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Research paper

Effect of castration and age at slaughter on sensory perception of lamb meat

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ABSTRACT

This study assessed the effect of castration and slaughter age (196–385 days old) on sensory quality of lamb meat from two sheep breeds (Scottish Blackface, SB; Texel x Scottish Blackface, TxSB). Results obtained using a trained sensory panel showed small but statistically significant differences due to castration, with rams having higher scores for *Intensity of Lamb Aroma*, *Animal Smell/Farm Smell*, *Woolly Aroma*, *Rancid Aroma*, *Manure/Faecal Aroma*, *Sweaty Aroma* and *Off-flavours*. SB lamb had higher scores for *Intensity of Lamb Aroma*, *Lamb Flavour*, *Lamb Aftertaste*, *Tenderness* and *Juiciness*. Age effects on sensory attributes were not linear and significant age × gender interactions were observed. The number of samples considered "extreme" in undesirable flavour attributes was higher among rams and T × SB animals. The impact of the sensory differences on consumer acceptability of lamb remains to be established.

1. Introduction

Consumer liking of cooked lamb is not universal (Young et al., 2003) and some studies have shown a lower preference for lamb compared to other meats (Crouse et al., 1983; Duckett and Kuber, 2001; Wong et al., 1975). One of the reasons for lower preference/consumption of lamb is its distinctive flavour (Hornstein and Crowe, 1963; Sink and Caporaso, 1977), sometimes associated with a waxy texture (Young et al., 1994). The sensory quality of lamb meat has been explored by many researchers (Hoffman et al., 2003; Priolo et al., 2002; Resconi et al., 2009; Rousset-Akrim et al., 1997) and is believed to be affected by factors such as gender (Purchas et al., 1979; Young et al., 2003), diet (Watkins et al., 2013), age at slaughter (Pethick et al., 2005) and breed (Hoffman et al., 2003; Notter et al., 1991). However, the nature and the extent of the influence of these factors, and their interactions, on lamb palatability are often unclear. Sanudo et al. (2007) highlighted the difficulty in defining the lamb characteristics, or types of lamb products, that would be acceptable to consumers in European countries. They attributed this difficulty to the variability in sheep production systems across Europe due to different husbandry conditions (local environmental conditions and agricultural methods). This high variability in production methods, and the need to understand how they relate to meat quality, emphasises the requirement for controlled studies, which through the elimination of confounding comparisions, identify the real influence of production factors on lamb flavour (Hopkins and Mortimer, 2014; Purchas, 2007).

Leaving lambs uncastrated results in improved animal performance and production efficiency which has economic benefits for producers (Dransfield et al., 1990; Purchas et al., 1979) while meeting increasing consumer demand for leaner meat, since ram carcasses are leaner (Dransfield et al., 1990; Field, 1971; Seideman et al., 1982). Age at slaughter also influences production efficiency and ultimate meat quality and, while the quality of meat from younger and older lambs differs, unravelling the age effects on quality characteristics is not simple because animal age is almost invariably confounded with other factors (Purchas, 2007). Thus, for example, lambs fed on cereal concentrate-based diets have higher average daily gains than those on pasture and, therefore, animals slaughtered at a fixed age differ in weight while those slaughtered at a fixed weight differ in age (Priolo et al., 2002). Breed type can also affect meat quality, leading to differences in the amount and deposition of fat, in combination with parameters like live weight, age and degree of maturity (Guerrero et al.,

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2013).

The objective of this study was to investigate the effects of castration (rams vs castrates) and slaughter age (five different slaughter ages) on the sensory quality, particularly the flavour quality, of lamb meat derived from two breed types.

2. Materials and methods

2.1. Animal husbandry, slaughter and sampling

Two hundred lambs (100 Texel × Scottish Blackface (T × SB), 100 Scottish Blackface (SB)) were sourced from Irish farms in March 2014. Within each breed type 50 lambs were castrated within 48 h of birth. Lambs were raised at pasture from birth, weaned at 130 days and selected for slaughter in groups of 40 (10 T × SB rams, 10 T × SB castrates, 10 SB rams, 10 SB castrates) in October 2014, November 2014, January 2015, March 2015 and April 2015, with the heaviest ram and castrate lambs selected for slaughter at each slaughter date. On selection, lambs were housed individually in slatted pens and, following a 12 d adaptation period during which the lambs were gradually introduced to a barley/maize-based concentrate ration and grass silage, they received *ad libitum* a finishing diet consisting of the barley/maize-based concentrate ration (95% dietary dry matter (DM) intake) and grass silage (5% DM intake) for 36 d pre-slaughter. Lambs were maintained in close proximity, but separate from, cyclic females while at pasture and following housing. At the end of the finishing period, lambs were transported to a commercial abattoir (Gillivan's, Moate, Co.Westmeath) for slaughter. The mean ages of the lambs at slaughter in October, November, January, March and April were 196, 242, 293, 344 and 385 days, respectively. A total of 198 animals were presented for slaughter (two SB rams died over the course of the experiment). After slaughter, carcasses were chilled overnight and transported to Teagasc, Food Research Centre, Ashtown, Dublin 15, Ireland for dissection. Mean carcass weights (± standard deviation) for the SB and T × SB animals of 20.8 (± 1.89) and 25.7 (± 2.43) kg, respectively, and for the rams and castrates of 23.2 (± 3.28) and 23.3 (± 3.31) kg, respectively, were recorded. Ultimate pH (pHu) of *M. longissimus thoracis et lumborum* (LTL) was measured 25 h post slaughter at the 13th rib using a SympHony SP70P hand-held pH meter (VWR, Dublin, Ireland). The LTL was 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. The study was carried out under licence from the Irish Government Department of Health and all procedures used complied with national regulations concerning experimentation on farm animals (HRB, 2011).

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. Branched chain fatty acids (BCFAs) were analysed using microwave assisted preparation of FAMEs (Brunton et al., 2015) with separation and quantification by GC-FID (PerkinElmer Clarus 580, PerkinElmer; ZB-5 column, 30 m x 0.25 mm internal diameter, 0.25 µm film thickness). The results were reported in µg/g with the response factor for each FAME set to 1.

2.3. Sensory analysis

2.3.1. Lamb meat preparation

The LTL muscle from the left side of each carcass was used for sensory analysis which took place at Teagasc Food Research Centre, Ashtown. On the days of sensory tasting, frozen steaks were thawed by immersion in water at room temperature for 45 min. Steaks were grilled, with adhering fat attached, to an internal temperature of 70 °C, using a Tefal OptiGrill clamp grill (Currys, Dublin, Ireland). On reaching 70 °C (monitored using a hand-held digital thermometer (Eurolec, Dublin, Ireland)) the steaks were removed from the grill, wrapped with aluminum 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. Samples from 193 animals were used for sensory analysis (of the initial 200 animals, samples from five (3 T × SB castrates, 1 SB ram, 1 SB castrate) were deemed unsuitable for human consumption in addition to the two lost during the production phase).

