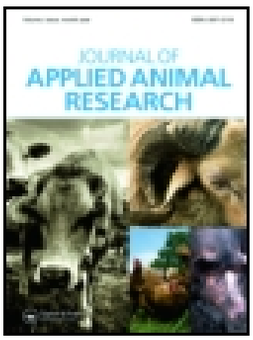

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Meat quality of lambs (hair and wool) slaughtered at different live weights

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ABSTRACT

In this research the meat quality of the two canary sheep local breeds, Canaria breed (CB) and Canaria Hair breed (CHB), was evaluated, making groups of 10 males and females from each, slaughtered at live weights of 9.78 ± 0.49 kg, 15.8 ± 0.66 kg and 24.9 ± 0.76 kg. The breed affected to meat and fat colour at 24 h after slaughter. Meat of CB showed more redness and more chroma values. Fat of CB showed greater lightness. Related to the physio-chemical analysis of the meat, CB showed higher water-holding capacity, shear force and intramuscular fat content that CHB; however, CHB showed higher protein and ash percentages that CB. In relation to fat quality, CB presented higher MUFA percentage and CHB had higher PUFA percentage. CHB showed the lower atherogenic and thrombogenic indexes. Slaughter weight affected the pH, meat and fat colour and also all physio-chemical parameters, except shear force and collagen content and the fatty acid profile. Males had higher moisture content, soluble collagen and PUFA, while females had higher MUFA. The breed effect on meat quality was shown mainly in lambs slaughtered at 10 kg. Owing to their fatty acid profile, the healthiest meat was from lambs slaughtered at 25 kg.

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Ovine; local breeds; meat quality; intensive management

1. Introduction

The sheep population in Canary Islands was 100,908 animals in 2012, all from the local breeds. The volume of sheep meat production was 101.8 t (MAGRAMA 2012). The study and categorization of lamb carcasses helps promote the consumption of meat sheep (Hernández-Castellano et al. 2013) and for preserve our breeds classified as special protection (R.D. 2129/2008), as well as access a protected geographical indication in the future.

Different studies have shown that the breed and slaughter weight of lamb affect meat quality (Hopkins et al. 2011; D'Alessandro et al. 2015; Santos et al. 2015). Production systems, culinary traditions and preferences of consumers determine the slaughter weight of lambs, with factors varying greatly depending on geographic origin of consumers (Indurain et al. 2007). In the Canary Islands, lambs are usually slaughtered between 10 and 20 kg live weight. Although fat and meat colour are the most important factors for consumers (Ripoll et al. 2008; Calnan et al. 2016), and tenderness when eating (Jeleníková et al. 2008), in recent years the quantity and the quality of fat of meat are also important because they affect consumer health (Martemucci & D'Alessandro 2013). A low intake of saturated fat and increased polyunsaturated (PUFA) to saturated fatty acid ratio is associated with a lower risk of human coronary heart disease (Simopoulos 2008).

Recent European Union policy directed towards extensive production systems of animal production and the promotion of a sustainable development of otherwise marginal areas has led to a renewed interest in local ovine breeds (Marino et al. 2008). Also, studies of meat quality have increased with the implementation of protected designations of origin (Teixeira et al. 2005). This work studies the meat quality of sheep breeds with more number of animals: Canaria breed (CB) (wool) and Canaria Hair breed. After studying the carcass quality of these breeds, the present study attempts to obtain information of the meat quality and to evaluate the influence of slaughter weight and sex on the meat quality of these breeds.

2. Material and methods

This study was complied with the rules of the Committee of Research Ethics and Comfort Animal of the University of La Laguna (R.D. 1201/2005 and Ley 14/2007).

2.1. Animals and sampling

Sixty lambs of the Canarian Hair breed (CHB) and 60 lambs of CB slaughtered at average live weights of 9.78 ± 0.49 kg (average age 49.6 days), 15.8 ± 0.66 kg (average age 69.8 days) and 24.9 ± 0.76 kg (average age 136.8 days) were studied. Meat samples from 10 males and 10 females of each weight and breed were analysed. Purebred sheep (sires and dams) of CB and CHB were used for breeding of lambs. Three rams were used in each breed group and the breeding period began simultaneously in all groups. The animals were reared in an intensive farm, located in Tenerife (Canary Island, Spain) (28.07 N and 16.35 W). Average annual temperature was 20.2°C and average

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relative humidity was 72%. Lambs were randomly selected after all the lambs had been born. During the whole experiment, the lambs were kept with their dams. Animals of both breeds were born and raised in permanent confinement, at the same time.

Lambs were weighed at birth and identified with a numbered collar. They were reared following a traditional production system. During the first week of age, all lambs received vitamins A, D_3 and E and were vaccinated against enterotoxemia. The lambs received only maternal milk until 15 days of age. After day 15, milk-feeding was continued and free access to forage, concentrate (1530 kilocalories of net energy and 18% crude protein) and water was initiated. Dams were fed with ray-grass hay *ad libitum* and a concentrate (1,638 kilocalories of net energy and 19% crude protein). When animals reached the slaughter weight, they were transported to the slaughterhouse, according to EU regulations (Council Regulation, EEC No 1/2005). After 12 h of fasting, the animals were electrically stunned and slaughtered according to standard commercial procedures.

