In addition, Tai and Ho (1997) found that an oxidized cysteine/glucose reaction model produced more pyrazines and furans as opposed to a non-oxidized cysteine/glucose reaction model that produced more sulphur compounds; thus, differences in susceptibility of muscle to lipid oxidation may contribute to differences in pyrazine formation.

For pentadecane there were differences among diets at all feeding durations whereby the S group and SC groups, which did not differ, had higher (P < 0.05) values than the C group (Supplementary Table S3). For hexadecane, differences among diets were found for all finishing durations whereby at 36 and 54 d the S group had higher levels (P < 0.05) than the C group but both were similar (P > 0.05) to the SC group, while at 72 d the S and SC groups, which did not differ, had higher values than the C group. Hydrocarbons like pentadecane and hexadecane, are lipid oxidation compounds, and have been characterised as tracers of a pasture diet in lamb (Sivadier, Ratel, & Engel, 2010); this could explain why levels were

lower with concentrate feeding at all durations. For 4-methyloctanoic acid differences among diets were detected only at the 36 d of feeding duration with the S and SC groups, which did not differ, having higher values ($P < 0.05$) than the C group.

In general, the majority of the aroma and flavour attribute scores as well as volatile compounds followed a quadratic pattern, i.e. values increased from 36 to 54 d and decreased from 54 to 72 d, mainly in S and SC groups (Supplementary Table S2 and Table S3). The PCA plot (Supplementary Figure S1) for all nine groups (using only the aroma and flavour attributes and selected volatiles) explained 46.55% of the variance, whereby the first component separated the three groups of 54 days duration (located on the right side of the plot) from the other six groups (left side of the plot). The plot showed that S54 group was characterised by the attributes "*Manure/Faecal Aroma*" and "*Rancid Aroma*", clustered with skatole, indole, p-cresol, 4-heptenal, 2-nonenal, 2,6-nonadienal 2,5-dimethylpyrazine and 2-ethyl-3,6-dimethylpyrazine (factor loadings 0.6-0.8 on PC2). Previous studies have shown that phenols and indoles (associated with animal-like odours) as well as 4-heptenal (Young, Berdagué, Viallon, Rousset-Akrim, & Theriez, 1997; Young *et al.*, 2003) and pyrazines (Bueno *et al.*, 2013) have low odour thresholds and may be causally involved in lamb meat aromas perceived by trained panellists. The SC54 group was characterised by "*Animal/Farm Smell*", "*Woolly Aroma*" and "*Sweaty Aroma*" (factor loadings 0.6-0.8 on PC1) (this association is more meaningful when comparing SC54 group with SC36 or SC72 groups; See supplementary Table S2). The compounds which may have contributed to these attributes (Factor loadings 0.6-0.9 on PC1) were mainly lipid oxidation compounds (heptanal, 1-hexanol, 1-heptanol, octanal, 2-octenal, 1-octanol, nonanal, decanal, 2-decenal, 2,4-decadienal, 2-octen-1-ol) and other compounds e.g. α-terpineol, 2-pentylfuran, nonanoic acid, benzaldehyde and phenylacetaldehyde, dimethyldisulfide and dimethyltrisulfide.

The results of the PCA plot could also be explained in part by the numerically higher (although not significant) proportions of C18:3n-3, eicosapentaenoic acid (EPA; C20:5n-3) and n-3 fatty acids in the S54 group compared to S36 and S72 groups, the higher proportion of arachidonic acid (C20:4n-6) of the SC54 compared to SC36 and SC72 groups and the higher level of PUFA of C54 group compared to C36 and C72 group (unpublished results).

4. Conclusion

When lambs receive different proportions of silage and concentrates for durations up to approximately ten weeks pre-slaughter effects on the sensory quality (and flavour volatiles) of lamb meat are relatively few. Some sensory attributes with potentially negative connotations (*Animal/Farm Smell*, *Manure/Faecal Aroma*, *Farmyard Flavour, Off-flavours*) appear to be lower when a mixed diet of silage and concentrate is fed. With regard to the duration of feeding, a diet composed of silage only, fed for an intermediate period, appears to be associated with less desirable sensory aroma attributes (*Manure/Faecal Aroma*, *Rancid Aroma*) which could be due to indoles or lipid oxidation compounds.