2.3.2. Panel training

Staff at Teagasc Food Research Centre, Ashtown, participated as sensory panellists, selected based on their availability, their interest in the project and their sensitivity as assessors following two screening sessions. Panellists participated in 16 training sessions. In the initial training sessions, a range of samples that included the flavours and off-flavours similar to those of interest were used. Samples of lamb meat, some with adhering fat, were presented to panellists who described the sensory attributes they perceived and generated descriptors for flavour, aroma, texture/mouthfeel, taste and aftertaste. In addition, in two sessions, panellists received lamb samples spiked with some of the recognised lamb flavour/aroma compounds (i.e. BCFAs, skatole, indole, p/m-cresol and 3-methylpentanoic acid) to aid in the generation of aroma descriptors. Sessions using physical and chemical reference standards were run so that the panellists would learn to differentiate and identify the sensory descriptors (Table 1). Training in the intensities of odour, flavour and texture (chewiness, tenderness and juiciness) was carried out based on the study of Braghieri et al. (2012) (adjusted for lamb, as opposed to beef). In brief, for low, medium and high odour/flavour intensity, lamb loin boiled for 15 min, microwave cooked (4.5 min at 800W), or grilled to an internal temperature 70 °C (using an electric grill preheated at 240 °C), respectively, was prepared. For low, medium and high chewiness/tenderness intensity, lamb shank cooked to an internal temperature of 70 °C, side loin cooked to an internal temperature of 70 °C and centre loin cooked to an internal temperature of 65 °C, respectively, were prepared. For juiciness of low, medium and high intensity side loin cooked to internal temperatures of 80 °C, 70 °C or 64 °C, respectively, was prepared. Training sessions were informed by AMSA (2015) guidelines.

2.3.3. Quantitative descriptive analysis

Quantitative descriptive analysis (QDA) was performed on one day per week over 16 weeks with two sensory sessions per day (morning and afternoon). In each session, 6 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. The sensory attribute definitions, agreed during the training sessions (Table 1), were available to each panellist during tasting. Panellist evaluations were recorded using *Compusense 5* (v4.4, Compusense Inc., Guelph, Ontario, Canada).

2.4. Statistical 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

Table 1
Attribute description, scale and reference standards used for aroma, flavour, texture and aftertaste attributes developed by the trained panel for quantitative descriptive analyses of grilled lamb.

Sensory attributes	Attribute description	Scale used	Reference used
Aroma			
Intensity of Roast Meat Aroma	Intensity of roast meat aroma	Weak–Strong	Adapted from Braghieri et al. (2012)
Intensity of Lamb Aroma	Aroma associated with cooked lamb	Weak–Strong	Adapted from Braghieri et al. (2012)
Grassy aroma	Intensity of freshly cut grass	Weak–Strong	Hexanal,100 ppm in propylene glycol (PG)
Aromatic/Herbal	Aroma associated with dried herbs	Weak–Strong	Dried mixture of herbs
Metallic/Bloody	Aroma of blood	Weak–Strong	
Animal Smell/Farm Smell	Aroma of barnyard, horse-stable	Weak–Strong	m-cresol, 10 ppm in PG
Woolly	Fleecy-animal aroma, cheesy-like aroma	Weak–Strong	3-methyl-pentanoic acid, 10 ppm in PG
Buttery	Aroma associated with natural, fresh, unsalted butter	Weak–Strong	Unsalted butter
Fatty	Aroma of cooked fat	Weak–Strong	Lamb fat
Rancid	Aroma associated with oxidized oil/fat	Weak–Strong	Rancid oil mixture
Manure/Faecal	Aroma associated with animal dung	Weak–Strong	Skatole, 10 ppm in PG
Sour	Pungent aroma associated with vinegar or lemon	Weak–Strong	Acetic acid, 10 ppm in PG
Sweaty	Aroma reminiscent of perspiration generated by foot odour, waxy, stale, moist	Weak–Strong	4-methyloctanoic acid, 10 ppm in PG
Soapy	Detergent, alkaline aroma, non-fragrant soap	Weak–Strong	Non-fragrant soap
Earthy-smell	Musty, wet-soil, reminding freshly-cut mushrooms	Weak–Strong	Fresh cut mushrooms or 1-octen-3-ol, 100 ppm in PG
Flavour			
Intensity of Roast Meat Flavour	Flavour associated with cooked meat	Low–High	Adapted from Braghieri et al. (2012)
Intensity of Lamb Flavour	Flavour intensity of cooked lamb	Low–High	Adapted from Braghieri et al. (2012)
Grassy	Flavour associated with freshly cut green grass		
Metallic/Bloody	Flavour associated with iron or blood	Not–Very	Liquid iron supplement in water
Aromatic/Herbal	Flavour associated with dried herbs	Low–High	
Soapy	A detergent-like taste, similar to when a food is tainted with a cleansing agent	Low–High	
Rancid	Flavour associated with oxidized oil/fat	Low–High	
Farmyard	Musty flavour, associated with horse-stable/damp earth	Low–High	
Sour	Acidic flavour	Low–High	Citric acid in water (0.06%)
Sweet	Sucrose like flavour	Low–High	Sucrose solution (4%)
Off-flavours	Intensity of other unpleasant flavours (not mentioned above)	Low–High	
Texture			
Tenderness	The resistance to teeth biting through the sample (through the outer “crust” and through the sample)	Not–Very	Adapted from Braghieri et al. (2012)
Juiciness	In the first 3–4 chews, the release of liquid from sample	Not–Very	Adapted from Braghieri et al. (2012)
Chewiness	Number of chews/the force required to break down sample to swallow	Not–Very	Adapted from Braghieri et al. (2012)
Fattiness/Greasiness	Perception of slipperiness or of fat coating of oral cavity	Not–Very	
Stringiness/Fibrousness	Extend to which fibers/strands are perceived during chewing	Not–Very	
Stickiness	Extent to which meat sticks to the palate and the teeth during tasting	Not–Very	
Aftertaste			
Intensity of Lamb Aftertaste	Intensity of lamb flavour left 12 s after swallowing	Low–High	
Soapy	Perception of “soapiness” in the mouth after swallowing	Not–Very	
Metallic/Bloody	Flavour associated with iron supplement or blood after swallowing	Not–Very	Liquid iron supplement in water
Fatty/Greasy	Fatty mouth coating after swallowing the sample	Not–Very	
Dry	Dry mouthfeel after swallowing the sample	Not–Very	Unsalted crackers
Astringent	A mouth-drying and harsh sensation.	Not–Very	Strong black tea

Box-Cox transformation (Fahey et al., 2007). The data were analyzed using a mixed model with gender, age, breed and their interactions (gender × age, gender × breed, age × breed, gender × age × breed) as fixed effects. The sensory analysis session was considered as the random effect. Analysis was conducted in the MIXED procedure of SAS (v9.4).

The Median Absolute Deviation (MAD) statistic (Leys et al., 2013; Wilcox, 2010) was applied to determine the extent to which sensory scores could be considered “extreme” or as “outliers”. In this manuscript it was applied to seven sensory attributes considered “undesirable” − *Animal Smell/Farm Smell* (Ames and Sutherland, 1999; Erasmus et al., 2016), *Woolly Aroma, Rancid Aroma* (Tejeda et al., 2008), *Manure/Faecal Aroma* (Leighton et al., 2007) *Rancid Flavour, Farmyard Flavour* (Erasmus et al., 2016), *Off-flavours* − with the objective of determining whether there was a preponderance of these attributes among animals in any of the treatments. The MAD statistic applied to the full set of sensory attributes is available in supplementary Table S1. The MAD statistic is estimated by first subtracting the median (M) from every observation (x_1, $x_2 \ldots x_n$), calculating the median of the absolute values: $|x_1 - M|$, $|x_2 - M|, \ldots |x_n - M|$ and multiplying the latter by 1.4826. Choosing the threshold two, the value X is considered an outlier if: $|x - M| > 2 \times (MAD \times 1.4826)$ (Leys et al., 2013; Wilcox, 2010).