Following slaughter, each lamb's head, feet, skin, liver, heart, lung-trachea, spleen, thymus, testicle-penis, ovary-uterus, full and empty gastrointestinal tract were weighed. Hot carcass included kidneys and pelvic-renal fat and but did not include the head (cut at occipital-atlantoidal articulation) or limbs (cut at carpo-metacarpal and tarso-metatarsal joints). Carcasses were weighed and hung by the Achilles tendon after processing. Subsequently, they were cooled at 4°C for 24 h. After cooling, carcasses were weighed and split down the dorsal midline. Half-left carcasses were disjointed (Colomer-Rocher et al. 1988) into seven anatomical parts: leg, rib, loin, shoulder, breast, neck and tail. All joints were vacuum packed, frozen and maintained at −20°C until dissection. For dissection, joints were defrosted in trays placed inside a refrigerator. The dissection method of Colomer-Rocher et al. (1988) was followed to obtain the different tissue components (muscle, subcutaneous fat, intermuscular fat, bone and remainders). At the same time, *Mm*. *Longissimus* (5th–13th rib level) and *Mm*. *Semimembranosus* were obtained, which were vacuum packaged and stored frozen (−20°C) until analysis.

2.2. Ph meat and fat colour

Carcasses were ribbed between the 12th and 13th ribs to have access to the *Longissimus* muscle. Meat pH and colour were estimated at 45 min and 24 h post-mortem in this muscle. A portable pH-meter, Crison, equipped with a penetrating electrode was utilized. Meat colour was assessed by the L* (lightness), a* (redness) and b* (yellowness) of the CIE (1986) system, using a Minolta CR 200 colorimeter (Minolta Camera Co., Osaka, Japan) with illuminant D65 as the light source. Colorimetric indices of chromaticity Chroma*$(a^{*2} + b^{*2})^{1/2}$ and Hue^{o} (arctan (b*/a*) were calculated. In addition, fat colour was measured at three points of the carcass (cervical, dorsal and lumbar). Colour values were the mean of three measurements.

2.3. Chemical composition

Meat moisture was determined by the official method for meat product analysis (AOAC 1990). First, an empty petrie dish was weighed; it was then weighed again with the *Longissimus* muscle (cut by hand using scissors) and placed into an oven at 105°C for 24 h. The weight difference represented the amount of water retained by the meat and was expressed as a percentage of the initial sample weight. The pressure method of Grau and Hamm (1953), modified by Sierra (1973), was used to measure water-holding capacity (WHC). 5 g of *Longissimus* muscle was cut into small pieces and placed between two sheets of filter paper, which were put between two glass capsules, and then subjected to a weight of 2250 g for 5 min. After this time, the sample was weighed. WHC was expressed as the percentage of free water. Cooking loss (CL) was evaluated by calculating the difference in weight before and after a 45 min immersion at 70°C in a water bath. The *Semimembranosus* muscle was weighed, then vacuum packed and placed in a water bath. CL was expressed as the percentage loss related to the initial weight. After determining cooking losses, the shear force (Warner–Bratzler Shear Force (WBSF)) was analysed with a texture analyser (Instron 4465), equipped with a Warner–Bratzler cell. Three meat prismatic portions of $1 \times 1 \times 4$ cm of the *Semimembranosus* muscle were subject to a test speed of 40 mm/s. Shear force value, expressed in Newtons, was the average of three meat portions obtained from each animal.

The *Longissimus* muscle was minced, frozen (−20°C), lyophilized and analysed for its chemical composition. The content of intramuscular fat (IMF), protein and ash was carried out following the method described by the AOAC (1990). Collagen was measured using the technique of Hill (1966) and Bonnet and Kopp (1984) and expressed as µg hydroxyproline/g fresh muscle.

2.4. Fatty acid composition

Fat was extracted from *m. Longissimus* as described by Hanson and Olley (1963). A 10 g homogenized meat sample was blended with extraction solvent chloroform/ethanol (2:1, v/v) and mixed with a solution of methanolic potassium hydroxide 0.88% + H_2O. The final mixture was centrifuged at 4°C and 3500 rpm for 10 min. After separation in three phases, the methanol aqueous and tissue fractions were discarded, whereas the lipid chloroform fraction was filtered using wool glass and washed with chloroform/methanol (2:1, v/v). The lipid extract was obtained by evaporation in a sand bath at 50°C. Fatty acid composition was determined according to Utrilla et al. (1996). 0.05 g of lipid was methylated by adding 2 ml of hexane and 1 ml of supersaturated solution of sodium chloride and left to stand for 10 min After separation in two phases, the upper fraction was transferred to test tubes for subsequent gas chromatographic analysis. A Varian CP3800 Gas Chromatograph with a capillary column Select^{TM} FAME (50 m, 0.24 mm, 0.25 µm) (REF-CP7419) was used, working from 105° C (5 min) to 185°C (20°C/min) for a total of 29 min, and then from 185°C to 225°C (20°C/min) for 46 min with an injector at 250°C and detector at 300°C and using an ionized lame detector. The carrier gas was helium.

Fatty acids were expressed as a percentage of total fatty acids identified and grouped as follows: saturated (SF), total unsaturated (TUFA), monounsaturated (MUFA) and PUFA.