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Conflict of Interest

The authors have no conflicts of interest to declare.

Authors contributions

V. Gkarane conducted the experimental work, collected and statistically analysed the data and drafted the manuscript. N. Brunton contributed to the method development for volatile analysis and interpretation of the volatile results. P. Allen contributed to the study design and sensory analysis. R. Gravador contributed to the sensory analysis and conducted the proximate analysis. N. Claffey contributed to the animal management and sample collection. M. Diskin contributed to the study design and animal management oversight. A. Fahey contributed to the study design and the univariate statistical analysis. L. Farmer contributed to the method development for volatile analysis and manuscript revision. A. Moloney contributed to the study design. M. Alcalde contributed to the sensory analysis. P. Murphy contributed to the multivariate statistical analysis. F. Monahan had overall responsibility for the project, contributed to the study design, method development and interpretation of the results. All authors read the manuscript and contributed to manuscript revisions.

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Table 1. Least square mean values for proximate analysis and ultimate pH (pHu) in *longissimus thoracis et lumborum* (LTL) muscle fed three different diets (100% Silage (S); 50% S: 50% Concentrate (C); 100% C) for three durations of feeding (36, 54, 72 days).

	Diet				Feeding duration				SEM	Significance		
	S	SC	C		36	54	72			Diet	Duration	Diet x Duration
Moisture	73.9[b]	73.1[a]	73.3[ab]		73.5	73.6	73.2		0.14	0.041		
Protein	21.1[a]	21.9[b]	22.0[b]		21.5	21.6	21.8		0.10	<0.001		0.001
Fat	3.71	3.94	3.79		3.77	3.78	3.88		0.13			
Ash	1.05	1.09	1.05		1.10[b]	1.08[b]	1.01[a]		0.01		0.001	0.023
pHu	5.73	5.71	5.78		5.69	5.78	5.76		0.02			

[a,b] Within row, means assigned different superscripts indicate differences among diets (S *vs* SC *vs* C) or durations (36 *vs* 54 *vs* 72 days).

Table 2. Least square mean scores for sensory attributes in grilled LTL muscle as affected by diet (100% Silage (S); 50% S: 50% Concentrate (C); 100% C) and duration of feeding (36, 54, 72 days)

	Diet			Duration			SEM	Significance[1]		
Sensory	Silage (S) 100%	50% (S) - 50% (C)	Concentrate (C) 100%	36	54	72		Diet	Duration	Diet × Duration
Aroma										
Intensity of Roast Meat Aroma	41.3	44.8	43.8	44.4	41.7	43.8	0.93			
Intensity of Lamb Aroma	39.8[a]	40.1[a]	43.1[b]	40.4	40.5	42.0	0.71	0.036		
Grassy Aroma	7.5	7.6	7.9	7.8	7.3	8.0	0.28			
Aromatic/Herbal	11.8	12.0	13.3	13.2	11.3	12.7	0.38			
Metallic/Bloody	14.0	14.0	15.3	14.2	14.0	15.1	0.34			
Animal/Farm Smell	15.5[b]	12.8[a]	15.1[b]	12.1[a]	16.6[b]	14.7[b]	0.60	0.039	0.007	0.032
Woolly	14.3[b]	12.5[a]	14.4[b]	11.9[a]	16.2[b]	13.0[b]	0.56	0.045	0.007	0.038
Buttery	7.0	6.8	7.1	6.8	7.3	6.8	0.30			
Fatty	8.2	8.0	7.9	7.6	8.2	8.3	0.33			
Rancid	8.0	6.2	6.3	6.6	7.5	6.4	0.43			
Manure/Faecal	9.8	6.8	7.7	6.9	10.1	7.4	0.55			0.016
Sour	7.8[b]	6.6[a]	7.2[ab]	6.0	8.7	7.0	0.43	0.078*		
Sweaty	14.9	14.5	16.2	14.0	16.5	15.1	0.49			
Soapy	3.7	3.2	3.4	3.5	3.3	3.5	0.16			
Earthy	10.5	9.9	10.0	9.8	10.2	10.4	0.27			
Flavour										
Intensity of Roast Meat Flavour	36.9	39.3	39.4	39.5	37.0	39.0	0.78			
Intensity of Lamb Flavour	42.9	43.5	42.9	43.9	42.8	44.1	0.70			
Grassy	8.3	8.4	8.0	7.8	8.2	8.6	0.24			
Metallic/Bloody	20.2	20.6	19.8	20.3	20.7	19.6	0.49			