Correlations between the sensory attributes and other parameters (IMF, pHu and BCFAs) (the full BCFA dataset to be published in a companion manuscript (Gravador et al., 2017) were determined by means of Spearman’s correlation coefficient (r). Analysis was conducted using the CORR procedure of SAS (v9.4). Principal component analysis (PCA) (Pearson-type) was performed using XLSTAT® statistical software (Version 19.01.41647; Addinsoft, Paris, France) and all variables were standardized to unit variance and zero mean prior to the analysis. Varimax rotation was applied to the PCA (Fig. 1) to facilitate interpretation of the data (Hair et al., 1998).

3. Results

3.1. Compositional analysis

Lamb from rams had lower ($P < 0.001$) fat content and higher

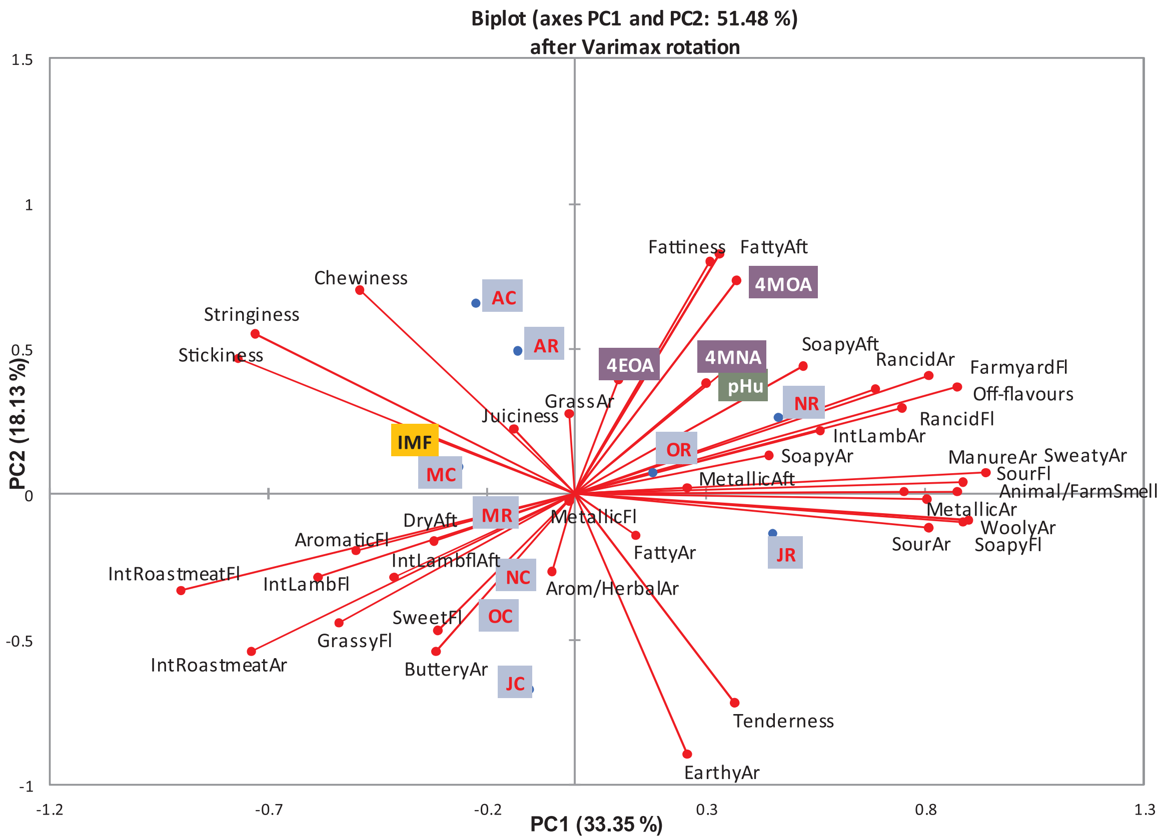

Fig. 1. Principal component analysis (PCA) loadings plots indicating the least square means of the sensory attributes, BCFAs, pHu and IMF as affected by gender - age groups. "Ar", "Fl" and "Aft" refer to Aroma, Flavour and Aftertaste attributes, respectively. 4-EOA, 4-ethyloctanoic acid; 4-MOA, 4-methyloctanoic acid; 4-MNA, 4-methylnonanoic acid detected in subcutaneous fat. "OR", October rams; "OC", October castrates; "NR", November rams; "NC", November castrates; "JR", January rams; "JC", January castrates; "MR", March rams; "MC", March castrates.

Table 2
Least square mean values for proximate analysis and pHu of LTL muscle as influenced by gender, age at slaughter and breed.

	Gender (G)		Age at slaughter (A)					Breed (B)		SEM	P values					
	R[1]	C	O	N	J	M	A	SB	T × SB		G	A	B	G × A	G × B	A × B
Fat	2.61	3.19	2.68	2.82	3.04	3.14	2.83	3.28	2.52	0.07	< 0.001		< 0.001			
Protein	21.4	21.5	21.5	21.4	21.5	21.3	21.4	21.3	21.6	0.04			< 0.001			
Moisture	74.8	74.0	74.4	74.3	74.1	74.4	74.6	74.2	74.5	0.07	< 0.001		0.050			
Ash	1.14	1.12	1.16[a]	1.15[a]	1.13[b]	1.10[b]	1.11[b]	1.12	1.14	0.01		0.0131			0.008[2]	
pHu	5.65	5.52	5.37[a]	5.55[b]	5.67[c]	5.65[c]	5.67[c]	5.60	5.56	0.02	< 0.001	< 0.001		0.002[3]		

[1]Rams (R), Castrates (C), October (O), November (N), January (J), March (M), April (A), Scottish Blackface (SB), Texel x Scottish Blackface (T × SB)
[a,b,c] Means assigned different superscripts differ significantly between ages ($P < 0.05$)
[2]Mean values for ash in LTL of 1.11 and 1.17 for rams and of 1.13 and 1.12 for castrates in SB and T × SB, respectively
[3]Mean pHu values in LTL of 5.38, 5.63, 5.83, 5.70 and 5.69 for rams and of 5.36, 5.46, 5.52, 5.61 and 5.64 for castrates in October, November, January, March and April, respectively

($P < 0.001$) moisture content than lamb from castrates (Table 2). T × SB lamb had higher ($P < 0.001$) protein content and lower ($P < 0.001$) fat content than SB lamb. There was a gender × age interaction for pHu whereby the pHu values of LTL from rams and castrates were not different ($P > 0.05$) in October, March and April but they were higher for rams than castrates in November ($P < 0.01$) and January ($P < 0.001$).