TUFA/SFA, PUFA/SFA and $n-6/n-3$ ratios were determined (Enser et al. 1998). Moreover, we calculated the atherogenic index (AI, (C12:0 + 4 × C14:0 + C16:0)/TUFA) to evaluate the risk of atherosclerosis, and the thrombogenic indexes (TI, (C14:0 + C16:0 + C18:0)/(0.5 × MUFA) + (3 × $n-3$) + (0.5 × $n-6$) + ($n-3/n-6$)) as a sign of the potential aggregation of blood platelets, according to the formula aggregation by Ulbricht and Southgate (1991).

2.3. Statistical analysis

Data were analysed by conducting Analysis of Variance (ANOVA). The fixed effects of the model included the breed, weight, sex and the interactions: breed × weight and breed × sex. The differences among weights were determined using Scheffe's test and differences among means in the interactions breed × weight were determined by the Bonferroni test. A multivariate analysis (canonical discriminate) was carried out for the interaction breed × weight. All analyses were performed using the SPSS 15.0 (SPSS Inc. 2006) for Windows.

3. Results and discussion

3.1. Ph, meat and fat colour

Effects of breed, slaughter weight and sex on pH and meat colour are summarized in Table 1. As it has been observed in other breeds (Hernández-Castellano 2010; Majdoub-Mathlouthi et al. 2013) between 45 min and 24 h after slaughter the pH decreased. This could be due to glycogen conversion into lactate and H+ (Shija et al. 2013). An ultimate pH value greater than 5.8 is regarded as undesirable (Young et al. 2004); therefore pH values after 24 h in CB and CHB can be considered acceptable. Significant differences in pH were found comparing the slaughter weights. The lambs of 10 kg showed the higher pH values. Schrama et al. (1996) attributed the greater pH value of young animals to their higher energy requirements, and therefore lower levels of reserves of glycogen before being slaughtered.

In relation to meat colour, between 45 min and 24 h after slaughter the lightness increased. MacDougall (1982) noted that proteolysis produces greater light reflection and therefore more lightness. At 24 h after slaughter, meat of CB (dairy sheep breed) shows higher values in redness (a*) and chroma; this matches with the findings of Juárez et al. (2009) who found that meat of dairy sheep breeds have more redness than meat of meat sheep breeds. This could be related to a different metabolism that demands a higher content of myoglobin in milk breeds. Lightness value (L*) decreased as slaughter weight increases, according to what was observed by Ripoll et al. (2008) and by Majdoub-Mathlouthi et al. (2013). Different authors have related meat luminosity to moisture content (Carraspiso & García 2005). The higher moisture content observed in meat from 10 kg lambs could explain this higher luminosity. Redness value (a*) increased as slaughter weight increases from 16 to 25 kg; this is related to myoglobin content (Calnan et al. 2016), which increases with age.

Except redness, the breed affected all parameters related to fat colour at 45 min after slaughter, (a*) (Table 2), but at 24 h after slaughter, the breed only affected the lightness (L*) of fat colour. In accordance with D'Alessandro et al. (2013), the lightness values (L*) observed in this study for two breeds are indicative of pale or pink-coloured meat which corresponds to the preference of Spanish consumers (Carrasco et al. 2009). CHB showed the lowest values for this parameter. This may be due to the fact that the lower thickness of external fat of the carcasses of this breed leads to greater moisture loss of the fat, after 24 h in the airing room. Moreover, Molinero (2009) observed that the reduction of moisture in the meat drives to a decrease in its luminosity. The differences observed in fat colour, related to slaughter weights, observed at 45 min after slaughter, were maintained at 24 h after slaughter. 10 kg lambs showed fat with more redness (a*). The reduced fat cover of these carcasses, which implies there is muscle underneath, may explain this result.

3.2. Chemical composition

All analysed parameters are shown in Table 3. Significant differences were found between breeds, CHB showed higher protein and ash, and lower IMF percentage. Although the meat from CB

Table 1. Predicted means and effects of breed, slaughter weight and sex for pH and meat colour (*m. Longissimus*) of lambs ($n = 120$) of Canaria and Canaria Hair breeds.

	Breed						Sex			Effect				
	Canaria			Canaria Hair										
Characteristics	10 kg	16 kg	25 kg	10 kg	16 kg	25 kg	Male	Female	SEM	Breed	Weight	Sex	Breed × weight	Breed × Sex
pH 45 min	6.90^{c}	6.62^{a}	6.66^{a}	6.73^{ab}	6.67^{ab}	6.71^{ab}	6.72	6.70	0.020	NS	0.001	NS	0.033	NS
pH 24 h	5.97^{c}	5.62^{ab}	5.58^{a}	5.77^{b}	5.67^{ab}	5.61^{ab}	5.74	5.68	0.019	NS	0.001	NS	0.001	NS
Colour coordinates 45 min														
L* (lightness)	42.99	40.17	39.16	42.98	38.98	37.13	40.77	39.64	0.330	0.045	0.001	0.022	NS	NS
a* (redness)	17.37	18.25	19.33	16.42	16.65	17.11	17.32	17.73	0.241	0.001	NS	NS	NS	NS
b* (yellowness)	5.13^{b}	2.26^{a}	2.16^{a}	2.69^{a}	2.17^{a}	2.13^{a}	2.68	2.74	0.123	0.001	0.001	NS	0.001	NS
Hue°	16.61^{b}	6.87^{a}	5.72^{a}	9.16^{a}	7.44^{a}	6.87^{a}	8.59	8.59	0.007	0.001	0.001	NS	0.001	NS
Chroma	18.15	18.40	19.46	16.67	16.81	17.28	17.59	17.99	0.240	0.001	NS	NS	NS	NS
Colour coordinates 24 h														
L* (lightness)	48.13	45.33	43.89	49.19	44.99	43.69	46.52	45.16	0.434	NS	0.001	NS	NS	NS
a* (redness)	18.66^{b}	16.65^{ab}	19.59^{b}	15.95^{a}	17.72^{ab}	18.03^{ab}	17.55	17.92	0.272	0.039	0.018	NS	0.009	NS
b* (yellowness)	8.31	7.44	6.08	7.25	8.34	6.06	6.86	7.63	0.203	NS	0.001	NS	NS	NS
Hue°	20.55	18.36	20.61	17.58	19.62	19.15	19.00	19.57	0.010	NS	0.001	NS	NS	NS
Chroma	20.55^{b}	18.36^{ab}	20.61^{b}	17.58^{a}	19.62^{ab}	19.15^{ab}	19.00	19.57	0.275	0.045	NS	NS	0.006	NS