Aromatic/Herbal	9.4	9.3	9.2		8.8	9.1	10.0		0.27			
Soapy	5.2	6.2	6.3		5.3	6.6	5.9		0.28			
Rancid	8.5	6.8	7.8		7.0	8.5	7.6		0.41			
Farmyard	8.9[ab]	7.3[a]	9.9[b]		8.3	8.9	8.9		0.47	0.015		
Sour	7.9	8.2	9.5		9.4	8.3	7.9		0.45			
Sweet	11.4	11.3	11.4		10.8	11.2	12.2		0.39			
Off-flavours	19.6[b]	15.8[a]	19.7[b]		18.9	18.7	17.5		0.67	0.066*		
Texture												
Tenderness	54.4	58.0	57.5		56.7	57.7	55.6		1.57			
Juiciness	48.4	49.1	45.7		47.8	46.1	49.3		0.81			
Chewiness	51.9	46.7	49.5		49.8	47.6	50.7		1.47			
Fattiness/Greasiness	30.7	25.5	26.4		27.1	28.4	27.2		0.65	0.003		0.044
Stringiness/Fibrousness	33.8	32.5	37.7		36.7	34.1	33.3		1.29			
Stickiness	26.8	25.7	27.9		27.2	27.2	25.9		0.63			
Aftertaste												
Intensity of Lamb Aftertaste	34.1	32.9	34.7		34.6	33.5	33.7		0.43			
Soapy	9.3	9.5	8.9		8.6	9.4	9.6		0.31			
Metallic/ Bloody	20.8	19.1	19.9		19.6	19.4	20.7		0.49			
Fatty/ Greasy	17.7	15.9	16.5		16.7	17.4	15.9		0.48			
Dry	11.3[a]	11.8[a]	13.5[b]		12.6	12.2	11.7		0.34	0.009		
Astringent	7.2[a]	7.6[a]	9.3[b]		7.6	8.3	8.2		0.35	0.030		

[1]Probability of significance for the main effects of diet, duration and diet x duration tested using the MIXED model ($P < 0.05$)

[a,b] within row, different superscripts indicate differences among diets (S *vs* SC *vs* C) or durations (36 *vs* 54 *vs* 72 days).

*$P < 0.1$

Table 3. Least square mean values for logarithmically transformed peak areas of aroma compounds detected in the headspace of grilled *longissimus thoracis et lumborum* (LTL) muscle fed three different diets (100% Silage (S); 50% S: 50% Concentrate (C); 100% C) for three durations (36, 54, 72 days).