3.2. Sensory analysis

Twenty four of the 38 sensory descriptors measured were affected by treatment (Tables 3 and 4). The differences between the two genders, although numerically small, were statistically significant for 11 descriptors. Lamb from rams had higher mean scores for *Intensity of Lamb Aroma* ($P = 0.01$), *Animal Smell/Farm Smell* ($P < 0.01$), *Woolly Aroma* ($P < 0.05$), *Rancid Aroma* ($P < 0.05$), *Manure/Faecal Aroma* ($P < 0.01$), *Sweaty Aroma* ($P < 0.05$), *Rancid Flavour* ($P < 0.01$), *Off-flavours* ($P < 0.001$) *and Fattiness/Greasiness* ($P < 0.05$) and lower mean scores for *Intensity of Roast Meat Aroma* ($P < 0.05$) and *Intensity of Roast Meat Flavour* ($P < 0.001$). Differences in *Soapy Aroma, Soapy Flavour* and *Fatty/Greasy Aftertaste* were close to significance ($P = 0.056$, $P = 0.058$ and $P = 0.057$, respectively) with rams having higher scores than castrates.

Sour Aroma was higher ($P < 0.01$) in November and January than in the other months. *Earthy Aroma* was lower in April ($P < 0.05$) than all other months except October (Table 3). November lamb had higher ($P < 0.05$) *Sour Flavour* than October, March and April lamb but was similar to January. January lamb had a higher mean score ($P < 0.001$) for *Tenderness* and lower scores for *Chewiness* ($P < 0.001$) and *Stringiness/Fibrousness* ($P < 0.001$) than October, November, March or April

Table 3
Least Square Mean scores for sensory attributes in grilled LTL muscle as affected by gender, age at slaughter and breed.

	Gender (G)		Age at slaughter (A)					Breed (B)			p-values		
Sensory attributes	R[1]	C	O	N	J	M	A	SB	T × SB	SEM	G	A	B
Aroma													
Intensity of Roast Meat Aroma	59.4[2]	62.1	60.4^{a}	58.9^{a}	60.8^{ab}	64.4^{b}	59.2^{a}	61.1	60.3	0.66	0.027	0.043	
Intensity of Lamb Aroma	49.1	46.5	47.6	47.5	48.9	46.6	48.3	49.6	45.9	0.52	0.010		0.000
Grassy Aroma	13.0	12.7	13.5	12.6	12.7	12.7	12.8	12.7	13.0	0.27			
Aromatic/Herbal	14.4	14.6	15.1	14.5	14.2	14.6	14.0	13.7	15.3	0.27			0.005
Metallic/Bloody	19.3	18.5	19.1	19.9	19.1	18.3	18.0	19.0	18.8	0.36			
Animal Smell/Farm Smell	10.1	8.1	10.3	9.9	9.3	8.1	8.0	8.6	9.6	0.31	0.002	0.052*	0.066*
Woolly	6.2	4.9	6.3	5.9	6.1	4.6	4.7	5.4	5.7	0.31	0.014		
Buttery	17.1	17.7	16.8	17.5	17.9	17.7	16.9	17.4	17.4	0.41			
Fatty	24.0	23.9	24.3	23.8	24.3	23.5	23.8	24.6	23.3	0.56			0.081*
Rancid	8.0	6.3	7.2	7.5	7.5	6.0	7.5	7.0	7.3	0.30	0.011		
Manure/Faecal	5.0	3.9	4.5	5.0	5.4	3.5	3.8	4.3	4.6	0.24	0.008	0.068*	
Sour	6.5	5.9	5.6^{a}	7.3^{c}	7.2^{bc}	5.1^{a}	5.8^{ab}	5.9	6.5	0.24		0.008	
Sweaty	10.4	8.9	10.2	10.3	9.8	9.2	8.7	9.5	9.8	0.35	0.018		
Soapy	4.4	3.8	4.1	4.5	4.1	4.0	3.9	3.7	4.6	0.16	0.056*		0.006
Earthy	7.7	7.7	7.7^{ab}	7.8^{b}	8.6^{b}	8.0^{b}	6.4^{a}	7.7	7.7	0.22		0.024	
Flavour													
Intensity of Roast Meat Flavour	48.9	54.0	50.9^{a}	48.8^{a}	50.8^{a}	55.2^{b}	51.6^{ab}	51.4	51.5	0.68	< 0.001	0.030	
Intensity of Lamb Flavour	49.5	50.6	49.1	49.2	51.0	50.6	50.4	52.0	48.1	0.50			< 0.001
Grassy	10.8	11.3	11.2	10.9	11.1	10.7	11.1	10.9	11.1	0.25			
Metallic/Bloody	36.2	35.4	35.3	35.3	36.0	35.5	36.9	36.1	35.5	0.64			
Aromatic/Herbal	10.8	10.8	11.2	10.6	10.3	11.2	10.5	10.5	11.1	0.30			
Soapy	6.7	5.8	6.2	6.9	6.6	6.2	5.5	5.9	6.6	0.22	0.058*		
Rancid	9.1	7.0	7.7	10.0	8.2	7.0	7.6	7.6	8.6	0.35	0.002	0.051*	
Farmyard	10.2	8.6	9.1	10.3	9.5	8.6	9.7	9.2	9.7	0.37			
Sour	9.7	8.9	9.2^{a}	11.1^{b}	9.6^{ab}	8.3^{a}	8.4^{a}	8.5	10.1	0.31		0.015	0.007
Sweet	5.8	6.5	6.2	5.8	6.9	5.9	6.1	6.2	6.2	0.25			
Off-flavours	13.0	9.7	10.4	14.0	11.5	10.0	10.8	10.3	12.4	0.58	0.001		0.040
Texture													
Tenderness	60.4	62.6	61.6^{ab}	62.3^{b}	70.5^{c}	57.2^{ab}	56.0^{a}	65.0	58.0	1.05		< 0.001	0.000
Juiciness	46.4	47.7	46.1	46.3	47.7	47.3	47.8	48.8	45.3	0.71			0.012
Chewiness	41.4	41.8	40.6^{b}	42.8^{bc}	33.0^{a}	44.8^{bc}	46.7^{c}	38.2	45.0	1.00		< 0.001	0.000
Fattiness/Greasiness	33.3	31.3	31.7	33.3	30.7	31.8	34.0	33.1	31.4	0.51	0.030		0.073*
Stringiness/Fibrousness	30.3	32.6	30.7^{b}	31.5^{b}	25.8^{a}	34.4^{b}	35.1^{b}	27.7	35.2	0.82		0.001	< 0.001
Stickiness	26.1	28.0	26.3	26.0	25.5	28.7	28.8	25.8	28.3	0.59			0.026
Aftertaste													
Intensity of Lamb Aftertaste	43.8	44.5	43.9	43.8	44.9	43.8	44.3	45.2	43.1	0.44			0.011
Soapy	10.9	10.3	10.4	10.8	10.6	10.8	10.5	10.2	11.0	0.26			
Metallic/Bloody	37.4	36.1	36.5	36.5	37.4	36.6	36.8	36.7	36.8	0.67			
Fatty/Greasy	22.1	20.6	21.3	21.5	20.6	20.1	23.3	21.9	20.9	0.41	0.057*		
Dry	14.7	15.0	15.0	15.1	14.2	15.1	14.9	13.9	15.9	0.40			0.014
Astringent	12.9	13.1	13.0	13.9	12.5	12.5	13.0	12.3	13.6	0.38			0.068*