Notes: SEM = standard error of mean; NS = non-significant ($P > .05$).
^{a,b}Means in the same row showing different letters are significantly different ($P \leq .05$).

Table 2. Predicted means and effects of breed, slaughter weight and sex for fat colour of lambs ($n = 120$) of Canaria and Canaria Hair breeds.

	Breed						Sex		SEM	Effect				
	Canaria			Canaria Hair										
Characteristics	10 kg	16 kg	25 kg	10 kg	16 kg	25 kg	Male	Female		Breed	Weight	Sex	Breed × Weight	Breed × Sex
Colour coordinates 45 min														
L* (lightness)	68.45	71.22	72.88	71.00	72.43	75.05	71.73	72.00	0.323	0.001	0.001	NS	NS	NS
a* (redness)	7.03	5.27	4.31	5.30	5.17	4.60	5.37	5.14	0.191	NS	0.001	NS	NS	NS
b* (yellowness)	5.39^{b}	3.42^{a}	3.15^{a}	1.77^{a}	3.01^{a}	3.54^{a}	3.10	3.58	0.180	0.001	NS	NS	0.001	NS
Hue°	36.66^{b}	32.08^{b}	35.51^{b}	13.74^{a}	28.64^{b}	37.23^{b}	28.64	32.08	0.025	0.002	0.002	NS	0.001	NS
Chroma	9.04^{b}	6.44^{a}	5.43^{a}	5.84^{a}	6.19^{a}	5.86^{a}	6.39	6.46	0.220	0.013	0.002	NS	0.001	NS
Colour coordinates 24 h														
L* (lightness)	70.13	71.69	72.50	68.04	70.96	71.46	70.78	70.86	0.317	0.043	0.001	NS	NS	NS
a* (redness)	8.94^{c}	7.22^{ab}	6.14^{a}	7.73^{b}	6.87^{ab}	7.01^{ab}	7.13	7.45	0.169	NS	0.001	NS	0.029	NS
b* (yellowness)	7.37^{b}	6.49^{ab}	5.45^{a}	5.82^{a}	6.10^{a}	6.07^{a}	5.97	6.43	0.172	NS	NS	NS	0.043	NS
Hue°	37.81	41.82	40.10	36.66	41.24	40.10	38.95	40.10	0.011	NS	0.040	NS	NS	NS
Chroma	11.68^{b}	9.74^{a}	8.28^{a}	9.80^{a}	9.24^{a}	9.33^{a}	9.39	9.89	0.216	NS	0.001	NS	0.017	NS

Note: NS = non-significant ($P > .05$).
^{a,b}Means in the same row showing different letters are significantly different ($P \leq .05$).

Table 3. Chemical composition de lambs ($n = 120$) of Canaria and Canaria Hair breeds.

	Breed						Sex			Effects				
	Canarian			Canarian Hair										
Characteristics	10 kg	16 kg	25 kg	10 kg	16 kg	25 kg	Male	Female	SEM	Breed	Weight	Sex	Breed × Weight	Breed × Sex
WHC, (% liquid expelled)	13.22	15.10	17.10	15.10	17.90	17.60	16.33	15.80	0.378	0.019	0.002	NS	NS	NS
CL, (%)	32.26^{b}	28.82^{a}	28.20^{a}	29.29^{ab}	29.85^{ab}	27.06^{a}	29.25	29.16	0.298	NS	0.001	NS	0.011	NS
WBSF, (N)	25.09^{a}	35.19^{ab}	36.19^{ab}	38.18^{b}	36.84^{b}	36.87^{b}	35.02	34.79	1.032	0.007	NS	NS	0.019	NS
Moisture, (%)	75.63^{c}	72.86^{a}	72.70^{a}	74.33^{b}	73.51^{ab}	73.72^{ab}	73.95	73.56	0.123	NS	0.001	0.012	0.001	NS
IMF, (%)	2.19	2.43	3.07	1.71	1.86	1.98	2.11	2.30	0.070	0.001	0.001	NS	NS	NS
Ash, (%)	0.89	0.99	0.92	0.96	1.03	0.99	0.95	0.98	0.010	0.001	0.001	NS	NS	NS
Protein, (%)	19.57^{a}	22.19^{b}	21.86^{b}	21.54^{b}	22.36^{b}	22.36^{b}	21.60	21.77	0.126	0.001	0.001	NS	0.001	0.045
Total collagen (TC)[1]	429.48	438.57	391.99	449.11	458.27	462.00	457.43	419.99	11.24	NS	NS	NS	NS	NS
Soluble collagen (SC)[1]	364.61	337.66	290.75	387.61	358.47	359.47	368.89	330.60	10.28	NS	NS	0.050	NS	NS
SC/TC	0.84	0.78	0.75	0.86	0.78	0.77	0.80	0.79	0.010	NS	0.001	NS	NS	NS

Notes: NS = non-significant ($P > .05$); WHC = water-holding capacity; WBSF = Warner–Bratzler Shear Force; IMF = intramuscular fat; SC/TC = soluble collagen/total collagen; CL = cooking losses.
[1]µg hydroxyproline/g fresh muscle.
^{a,b,c} means in the same row showing different letters are significantly different ($P \leq .05$).