Volatile compound	LRI[1]	Ions	Method of	Diet			Feeding Duration (days)			SEM	
		Used	Identification[2]	S	SC	C	36	54	72		Diet
Sulphur compounds											
Dimethyl sulfide		63,62,61	NIST, Std LRI,	1.97[a]	2.90[b]	2.70[b]	2.73	2.63	2.22	0.151	0.02
Dimethyl disulfide	719	94,79	NIST, Std LRI	2.34	2.71	2.41	2.42	2.89	2.16	0.176	
Dimethyl trisulfide	963	126	NIST, Std LRI,	4.27	4.36	4.21	4.25	4.39	4.21	0.037	
Aldehydes											
2-Methylbutanal		39,41,57	NIST, Std LRI,	4.17	4.36	4.29	4.40	4.28	4.15	0.095	
3-Methylbutanal		41,43,58	NIST, Std LRI,	4.33	4.47	4.47	4.57	4.47	4.24	0.097	
Pentanal		43,44,58	NIST, Std LRI,	4.26	4.32	4.36	4.39	4.42	4.13	0.082	
(*E*)-2-Hexenal	849	39,41,55	NIST, Std LRI,	3.01	2.65	2.97	3.12	2.70	2.82	0.139	
Hexanal	800	39,41,56	NIST, Std LRI,	5.26[a]	5.37[ab]	5.45[b]	5.32	5.43	5.33	0.031	0.04
Methional	905	48,104	NIST, Std LRI,	3.82	4.13	3.86	4.13	3.93	3.76	0.117	
(*E,E*)-2,4-Heptadienal	1008	81,53	NIST, Std LRI,	2.20	2.04	1.91	2.23	2.25	1.66	0.194	
(*Z*)-4-Heptenal	898	67,39,55	NIST, Std LRI,	4.08	4.00	3.96	4.08[b]	4.06[b]	3.90[a]	0.029	
Heptanal	900	39,41,70	NIST, Std LRI,	5.33	5.30	5.35	5.32	5.40	5.26	0.025	
(*E*)-2-Octenal	1056	39,55,83	NIST, Std LRI,	4.40	4.44	4.48	4.40	4.51	4.41	0.027	
Octanal	1002	41,67,69	NIST, Std LRI,	5.41	5.44	5.50	5.42[a]	5.55[b]	5.39[a]	0.024	
(*E,Z*)-2,6-Nonadienal	1150	41,69,70	NIST, Std LRI,	4.10[b]	4.01[b]	3.93[a]	4.06	4.09	3.89	0.028	0.02
(E)-2-Nonenal	1158	29,41,55	NIST, Std LRI,	4.99	4.86	4.86	4.92	4.96	4.82	0.028	
Nonanal	1101	69,81,57	NIST, Std LRI,	6.02	6.03	6.03	6.01[a]	6.13[b]	5.95[a]	0.023	
(*E,E*)-2,4-Decadienal	1315	81,67	NIST, Std LRI,	3.98	4.05	4.03	3.97	4.09	4.01	0.031	
(*E*)-2-Decenal	1260	39,81,55	NIST, Std LRI,	4.47	4.40	4.46	4.42	4.53	4.37	0.029	
Decanal	1204	41,67,55	NIST, Std LRI,	4.83	4.83	4.84	4.82	4.89	4.79	0.021	
Undecanal	1306	41,67,81	NIST, Std LRI,	3.90	4.04	3.78	3.66	3.97	4.09	0.126	
Dodecanal	1406	41,67,81	NIST, Std LRI,	4.43	4.43	4.36	4.39[a]	4.48[b]	4.35[a]	0.022	
Tridecanal	1510	41,67,81	NIST, LRI	4.48	4.47	4.40	4.46[a]	4.52[b]	4.37[a]	0.024	
Tetradecanal	1607	41,67,81	NIST, LRI	4.97	4.93	4.85	4.90	4.97	4.87	0.023	
Pentadecanal	1705	41,67,81	NIST, LRI	5.07	5.05	4.96	5.02	5.09	4.97	0.026	
Hexadecanal	1818	41,67,81	NIST, LRI	5.67	5.65	5.55	5.62	5.66	5.59	0.030	
Alcohols											
1-Pentanol	809	41,55,70	NIST, Std LRI,	3.24	3.73	3.88	3.67	3.63	3.55	0.132	
1-Hexanol	868	41,56,39	NIST,Std LRI,	4.35	4.35	4.40	4.35	4.44	4.31	0.026	
1-Heptanol	969	41,55,70	NIST, Std LRI,	4.48	4.52	4.60	4.51	4.60	4.49	0.025	
1-Octen-3-ol	980	43,57,69	NIST, Std LRI,	4.81	4.93	4.93	4.84	4.94	4.89	0.027	
2-Octen-1-ol	1066	41,57,67	NIST, Std LRI,	3.97	4.00	4.01	3.93	4.05	4.01	0.024	
2-Ethyl-1-hexanol	1027	41,55,57	NIST, Std LRI,	4.43	4.27	4.46	4.27	4.48	4.41	0.053	
1-Octanol	1069	41,55,69	NIST, Std LRI,	5.11	5.12	5.14	5.10[ab]	5.22[b]	5.04[a]	0.023	
α-Terpineol	1191	93,59,121	NIST, Std LRI,	4.91	4.89	4.91	4.87	4.95	4.88	0.036	
1-Pentadecanol	1766	69,83,97	NIST, Std LRI,	5.57[c]	5.35[b]	5.00[a]	5.31	5.31	5.29	0.034	<0.00
Ketones											
2-Pentanone		43,71,86	NIST, Std LRI,	0.70	1.42	1.59	1.24	1.45	1.02	0.166	
2,3-Butanedione		43	NIST, Std LRI,	2.59	3.13	3.42	2.99	3.35	2.80	0.202	
2-Heptanone	887	43,58	NIST, Std LRI,	3.73	4.04	4.03	3.74	4.07	3.99	0.062	
2-Nonanone	1089	43,58	NIST, Std LRI,	3.91	4.01	4.00	3.92	4.04	3.95	0.027	