[1] Rams (R), Castrates (C), October (O), November (N), January (J), March (M), April (A), Scottish Blackface (SB), Texel x Scottish Blackface (T × SB)
[2] Mean values for attributes evaluated on a 100-point unstructured line scale (0 = low intensity; 100 = high intensity)
[a,b,c] Means assigned different superscripts differ significantly between ages ($P \leq 0.05$)
*P values on the threshold of statistical significance ($P \leq 0.1$)

lamb. The effect of age on *Animal Smell/Farm Smell* approached significance (P = 0.052) with March and April having lower scores (P < 0.05) than October, and April scores having lower scores than November. Similarly, the effect of age on *Manure/Faecal Aroma* and *Rancid Flavour* approached significance (P = 0.068 and P = 0.051, respectively). Thus, for *Manure/Faecal Aroma,* January lamb had higher score than March (P < 0.05) and April (P < 0.05) lamb, while November lamb higher than March lamb (P < 0.05). For *Rancid Flavour* November lamb had higher score than October, March and April lamb (P < 0.05).

Lamb from SB had higher mean scores for *Intensity of Lamb Aroma* (P < 0.001), *Intensity of Lamb Flavour* (P < 0.001) and *Intensity of Lamb Aftertaste* (P < 0.05) than T × SB (Table 3). Lamb from SB also scored higher for *Tenderness* (P < 0.001) and *Juiciness* (P < 0.05) and lower for *Chewiness* (P < 0.001), *Stringiness* (P < 0.001) and *Stickiness/Fibrousness* (P < 0.05) than the T × SB lamb. On the other hand, T × SB had higher scores (P < 0.05) for *Aromatic/Herbal Aroma* (P < 0.01), *Soapy Aroma* (P < 0.01), *Sour Flavour* (P < 0.01), *Off-flavours* (P < 0.05) and *Dry Aftertaste* (P < 0.05). Differences in *Animal Smell/Farm Smell* and *Astringent Aftertaste* were close to significance (P = 0.066 and P = 0.068, respectively) with T × SB having higher scores than SB, while *Fatty Aroma* and *Fattiness/Greasiness* approached significance (P = 0.081 and P = 0.073, respectively) with SB scoring higher than T × SB.

Significant gender × age interactions were found for five attributes (Table 4) and two approached significance. Mean scores for *Intensity of Roast Meat Aroma* were higher for lamb from castrates than rams in November (P < 0.01) and January (P < 0.01) but not in the other months. In addition, *Intensity of Roast Meat Aroma* increased with age in lamb from rams but not in castrates. Similarly, for *Intensity of Roast Meat Flavour* scores for castrates were higher than rams in November (P = 0.0001) and January (P < 0.001) but not in the other months. There were no significant differences in *Intensity of Roast Meat Flavour* due to age in castrates; however, in rams, November lamb had a lower mean score than October (P < 0.05), March (P = 0.0001) and April (P < 0.01) lamb but was similar to January lamb (P > 0.05). For

Table 4
Significant interactions for sensory attributes between gender, age at slaughter and breed.

	Gender (G)	Age at slaughter (A)					Breed (B)		SEM	P values		
	R/C[1]	O	N	J	M	A	SB	T × SB		G × A	G × B	A × B
Intensity of Roast Meat Aroma[2]	R	58.9^{ab}	55.4^{ax}	57.0^{abx}	65.1^{c}	60.5^{bc}			0.90	0.017		
	C	$61.\ 9^{ab}$	62.5^{aby}	64.6^{by}	63.5^{b}	57.9^{a}			0.91			
Manure/Faecal Aroma[3]	R	4.9^{ab}	6.2^{bcx}	7.0^{cx}	3.1^{a}	3.9^{a}			0.45	0.048		0.048[3]
	C	4.1	3.8^{y}	3.8^{y}	3.8	3.8			0.35			
Soapy Aroma	R						3.7^{a}	5.2^{bx}	0.27		0.038	
	C						3.7	3.9^{y}	0.24			
Intensity of Roast Meat Flavour	R	50.1^{bc}	43.5^{ax}	45.1^{abx}	54.1^{c}	51.8^{c}			0.93	0.005		
	C	51.9	54.2^{y}	56.7^{y}	56.1	51.7			0.93			
Rancid Flavour	R	10.1^{bcx}	12.7^{cx}	8.3^{ab}	6.9^{a}	7.8^{ab}			0.54	0.010		
	C	5.4^{y}	7.3^{y}	8.1	6.9	7.7			0.46			
Off-flavours	R	11.7^{a}	17.6^{bx}	14.8^{abx}	10.7^{a}	10.4^{a}			0.83	0.049		
	C	9.2	10.4^{y}	8.2^{y}	9.3	11.3			0.73			

[1]Rams (R), Castrates (C), October (O), November (N), January (J), March (M), April (A), Scottish Blackface (SB), Texel x Scottish Blackface (T × SB).
[2] Mean values for attributes evaluated on a 100-point unstructured line scale (0 = low intensity; 100 = high intensity).
[3] AxB interaction: scores of 3.8, 4.7, 5.8, 3.9, and 5.0 for October, November, January, March and April, respectively, in T × SB lambs; scores of 5.2, 5.3, 5.1, 3.1 and 2.7 for October, November, January, March and April, respectively, in SB lambs.
[a,b,c] Means assigned different superscripts within rows differ significantly (P ≤ 0.05).
[x,y] Means assigned different superscripts within columns differ significantly between genders (P ≤ 0.05).

Manure/Faecal Aroma, rams had higher mean scores than castrates in November (P < 0.05) and January (P < 0.01). In addition, in rams, January and November scores were higher than March (P < 0.01) and April (P < 0.05) while in castrates there were no significant differences due to age. For *Rancid Flavour*, in rams November scores were higher than January (P < 0.01), March (P < 0.001) and April scores (P < 0.001), while October scores were also higher than March (P < 0.05). In castrates there was no difference (P > 0.05) due to age for this attribute. Lamb from rams had a higher *Rancid Flavour* score than castrates in October (P < 0.01) and November (P < 0.001). For *Off-flavours*, rams had higher mean scores than castrates only in November (P < 0.01) and January (P < 0.01). In rams, only November scores were higher than April scores (P < 0.01) while in castrates there were no significant differences due to age. For *Fattiness/Greasiness,* the gender × age interaction approached significance (P = 0.057) (data not shown); thus, rams had higher mean scores than castrates only in October (P < 0.05) and November (P < 0.01). In addition, in rams, November scores were higher than January (P < 0.05) and March (P < 0.05) while in castrates April scores were higher (P < 0.05) than October scores. Similarly for *Rancid Aroma* the gender × age interaction approached significance (P = 0.057) (data not shown); rams had higher mean scores than castrates only in October (P < 0.05) and January (P < 0.01).