Table 4. Saturated fatty acid composition (%) of intramuscular lipids in *m. Longissimus* of lambs ($n = 120$) of Canarian and Canarian Hair breeds.

	Breed						Sex			Effects				
	Canarian			Canarian Hair										
	10 kg	16 kg	25 kg	10 kg	16 kg	25 kg	Male	Female	SEM	Breed	Weight	Sex	Breed × Weight	Breed × Sex
SFA	47.61	46.83	44.78	47.76	45.99	43.00	46.21	45.74	0.27	NS	0.001	NS	NS	NS
C10: 0	0.20	0.15	0.11	0.15	0.15	0.10	0.15	0.14	0.00	NS	0.001	NS	NS	NS
C12: 0	0.64	0.41	0.23	0.57	0.43	0.19	0.44	0.37	0.02	NS	0.001	0.010	NS	NS
C13: 0	2.47	1.94	1.29	3.42	2.37	1.61	2.42	1.94	0.12	0.012	0.001	0.024	NS	NS
C14: 0	5.84	5.34	3.75	5.51	5.06	3.19	4.78	4.76	0.13	NS	0.001	NS	NS	NS
C15: 0	0.40	0.37	0.33	0.43	0.37	0.31	0.37	0.36	0.01	NS	NS	NS	NS	NS
C16: 0	25.90	25.83	25.93	24.56	25.48	24.92	25.14	25.71	0.18	NS	NS	0.014	NS	NS
C18: 0	10.62	11.50	12.53	11.55	10.75	11.36	11.53	11.26	0.17	NS	NS	NS	NS	NS
C20: 0	0.57	0.62	0.42	0.62	0.68	0.39	0.56	0.54	0.02	NS	0.001	NS	NS	NS
C22: 0	0.27	0.18	0.13	0.27	0.20	0.19	0.23	0.18	0.00	NS	0.001	0.002	NS	0.016
C23: 0	0.30	0.27	0.13	0.39	0.29	0.22	0.30	0.24	0.01	0.003	0.001	0.002	NS	NS
C24: 0	0.37	0.17	0.15	0.25	0.16	0.20	0.24	0.18	0.01	0.049	0.001	0.001	NS	NS

Notes: SFA = saturated fatty acids; NS = non-significant ($P > .05$); SEM = standard error of the mean.

Table 5. Monounsaturated fatty acid composition (%) of intramuscular lipids in *longissimus* muscle of lambs ($n = 120$) of Canarian and Canarian Hair breeds.

	Breed						Sex			Effects				
	Canarian			Canarian Hair										
	10 kg	16 kg	25 kg	10 kg	16 kg	25 kg	Male	Female	SEM	Breed	Weight	Sex	Breed × Weight	Breed × Sex
TUFA	52.38	53.16	55.21	52.23	54.00	56.99	53.78	54.25	0.27	NS	0.001	NS	NS	NS
MUFA	34.99	39.78	43.89	33.52	38.63	42.80	38.03	39.95	0.44	0.036	0.001	0.001	NS	NS
C14: 1	0.48	0.34	0.27	0.36	0.34	0.27	0.36	0.33	0.01	NS	0.007	NS	NS	NS
C15: 1	0.18	0.21	0.13	0.20	0.19	0.13	0.18	0.17	0.00	NS	0.001	NS	NS	NS
C16: 1	2.15	2.38	2.10	1.73	3.20	2.22	2.29	2.32	0.15	NS	NS	NS	NS	NS
C18: 1t	1.61	1.24	1.88	1.12	1.46	1.46	1.49	1.43	0.07	NS	NS	NS	NS	NS
C18: 1c	30.55	35.59	39.48	30.08	33.42	38.70	33.70	35.68	0.41	0.027	0.001	0.001	NS	NS
PUFA	17.39	13.37	11.32	18.71	15.36	14.18	15.75	14.30	0.33	0.001	0.001	0.002	NS	NS
C16: 2	0.90	0.84	0.85	0.79	0.90	0.80	0.83	0.86	0.03	NS	NS	NS	NS	NS
C16: 3	0.96	0.98	1.34	0.82	0.88	1.21	1.00	1.06	0.03	0.023	0.001	NS	NS	NS
C16: 4	0.43	0.46	0.63	0.39	0.45	0.65	0.47	0.54	0.03	NS	0.020	NS	NS	NS
C18: 2	8.47	5.99	5.36	8.79	7.46	7.28	7.55	6.86	0.18	0.001	0.001	0.012	NS	NS
C18: 3	0.59^{a}	1.10^{b}	0.61^{a}	1.34^{c}	1.14^{bc}	0.63^{a}	0.93	0.89	0.03	0.001	0.001	NS	0.001	NS
C18: 4	0.13	0.12	0.09	0.14	0.12	0.10	0.12	0.11	0.00	NS	0.001	0.010	NS	NS
C20: 3	0.39	0.24	0.14	0.43	0.28	0.19	0.29	0.26	0.01	0.034	0.001	NS	NS	NS
C20: 4	3.82^{c}	2.21^{a}	1.60^{a}	3.26^{bc}	2.36^{b}	2.26^{a}	2.81	2.32	0.10	NS	0.001	0.001	0.011	NS
C20: 5	0.35^{bc}	0.44^{bc}	0.16^{a}	0.80^{d}	0.51^{c}	0.28^{b}	0.48	0.38	0.02	0.001	0.001	0.001	0.001	NS
C22: 6	0.36	0.25	0.10	0.51	0.28	0.17	0.31	0.25	0.01	0.001	0.001	0.001	NS	NS
C24: 4	0.93	0.70	0.37	1.38	0.93	0.56	0.90	0.73	0.04	0.001	0.001	0.001	NS	0.030