γ-Octalactone	1251	85,57	NIST, Std LRI,	1.11	1.82	1.89	1.15	1.87	1.80	0.153	
γ-Nonalactone	1356	85,29	NIST, Std LRI,	3.06	3.12	3.13	2.91	3.22	3.18	0.089	
Terpenes											
p-cymene	1020	119,91	NIST, Std LRI,	2.81	2.80	2.82	2.51	3.06	2.87	0.122	
Limonene	1024	67,68,93	NIST, Std LRI,	4.27	4.31	4.32	4.25	4.38	4.27	0.029	
Phenols											
p-Cresol	1071	107,108	NIST, Std LRI,	3.32	3.19	2.99	3.46	3.17	2.88	0.171	
Indoles											
Indole	1287	117,89	NIST, Std LRI,	0.64^{b}	0.09^{a}	0.07^{a}	0.09	0.54	0.17	0.086	0.0
Skatole (3-methyl indole)	1379	130,131	NIST, Std LRI,	1.11^{b}	0.51^{ab}	0.34^{a}	0.59	1.05	0.32	0.137	0.0
Pyrazines											
2-Methyl pyrazine	822	94,67	NIST, Std LRI,	1.09	1.07	0.65	0.94	1.23	0.64	0.183	
2,5-Dimethyl pyrazine	909	108,42	NIST, Std LRI,	2.44^{b}	2.14^{b}	0.68^{a}	2.27	1.55	1.45	0.222	0.0
2,6-Dimethyl pyrazine	909	108,42	NIST, Std LRI,	4.27^{b}	4.11^{ab}	3.09^{a}	3.58	4.05	3.85	0.216	0.0
2-Ethyl-3,5-dimethyl-pyrazine	1071	135,134	NIST, Std LRI,	4.86	4.93	4.54	4.83	4.81	4.69	0.084	
2-Ethyl-3,6-dimethyl-pyrazine	1083	135,136	NIST, Std LRI,	2.69^{b}	1.66^{ab}	1.03^{a}	2.45^{b}	1.92^{ab}	1.01^{a}	0.213	0.0
Benzenoid compounds											
Benzaldehyde	957	105,77	NIST, Std LRI,	6.19	6.25	6.12	6.15	6.29	6.12	0.034	
Phenyl acetaldehyde	1039	91,92	NIST, Std LRI,	4.97	4.94	4.86	4.90	4.99	4.89	0.033	
Toluene	748	91,92	NIST, Std LRI,	4.68	4.82	4.73	4.72	4.83	4.67	0.038	
Furans											
2-Pentylfuran	987	81,138,53	NIST, Std LRI,	4.03	4.25	4.43	3.66^{a}	4.46^{b}	4.60^{b}	0.139	
Hydrocarbons											
Tridecane		41,57,71	NIST, Std LRI,	4.52	4.55	4.46	4.49	4.57	4.47	0.028	
Tetradecane		41,57,71	NIST, Std LRI,	4.57	4.54	4.44	4.48	4.60	4.47	0.025	
Pentadecane		41,57,71	NIST, Std LRI,	4.88^{b}	4.84^{b}	4.62^{a}	4.77	4.82	4.75	0.023	<0.0
Hexadecane		41,57,71	NIST, Std LRI,	4.57^{b}	4.46^{b}	4.33^{a}	4.47	4.49	4.41	0.021	<0.0
Heneicosane		41,57,71	NIST, Std LRI,	0.98	0.59	0.58	0.52	0.96	0.67	0.122	
BCFAs											
4-Methyloctanoic acid	1232	55,57,73	NIST, Std LRI,	1.31	1.58	0.76	1.18	1.44	1.04	0.157	
4-Ethyloctanoic acid	1313	55,57,71	NIST, Std LRI,	1.94	2.12	1.81	2.34	1.42	2.11	0.168	
4-Methylnonanoic acid	1323	55,57,71	NIST, Std LRI,	1.26	0.89	0.86	0.98	0.76	1.27	0.149	
Organic acids											
Nonanoic acid	1275	60	NIST, Std LRI,	3.74	3.67	3.71	3.58^{a}	3.89^{b}	3.65^{ab}	0.051	