An age × breed interaction was found for *Manure/Faecal Aroma* (P < 0.05) (Table 4)*;* thus, for SB lambs, April scores were lower than October (P < 0.01), November (P < 0.01) and January (P < 0.01) whereas for T × SB lambs January scores were higher (P ≤ 0.05) than October scores. In addition, SB lambs scored lower (P < 0.05) than T × SB lambs in April, but not in the other months.

A gender × breed interaction was found for *Soapy Aroma* whereby there was no difference in mean scores between ram and castrates in SB, but scores were higher (P < 0.01) for rams than castrates in T × SB (Table 4). For *Soapy Aftertaste* the gender × breed interaction approached significance (P = 0.061) (data not shown) whereby SB rams had lower scores than T × SB rams (P < 0.05) and T × SB rams had higher scores than T × SB castrates (P < 0.05). A gender × age × breed interaction was found for *Fatty Aroma* (data not shown).

Using the MAD statistic, a higher percentage of rams than castrates (34% vs 17%) exceeded the cut-off (i.e. were considered "outliers" as defined in 2.4) for at least one of the seven aroma and flavour attributes tested (Table 5). Similarly, a higher percentage of T × SB compared to SB (32% vs 19%) were considered outliers. There was no clear age effect and lambs from all slaughter ages were included among the animals exceeding the cut-off values (data not shown).

Table 5
Percentage of animals per gender and breed that exceeded the cut-off point for seven "undesirable" attributes using the Median Absolute Deviation statistic.

	T × SB		SB	
	Rams n = 50	Castrates n = 47	Rams n = 47	Castrates n = 49
Animal smell/ Farm smell	18	0	9	4
Woolly Aroma	14	6	4	4
Rancid Aroma	6	2	4	0
Manure/Faecal Aroma	10	2	4	2
Off-flavours	8	0	4	0
Rancid Flavour	18	4	11	4
Farmyard Flavour	22	13	9	6
Total[a]	42	21	26	12

[a] Percentage of animals with one or more "undesirable" attribute.

Principal component analysis (Fig. 1), in which PC1 explained 33.3% and PC2 explained 18.13% of the variance, divided the gender-age groups into two categories: groups of October rams, November rams and January rams on the right side and the other gender-age groups on the left side of the plot. November rams were associated mostly with *Intensity of Lamb Aroma*, *Rancid Aroma, Rancid Flavour, Farmyard Flavour* and *Off-flavours* (factor loadings 0.7–1 in PC1). January rams were more associated with *Manure Aroma, Sweaty Aroma, Animal Smell/Farm Smell, Sour Aroma, Metallic Aroma, Woolly Aroma, Sour Flavour* and *Soapy Flavour* (factor loadings 0.7–1 in PC1). Groups on the lower left quadrant (October castrates, November castrates, January castrates) were broadly associated with *Intensity of Roast Meat Aroma, Intensity of Roast Meat Flavour, Intensity of Lamb Flavour, Grassy Flavour, Sweet Flavour* and *Buttery Aroma.* April lambs on the upper left quadrant were characterised more by textural attributes (*Chewiness, Stringiness* and *Stickiness*).

Principal component analysis (Supplementary Fig. S1), in which PC1 explained 51.54% and PC2 explained 38.18% of the variance, also showed a clear separation among the four gender-breed groups: SB rams and SB castrates, T × SB rams and T × SB castrates. For the sensory characteristics PC1 separated T × SB rams (in the right quadrant) from SB castrates (in the left quadrant). This separation was driven by the association of T × SB rams with the attributes *Grassy*

Aroma, *Animal Smell/Farm Smell*, *Woolly Aroma*, *Rancid Aroma*, *Manure/Faecal Aroma*, *Sour Aroma*, *Sweaty Aroma*, *Soapy Aroma, Soapy Flavour, Rancid Flavour, Farmyard Flavour, Sour Flavour*, *Off-flavours*, *Soapy Aftertaste, Metallic Aftertaste* (factor loadings 0.7–1 in PC1). SB castrates were associated with *Intensity of Roast Meat Aroma*, *Buttery Aroma*, *Fatty Aroma*, *Intensity of Lamb Flavour, Sweet Flavour, Tenderness, Juiciness, Intensity of Lamb Aftertaste* and IMF. PC2 separated SB rams from T × SB castrates. *Fattiness*, *Fatty Aftertaste, Intensity of Lamb Aroma Metallic Aroma*, pHu and two of the BCFAs, 4-methyl-nonanoic acid (4-MNA) and 4-ethyl-octanoic acid (4-EOA), had high positive loadings in PC2 and were broadly associated with SB rams. *Aromatic/Herbal Aroma, Intensity of Roast Meat Flavour*, *Grassy Flavour, Chewiness, Stringiness, Stickiness*, *Dry Aftertaste* and *Astringent Aftertaste* had high negative loadings in PC2. T × SB castrates were broadly associated with *Intensity of Roast Meat Flavour* and *Grassy Flavour*.

4. Discussion

4.1. Compositional analysis

In agreement with the results of other studies (Dransfield et al., 1990; Field, 1971; Kemp et al., 1970) the IMF content of the meat from rams was lower than that of castrates. The increased deposition of fat in castrates may be explained by the reduced rate of gain and feed efficiency that castration causes. Compared to castrates, the development of forequarter musculature in rams is also enhanced (Economides, 1983; Turton, 1969) which according to Seideman et al. (1982) can be attributed to androgens which trigger muscle growth in the neck and shoulder muscles.

4.2. Sensory analysis

4.2.1. Gender effects

Many earlier studies on the effects of production factors, particularly castration, on lamb meat quality have focused on overall palatability (flavour, tenderness, juiciness) (Kemp et al., 1972; Lirette et al., 1984; Misock et al., 1976). The findings with regard to gender effects on sensory quality (particularly flavour) are equivocal with some studies showing differences in lamb from castrates vs rams (Field, 1984; Kemp et al., 1972; Misock et al., 1976) and others showing no difference (Dransfield et al., 1990; Kirton et al., 1982; Lloyd et al., 1980; Purchas et al., 1979). Studies showing a preference for lamb from rams over castrates are rare (Jeremiah et al., 1998). Few studies to date have used QDA to investigate the effect of production factors, such as castration, on lamb meat quality. Ames and Sutherland (1999) assessed the sensory quality of lamb (lean plus adipose tissue) using QDA and a trained panel of 9 female assessors using the following descriptors: *Lamby, Meaty, Roast, Stale, Urine* and *Farmyard*, where the latter three attributes were considered ‘unpleasant’. They found higher scores for all attributes in 30 week old rams compared to 30 week old castrates. In agreement with the findings of Ames and Sutherland (1999), our data showed significantly more *Intense Lamb Aroma* in rams compared to castrates although *Intensity of Roast Meat Aroma* and *Roast Meat Flavour* were higher in castrates. Our data include lambs at 28 weeks (the October group) and 35 weeks (the November group) of age, close to the age group used by Ames and Sutherland (1999) in their ram versus castrate comparison. Our results also concur with those of Ames and Sutherland (1999) in showing that lamb from rams scored higher ($P < 0.05$) than that from castrates for some attributes that may be viewed as undesirable or have negative connotations. These attributes include *Animal Smell/Farm Smell* (Ames and Sutherland, 1999; Erasmus et al., 2016), *Woolly Aroma*, *Rancid Aroma* (Tejeda et al., 2008), *Sweaty Aroma* (Wong et al., 1975), *Manure/Faecal Aroma* (Leighton et al., 2007) *Rancid Flavour, Farmyard Flavour* (also referred to as “*Barnyard/Kraal*” (Erasmus et al., 2016)) and *Off-flavours*. Spearman correlation confirmed positive (although weak) correlations ($r = 0.17–0.59$; $P < 0.05$) between all of these attributes (supplementary Table S2). The MAD statistic indicated the percentage of animals within gender and breed categories that exceeded an arbitrary cut-off for so called “undesirable” attributes (Table 5). It is notable that some castrates were among the animals exceeding the cut-off, suggesting that potential off-flavours and aromas in lamb samples are not confined to rams.