Notes: MUFA = monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids; TUFA = total unsaturated fatty acids; NS = non-significant ($P > .05$); SEM = standard error of the mean.
[a,b,c,d]Means in the same row showing different letters are significantly different ($P \leq .05$).

showed greater IMF content, it is listed as a lean meat according to the criteria of the Food Advisory Committee, as its fat content is lesser than 5%. In agreement with Santos-Silva et al. (2002), a greater IMF content in meat leads to a higher WHC. CB was the breed that showed a lower percentage of free water, thus having greater WHC ($P < .05$). The values of shear force (WBSF) found in this study for both breeds were significantly different. The higher IMF content of CB may explain their lower values of hardness observed. Fahmy et al. (1992) have shown that meat characteristics such as hardness or colour parameters are related to IMF content. Shear force below 4 kg (40 N) equates an acceptable level of tenderness of the meat in Australian

Table 6. Nutritional indexes and fatty acid ratios of meat from *longissimus* muscle of lambs ($n = 120$) of Canarian and Canarian Hair breeds.

	Breed						Sex			Effects				
	Canarian			Canarian Hair										
	10 kg	16 kg	25 kg	10 kg	16 kg	25 kg	Male	Female	SEM	Breed	Weight	Sex	Breed × Weight	Breed × Sex
TUFA/SFA	1.10	1.13	1.23	1.09	1.18	1.33	1.17	1.19	0.01	0.045	0.001	NS	NS	NS
PUFA/SFA	0.36	0.28	0.25	0.39	0.33	0.33	0.34	0.31	0.00	0.001	0.001	0.015	NS	NS
AI	0.96	0.90	0.74	0.90	0.86	0.66	0.84	0.83	0.01	0.043	0.001	NS	NS	NS
TI	1.80	1.62	1.58	1.64	1.56	1.47	1.62	1.59	0.01	0.001	0.001	NS	NS	NS
n−6	12.68^{b}	8.44^{a}	7.11^{a}	12.49^{b}	10.11^{a}	9.74^{a}	10.66	9.45	0.27	0.002	0.001	0.003	0.028	NS
n−3	1.45^{b}	1.93^{c}	0.99^{a}	2.82^{d}	2.07^{c}	1.19^{ab}	1.85	1.64	0.06	0.001	0.001	0.002	0.001	NS
n−6/*n*−3	9.18^{b}	4.34^{a}	7.68^{b}	4.40^{a}	5.07^{a}	8.87^{b}	6.59	6.48	0.26	0.015	0.001	NS	0.001	NS

Notes: AI = atherogenic index; TI = thrombogenic index; TUFA = total unsaturated fatty acids; PUFA = Polyunsaturated fatty acids; SFA = saturated acids; NS = non-significant ($p > .05$); SEM = standard error of the mean. *n*−6 = (C18:2 + C20:3 + C20:4); *n*−3 = (C18:3 + C18:4 + C20: 5 + C22:6).
[a,b,c,d]Means in the same row showing different letters are significantly different ($P \leq .05$).

markets (Shija et al. 2013). Hopkins et al. (2006) concluded that sheep meat with shear force values less than 49 N is considered as tender. Significant differences between breeds were observed in 10 kg lambs in WBSF, moisture and protein percentages.

Slaughter weight influenced all parameters studied, except WBSF and collagen. Young and Braggins (1993) reported that heavier lambs can produce less tender meat because solubility of intramuscular collagen decreases parallel to weight. In this study, collagen solubility was not affected by slaughter weight; this could explain why the weight does not affect WBSF. In accordance with data obtained from other breeds (Abdullah & Qudsieh 2009; Juárez et al. 2009), IMF content increases parallel to slaughter weight and WHC decreases. Rodríguez et al. (2008) observed that as pH decreases the meat expels more water. In the present study, the pH could have affected the WHC, as 10 kg lambs, with higher pH, showed the lowest value of WHC. CB lambs slaughtered at 10 kg were significantly different to 16 and 25 kg lambs in cooking loss, moisture and protein percentages. Meat from 10 kg lambs showed the highest moisture content ($P < .001$), which coincides with other research (Martínez-Cerezo et al. 2005). The lower cooking loss in heavier carcasses could be due to the greater fatness of these lambs (Abdullah & Qudsieh 2009).

Sex affected significantly the content in moisture and soluble collagen, displaying higher values in males. CHB females showed the highest protein percentage ($P < .05$).