[1] Linear retention indices (LRI) calculated from the n-alkanes (C7-C30) run under the same GC-MS conditions as LTL muscle samples;

[2] Method of identification: NIST (NIST library), Std (authentic standard) and LRI;; Specific ions used for volatile identification and peak area integration

[a,b] Within row, means assigned different superscripts indicate differences among diets (S vs SC vs C) or durations (36 vs 54 vs 72 days).

* $P < 0.1$

Highlights

- The volatile profile of lamb meat differed between silage and concentrate-fed lambs
- Differences in the sensory attributes of lamb meat due to differing diets were minor
- Finishing diet duration influenced the sensory and volatile profile of lamb meat
- Discriminant analysis permitted separation of lamb meat based on the diet consumed

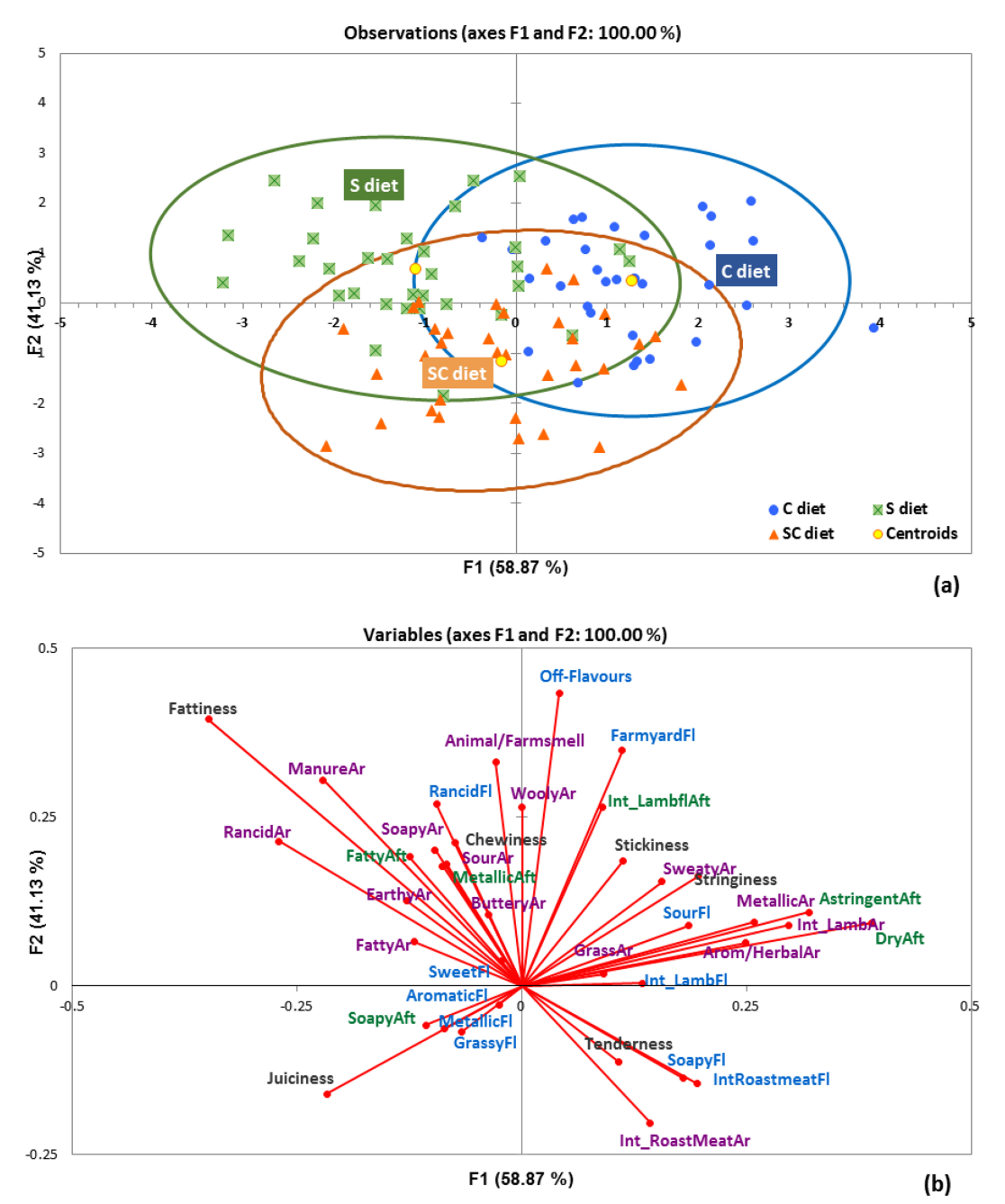
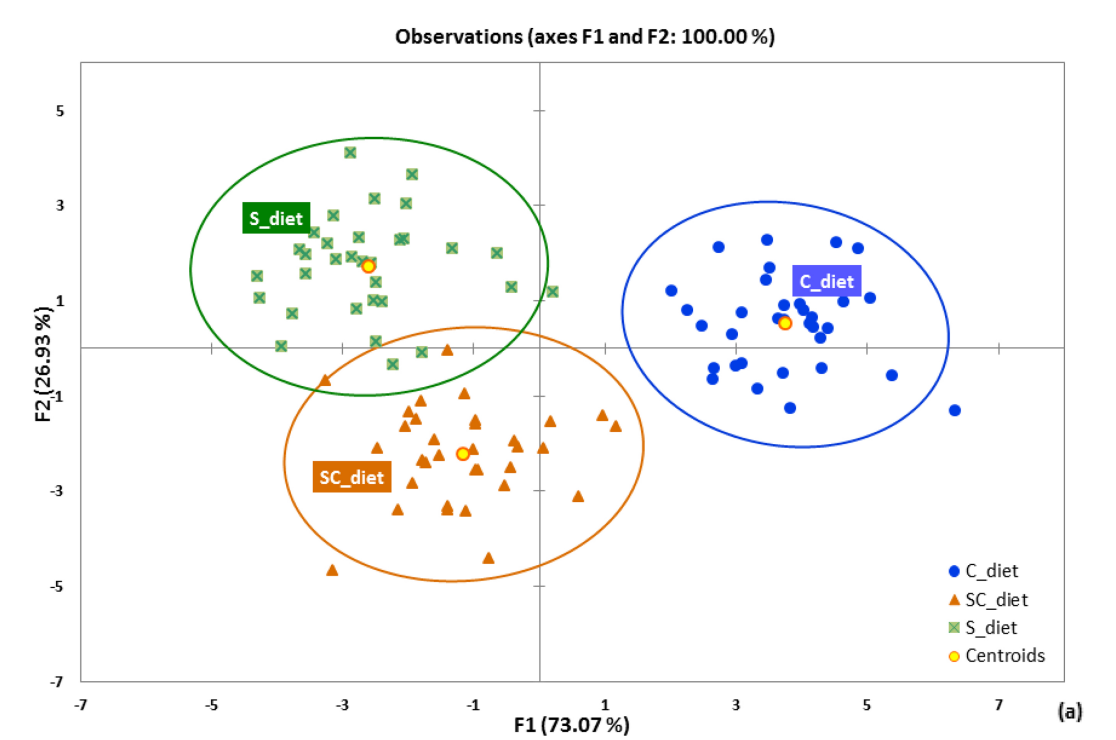

Observations (axes F1 and F2: 100.00 %)
S diet
C diet
SC diet
C diet
S diet
SC diet
Centroids
F1 (58.87 %)
F2 (41.13 %)
(a)
Variables (axes F1 and F2: 100.00 %)
Off-Flavours
Fattiness
Animal/Farmsmell
FarmyardFl
ManureAr
RancidFl
WoolyAr
Int_LambflAft
RancidAr
SoapyAr
Chewiness
Stickiness
FattyAft
SourAr
SweatyAr
MetallicAft
Stringiness
EarthyAr
ButteryAr
MetallicAr
AstringentAft
SourFl
Int_LambAr
DryAft
FattyAr
GrassAr
Arom/HerbalAr
SweetFl
Int_LambFl
AromaticFl
SoapyAft
MetallicFl
GrassyFl
Tenderness
SoapyFl
Juiciness
IntRoastmeatFl
Int_RoastMeatAr
F1 (58.87 %)
F2 (41.13 %)
(b)