In contrast to our findings, and with sheep that included the age range in our study, Young et al. (2006) found no significant difference between rams and castrates in *Sheepmeat Flavour* or *Barnyard Flavour* of lean meat or in *Sheepmeat odour or Barnyard odour* of subcutaneous fat. However, panellists only evaluated the lean meat samples on the basis of the two attributes listed; it is also noteworthy that rams and castrates were not compared at individual time points (between 4 and 22 months of age) and that, in this context, rams had numerically higher scores than castrates for *Barnyard Flavour* at the older slaughter ages (19 and 22 months of age) (Young et al., 2006). In an earlier study Young et al. (2003) reported that the attributes *Barnyard, Sheep, Oily* were used more frequently for castrate lamb than ram lamb when raised on pasture, with a higher ($P < 0.05$) score for *Barnyard* in castrates compared to rams, slaughtered at 4.3 months but not at 7.6 months of age. The latter group fall within the age range of lambs in our study (6.4 (the October group) to 12.4 (the April group) months). The apparent difference in findings between our study and those of Young et al. (2006, 2003) could be due to different production factors (the animals used in the studies of Young et al. (2006, 2003) were entirely raised at pasture and of Romney breed), to differences in the sensitivity of the sensory panellists (QDA was used in our study but not in the studies of Young et al. (2006, 2003) or to cultural differences in preference for lamb (Ireland vs New Zealand).

In support of our findings showing significant effects of castration on flavour, data obtained from the analysis of BCFAs in subcutaneous fat from the same animals used in this study (Gravador et al., 2017) showed higher levels of 4-MNA in rams compared to castrates (0.05 vs 0.01 mg/g, respectively) ($P < 0.001$) and of 4-MOA (0.15 vs 0.13 mg/g, respectively) ($P < 0.1$). 4-MNA and 4-MOA (along with 4-EOA) have been associated with descriptors such as ‘sweaty’, ‘sour’, ‘waxy’, ‘soapy’ (Brennand et al., 1989; Jamora and Rhee, 1999; Wong et al., 1975) and with “sheep/sheepmeat” notes (Ha and Lindsay, 1991; Wong et al., 1975) and this may explain the higher sensory scores for *Sweaty Aroma, Fattiness/Greasiness* and *Intensity of Lamb Aroma* for rams compared to castrates (Table 3). Furthermore, PCA (Supplementary Fig. S1) showed 4-MOA and 4-MNA closely clustered with *Fattiness* and *Fatty Aftertaste*. Of the two BCFAs, 4-MNA was more associated with *Metallic Aroma/Flavour* and *Aftertaste* as well as with *Rancid Aroma, Sweaty Aroma, Woolly Aroma* and *Manure/Faecal Aroma* and more broadly associated with other less desirable attributes in the first quadrant. 4-EOA was more associated with *Intensity of Lamb Aroma*. It seems likely that the association of BCFAs with these attributes is causal since these compounds are known to have odour attributes aligned with these traits. In addition, it is clear that the three BCFAs were more closely associated with rams than with castrates (Supplementary Fig. S1), which may in part explain the difference detected among genders.

Although lamb from castrates had higher ($P < 0.001$) IMF than rams (Table 2), panellists perceived the texture of lamb rams to be higher ($P < 0.05$) in *Fattiness/Greasiness* and they scored lamb from rams slightly higher for *Fatty/Greasy Aftertaste* ($P = 0.057$) (Table 3). *Fatty/Greasy Aftertaste* was also positively, although weakly, correlated with *Intensity of Lamb Aroma* ($P < 0.05$, $r = 0.18$) (Supplementary Table S2). It may be the case that the presence of higher levels of BCFAs (notably 4-MOA and 4-MNA) in lamb from rams may have a more dominant effect than the level of IMF on the intensity of attributes such as *Fatty/Greasy Aftertaste*. In addition, analysis of muscle volatiles from the same animals used in this study (Gkarane et al., in preparation) showed that castrates (which scored higher for *Intensity of Roast Meat Aroma* and *Intensity of Roast Meat Flavour*) had a higher relative abundance of volatiles such as dimethylsulphide and pyrazines which are associated with roast meat aroma (Belitz et al., 2004).

Some of the differences in sensory attributes between the two genders could be attributed to differences in pHu. Studies show that meat flavour can be influenced by pH (Calkins and Hodgen, 2007) and that ram lambs may have higher pH than castrates or female lambs (Bray, 1988; de Lima Júnior et al., 2016). Rams in our study had higher ($P < 0.001$) pHu (5.65) than castrates (5.52) (Table 2), which could be due to the higher physical activity of rams in general (associated with higher testosterone) leading to a reduction in muscle glycogen at slaughter (Pösö and Puolanne, 2005). Furthermore, in our study, there were positive correlations (although weak) between two attributes (*Fattiness/Greasiness* and *Off-flavours)* and pH ($r = 0.17$ and $r = 0.16$, respectively; $P = 0.019$ and $P = 0.023$, respectively.) (supplementary Table S2).

Other possible explanations for the flavour differences among genders include the higher testosterone in rams giving rise to intestinal conditions that could favour bacteria or bacterial metabolic processes resulting either in higher levels of phenols, causing off-flavours (Ames and Sutherland, 1999), or in the formation of BCFAs (Sutherland and Ames, 1995). Fatty acid composition affects flavour (Wood et al., 2008) and there are indications that androgens can influence fat composition (Tichenor et al., 1970), although this is not accepted unequivocally (Crouse et al., 1972; Young et al., 2003). Schanbacher and Ford (1976) suggested that a threshold level of testosterone might be necessary to change the protein and lipid metabolism, which could ultimately affect flavour. Further research is required to confirm this possible linkage.

4.2.2. Age effects

Sink and Caporaso (1977) opined that it is “a generally accepted fact that animal flavour intensity increases with chronological age” while Jamora and Rhee (1999) stated that dislike of sheepmeat increases with animal age. In the current study, there was no consistent effect of age on sensory attributes, as described above. Similar to our findings for the majority of attributes listed in Table 3, Jeremiah et al. (1998) did not detect a linear trend in flavour attributes with animal age, using four different age groups (3–6, 6–9, 9–12, 12–15 months). They concluded that lamb flavour is more likely correlated quadratically as opposed to linearly with chronological age and maturity, which concurs with the results of our study for most attributes.