3.3. Fatty acid composition

The fatty acid composition is shown in Table 4. Fatty acids C16:0 and C18:0 were the most abundant SFA. Palmitic acid (C16:0) is responsible for the increase in total cholesterol or in LDL cholesterol concentrations (Shingfield et al. 2008), whereas stearic acid (C18:0) is not hypercholesterolaemic (Muchenje et al. 2009). The high content of C16:0 observed in this study was similar to that recorded by Cañeque et al. (2005) and by D'Alessandro et al. (2015), although in both studies the breeds were raised under a pasture management system. Weight was the factor that more affected fatty acid composition. Marino et al. (2008) attributed the changes in fatty acid composition, as the slaughter weight increased, to differing physiological condition and digestive ability of animals. Significant differences between breeds were observed in C13:0, C23:0 and C24:0 saturated fatty acids (SFA). Differences found between breeds in IMF percentage could explain these results. Total content of SFA was significantly influenced by slaughter weight, decreasing SFA as the slaughter weight increased. These results agree with those of Juárez et al. (2009) in the Grazalema Merino breed and Churra Lebrijana breed. These authors attributed the lower content of SFA in heavier lambs to the addition of concentrate in the diet. Lambs of 10 and 16 kg had higher content of C12:0 and C14:0 than lambs of 25 kg ($P < .001$). Miguélez et al. (2008) also observed that the percentage of these fatty acids decreased as slaughter weight increased, probably because light lambs have free access to concentrate and suckling lambs feed only on milk. Velasco et al. (2004) suggested that the highest prevalence of C12:0 and C14:0 in the meat of suckling lambs was due to the presence of these fatty acids in maternal milk. Note that C12:0 and C14:0 are considered dangerous for human health (Shingfield et al. 2008). In this study, mean value for C14:0 in lambs slaughtered with 10 and 16 kg was lower than the content reported in other breeds (Vacca et al. 2008; D'Alessandro et al. 2015). It is generally accepted that the fatty acid profile from suckling lambs reflects the composition of the ewes' milk (Bas & Morand-Fehr 2000); so the lower values observed in the present study for C14:0 could be explained by this reason.

Significant differences in MUFA were found between breeds, slaughter weights and sexes (Table 5). CB had a greater total MUFA percentage, perhaps due to the greater fatness of this breed. Miguélez et al. (2008) observed a higher percentage of MUFA in the Churra breed (a breed with fatty carcasses) than in the Castellana and Ojalada breeds. Oleic acid (C18:1c) was the most abundant MUFA observed in this study ($P = .027$). This fatty acid benefits human health because it helps to decrease LDL cholesterol concentrations (Bonanome & Grundy 1988). In addition, together with others fatty acids, it influences the firmness and oxidative stability of muscles thus affecting the juiciness, flavour and colour of the meat (Martemucci & D'Alessandro 2013).

MUFA content increased with slaughter weight. Mazzone et al. (2010) attributed the high concentration of oleic acid in meat from Apennine lambs to the great consumption of concentrate. Female lambs exhibited a greater proportion of MUFA (mainly oleic acid) than males ($P < .001$). This result

Table 7. Lambda of Wilks values and significance levels of different discriminant functions for meat quality.

Functions	Lambda of Wilks	Chi-square	Variance %	Sig.
1	0.006	502.231	43.2	.001
2	0.034	328.235	30.8	.001
3	0.155	180.747	18.5	.001
4	0.487	69.778	3.9	.001
5	0.705	33.879	3.6	.006

Table 8. Combined intra-group correlations between discriminant variables and canonical discriminant functions.

	Function		
Variables	1	2	3
n−3 fatty acids	**0.559**	**−0.502**	0.004
Monounsaturated fatty acids	**−0.539**	−0.020	0.107
Polyunsaturated fatty acids	**0.394**	0.019	0.034
n−6 fatty acids	**0.357**	0.109	0.047
Saturated fatty acids	0.238	0.004	−0.165
SC	0.109	−0.011	0.082
Protein	−0.222	**−0.403**	0.222
Shear force	−0.061	−0.203	0.056
pH	−0.125	−0.081	−0.574
Ash	−0.023	−0.186	0.250
Lightness (L*)	0.022	−0.102	−0.246
TC	0.044	−0.037	0.109
IMF	−0.242	0.080	−0.253
WHC	−0.136	−0.110	0.061
Moisture	0.352	0.353	0.034
Thrombogenic index	−0.040	0.161	−0.135
Yellowness (b*)	−0.020	−0.061	−0.248
CL	0.164	0.157	−0.091
AI index	0.241	0.043	−0.123
Chroma	−0.096	0.009	−0.162
Redness (a*)	−0.099	0.029	−0.111

Note: The highest correlations are shown in bold.

Table 9. Predicted means and effect of functions 1 and 2.