Figure 1


Observations (axes F1 and F2: 100.00 %)
S_diet
C_diet
SC_diet
C_diet
SC_diet
S_diet
Centroids
F2 (26.93 %)
F1 (73.07 %)
(a)

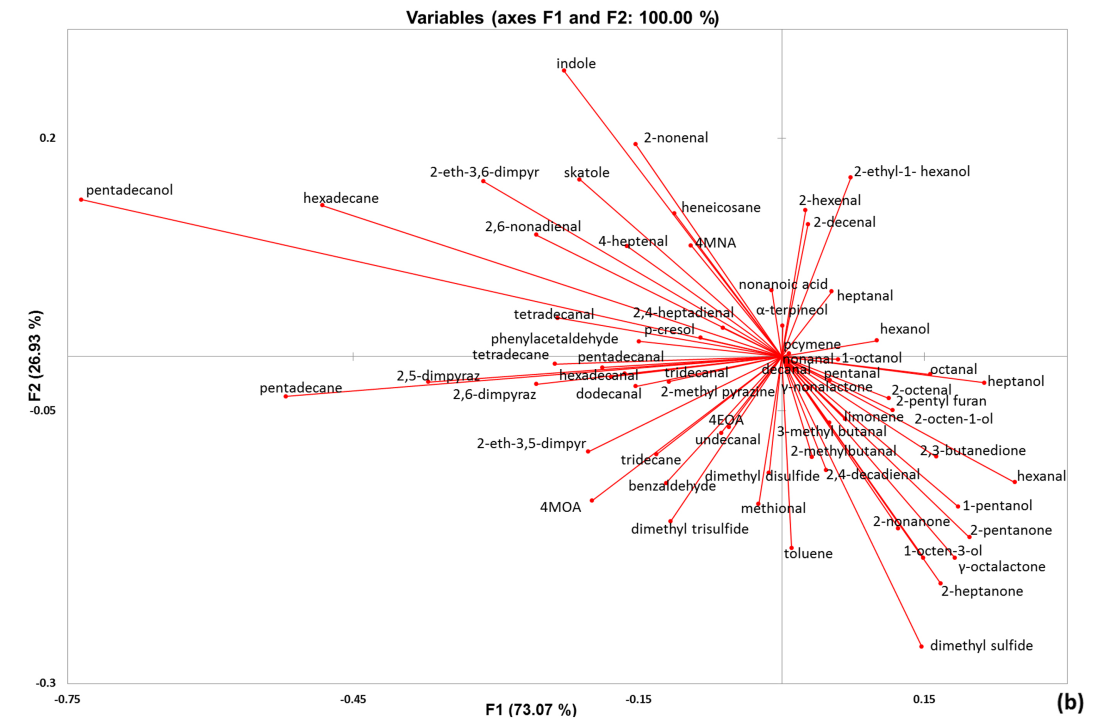

Variables (axes F1 and F2: 100.00 %)
indole
2-nonenal
2-eth-3,6-dimpyr
skatole
2-ethyl-1- hexanol
pentadecanol
hexadecane
heneicosane
2-hexenal
2-decenal
2,6-nonadienal
4-heptenal
4MNA
nonanoic acid
heptanal
tetradecanal
2,4-heptadienal
α-terpineol
p-cresol
hexanol
phenylacetaldehyde
o-cymene
tetradecane
pentadecanal
nonanal
1-octanol
2,5-dimpyraz
hexadecanal
tridecanal
decanal
pentanal
octanal
heptanol
pentadecane
2,6-dimpyraz
dodecanal
2-methyl pyrazine
γ-nonalactone
2-octenal
2-pentyl furan
4EOA
limonene
2-octen-1-ol
3-methyl butanal
2-eth-3,5-dimpyr
undecanal
2-methylbutanal
2,3-butanedione
tridecane
dimethyl disulfide
2,4-decadienal
hexanal
benzaldehyde
4MOA
methional
1-pentanol
dimethyl trisulfide
2-nonanone
2-pentanone
toluene
1-octen-3-ol
γ-octalactone
2-heptanone
dimethyl sulfide
F2 (26.93 %)
F1 (73.07 %)
(b)

Figure 2