A possible explanation for the apparent quadratic nature of the age effect on aroma attributes may be changes in photoperiod; its impact on reproductive behaviour/cycle and endocrine activity of sheep is well established (Chilliard and Bocquier, 2000; Terqui et al., 1984). In countries of the Northern hemisphere (like Ireland) the longest day of the year occurs at the summer solstice (21 June) and non-castrated lambs living under natural conditions reach peak sexual activity 4–5 months after the summer solstice (i.e. around October-November) (Lincoln and Davidson, 1977). Studies by other authors on lambs raised in the Northern hemisphere have shown that luteinizing hormone and testosterone concentrations in rams reached a peak in November (along with aggressive and sexual behaviour) and declined afterwards (Lincoln and Davidson, 1977; Lincoln et al., 1990; Pelletier et al., 1982), while follicle-stimulating hormone concentration reached a peak in September and October. The higher scores for *Manure/Faecal Aroma* and *Off-flavours* in November and/or January, and the lower score for *Intensity of Roast Meat Aroma* and *Intensity of Roast Meat Flavour* in the same months in rams compared to castrates (Table 4), as well as the higher scores for *Rancid Flavour* in October and November in rams compared to castrates (Table 4) may be attributed to the increased hormonal activity in rams at this time. Indeed the PCA in which the gender − age effect was considered (Fig. 1) showed a positive correlation of less desirable attributes with November and January rams. November lambs were closely associated with the BCFAs and the pHu, while castrates of October, November and January (lower left quadrant) had more positively perceived sensory attributes.

Overall, the results suggest that rams were more susceptible to higher scores in less desirable attributes closer to the winter solstice. Mushi et al. (2008) identified age at slaughter along with diet as controllable factors for preventing ram odour. The authors, using a trained sensory panel and with a hypothesis that ram flavour would be strongest during the mating period (mid-November to mid-December, when the animals were aged 6–7 months), found stronger ram taste in ram lambs slaughtered around this period, an effect linked with their sexual maturity that was not detected when meat from ewes was tasted. Ames and Sutherland (1999) found higher scores for *Lamby, Meaty, Roast, Stale, Urine* and *Farmyard* in 30 week old rams compared to 12 week old rams. In castrates, scores for *Lamby, Meaty* and *Roast* descriptors increased with age (12 vs 30 weeks at slaughter). In further support of a possible age effect on the sensory attributes of lamb, Sutherland and Ames (1996) found that levels of 4-MOA and 4-MNA increased with age and were greater ($P < 0.05$) in rams slaughtered at 30 weeks of age compared to 12 week old rams (before sexual maturity). However, Young et al. (2006) analysing lean and fat (subcutaneous and perirenal) of rams and castrates slaughtered at 4, 7, 10, 13, 17, 20 and 23 months, found no clear effect of age on *Barnyard Odour* (in fat) and *Barnyard Flavour* (in lean). Another factor that could have influenced any age effects in our study is month to month variation in the composition of the pasture that lambs received prior to housing and concentrate feeding. The content of carbohydrates, glucosinolates, and crude protein, as well as their digestibility between seasons, may vary within pasture species and type, thereby affecting the animal's deposition of muscle, fat and glycogen, as well as absorption of nutrients, and ultimately affecting flavour (Watkins et al., 2013).

The pHu may have contributed to the significant age effect on texture (*Tenderness, Chewiness, Stringiness/Fibrousness*) being higher in January lamb compared to October and November lamb. Water binding capacity and the tenderising effect of the proteolytic calpains is known to be higher at higher pHu (Huff-Lonergan and Lonergan, 2005; Watanabe et al., 1996). Although pHu was not different in lambs slaughtered in March and April (compared to January) an increase in total collagen and decrease in collagen solubility in the older lambs (Weston et al., 2002) may explain the decrease in tenderness in the later months. In agreement with the sensory data, Warner-Bratzler Shear Force values of muscle from the same animals used in this study were lower in January lambs compared to the other months (although statistically significant only when compared with the April lamb) (Claffey et al., 2017).

4.2.3. Breed effects

Among the factors that may explain the breed differences in the sensory attributes of the lamb (higher scores for *Intensity of Lamb Aroma, Intensity of Lamb Flavour, Intensity of Lamb Aftertaste, Tenderness* and *Juiciness* and lower scores for *Chewiness*, *Off-flavours, Dry Aftertaste* in SB) is the difference in IMF (mean values of 3.3 and 2.5% for SB and T × SB, respectively) (Table 2). These differences in IMF also coincide with the higher scores (approaching significance) for *Fatty Aroma* ($P = 0.081$) and *Fattiness/Greasiness* ($P = 0.068$) in SB lambs. Similarly, Hopkins et al. (2006) found that sensory characteristics (*Tenderness, Flavour, Juiciness* and *Overall Liking*) declined when IMF declined. Navajas et al. (2008) reported higher *Tenderness* and stronger *Flavour* (and *Overall Liking*) for SB compared to Texel lambs, while Texel lambs exhibited higher muscularity. Although, the Texel lambs used in our study were not purebred, it seems that the Texel genetics may contribute to lower scores for *Tenderness*. Carson et al. (1999) reported a quadratic relationship between meat tenderness (evaluated by Warner-Bratzler Shear Force) and the proportion of Texel genes (0, 50, 75 and 100%) in lambs, with tenderness increasing from 0 to 50% then decreasing to 100%. Lambe et al. (2010) suggested that the presence of a quantitative trait locus (QTL) on chromosome 18 in Texel sheep could explain the significant loin toughness that was found in male (vs female) lambs and the low IMF (< 2%) that most of the lambs (with QTL) had. The PCA (Fig. 1) revealed a negative correlation between IMF and

Chewiness and Dry Aftertaste (the last two being closely correlated). As *Tenderness* and *Juiciness* have a strong influence on meat acceptability (Koohmaraie et al., 2002), it may be that the lower scorings for these attributes in T × SB animals affects the overall perception negatively. While the MAD statistic indicated that a higher percentage of T × SB than SB lambs were considered to have undesirable attributes, it is noteworthy that SB lambs were also among those with undesirable attributes.

The gender × breed interaction for *Soapy Aroma* may be due to differences in content of the aldehyde nonanal which has a soapy aroma note. Volatile analysis of muscle samples from the current study (Gkarane et al. in preparation) showed that nonanal was higher in T × SB rams compared to castrates but not in SB rams compared to castrates.

5. Conclusion

The data indicate that lamb from rams scores lower for *Intensity of Roast Aroma* and *Flavour* and higher for *Intensity of Lamb Aroma* although differences are often small numerically. Rams also score higher for undesirable aroma and flavour attributes. In both instances the aroma and flavour differences may be due to the greater accumulation of compounds typically associated with lamb meat flavour and off-flavours in rams, such as BCFAs. Age and gender × age effects suggest that differences in sensory traits between rams and castrates may be influenced by age- and maturity-dependent differences in hormonal activity at particular periods of the year. T × SB score lower for *Intensity of Lamb Aroma, Flavour* and *Aftertaste*, *Tenderness, Juiciness* and higher for *Off-flavours,* possibly related to compositional differences between breeds particularly IMF. Overall, there are few gender × breed and age × breed interactions suggesting that the gender and age effects observed are applicable across different breed types. It remains to be established whether or not the differences in sensory characteristics detected by a trained panel in this study would be detected by consumers.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.smallrumres.2017.10.011.

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