	Breed × Weight						Effect		
	Canaria			Canaria Hair					
	10 kg	16 kg	25 kg	10 kg	16 kg	25 kg	Breed	Weight	Breed × Weight
Function 1	2.023[d]	−0.343[c]	−3.299[a]	2.966[e]	0.105[c]	−2.073[b]	0.001	0.001	0.001
Function 2	3.740[e]	−1.093[b]	0.053[c]	−1.880[a]	−1.178[b]	0.747[d]	0.001	0.001	0.001

[a,b,c,d,e]Means in the same row showing different letters are significantly different ($P \leq .05$).

could be related with the IMF depots. Jackson and Winkler (1970) reported that the insaturation of the fat depots increases with adiposity due to Δ9 desaturase enzyme activity, responsible for the synthesis of oleic acid (C18:1) from stearic acid (C18:0). Breed, slaughter weight and sex influenced total polyunsaturated fatty acid (PUFA) (Table 5). CHB had a greater total PUFA percentage. Marino et al. (2008) show that lean breeds have a relatively high proportion of PUFA compared with less lean ones, probably due to the phospholipids proportion being diluted by higher level of neutral storage lipid. Total PUFA percentage decreased with increase in slaughter weight. The development of the rumen and the saturation of PUFA by microorganisms described by Cifuni et al. (2000) may explain the observed decrease. Males showed greater total PUFA percentages than females perhaps due to their lesser tendency to fatten, as observed by Arsenos et al. (2006).

AI and TI as well as the values of TUFA/SFA, PUFA/SFA, *n*−6, *n*−3 and *n*−6/*n*−3 were significantly affected by breed and slaughter weight (Table 6). PUFA/SFA ratio of both breeds exceeded the recommendation of 0.45 (Department of Health 1994). CHB showed a higher *n*−6/*n*−3 ratio than CB. This ratio is a risk factor in cancers and coronary heart disease (Rodrigues et al. 2015) and should not exceed four (Department of Health 1994).

3.4. Discriminant analysis

Five functions were obtained and all were significant in the canonical discriminant analysis. The first two functions explained a 74% of the variance (Table 7).

For function 1, the variables that showed the biggest differences among lambs were *n*−3 fatty acids, MUFA fatty acids, polyunsaturated fatty acids and the *n*−6 fatty acid percentage (Table 8). As body weight of the lambs increases, the meat contains less *n*−3, *n*−6 and polyunsaturated fatty acids and more MUFA fatty acids, so the value of function 1 moves from the positive zone of the figure to the negative (Figure 1). Significant differences in function 1 were found between breeds (−0.628 CB vs. 0.329 CHB), also among weights and in the interaction of breed × weight. For function 1, breeds were significantly different in 10 and 25 kg lambs (Table 9).

For function 2, the most distinct variables were *n*−3 fatty acids and protein percentage (Table 8). Significant differences in function 2 were found between breeds (0.802 CB vs. −0.776 CHB), weights and in the interaction breed × weight. For function 2, breeds are significantly different in 10 and 25 kg lambs (Table 9). For the lambs slaughtered at 10 kg, function 2 values were negative for the hair breed and positive for the wool breed, indicating that meat from the hair breed contained greater amount of protein and *n*−3 fatty acids.

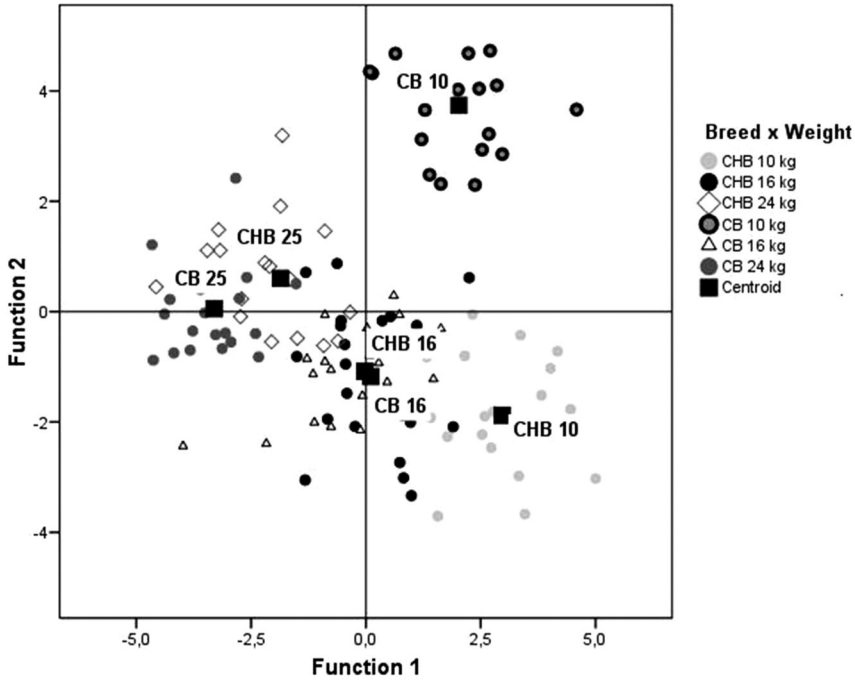

Figure 1. Discriminant functions and centroids of breed × weight interaction.

4. Conclusions

Breed and slaughter weight were the most important factors that affected meat quality. The effect of breed on meat quality is manifested primarily in 10 kg lambs. From the nutritional point of view, meat from lambs slaughtered at 25 kg of the CHB presented a better fatty acid profile because of the higher PUFA content and ratio to SFA, as well as having the lowest AI and TI. These results justify and guide the production of sheep meat to two different carcasses by weight (10 y 25 kg) in CHB and one type of carcass (10 kg) in CB. This enable offering two differentiated products that could be labelled as 'local breed' (different to the imported product) and two categories of carcass weight which are highly demanded by the market.

Disclosure statement

No potential conflict of interest was reported by the authors.

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