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The effect of carcass weight on fatness and muscle and fat colour of male Ojinegra de Teruel light lambs

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Abstract. This study aimed to evaluate the effects of increases in lamb carcass weight in 1-kg steps from 8 to 11 kg on carcass fatness, muscle colour, subcutaneous and renal fat colour, tissue composition of the thoracic limb, and intramuscular fatty acid composition. Sixty-two carcasses from Ojinegra de Teruel male lambs fed concentrates *ad libitum* and barley straw were used. Both carcass scores and renal fat weight increased with carcass weight ($P = 0.0001$), but the percentage increase in renal fat weight was twice that of fat scores. Renal fat was prone to store carotenoids earlier than caudal fat, resulting in increased chroma. With increasing carcass weight, muscle colour became less light (decreased L* ($P = 0.0001$) and an increased in chroma scores ($P = 0.001$). Increments of 1 kg of carcass weight led to noticeable changes in the *M. rectus abdominis* colour, except at the increment from 10 kg to 11 kg. Slaughtering lambs at light weights was found to be advisable because renal fat is not a valuable part of the carcass. The lean percentage of the thoracic limb did not increase with carcass weight, as the increased muscle : bone ratio ($P = 0.0001$) was offset by an increased fat percentage (especially the intermuscular fat %). Changes with increasing carcass weight in the proportions of the main fatty acids in intramuscular fat were small. Moreover, intramuscular fat did not change in quantity or quality. However, when selling carcasses at heavier weights is preferred, achieving carcasses of 11 kg rather than 10 kg was found to be advisable because the deposition of fat in both was similar. Breeds that deposit fat earlier than the breed used in this study should be fed low-energy diets to improve carcass quality. This feeding strategy could also be considered if fat deposition differs between sexes.

Additional keywords: carcass assessment, carcass composition, fatty acids, fat deposition.

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Introduction

Traditional lamb meat production in Spain and other Mediterranean areas is based on light lambs slaughtered at ~22 kg of liveweight and 3 months of age. A particular system of lamb production is the 'Ternasco de Aragón' PGI (E.U. 1996; B.O.E. 2006), in which lambs are weaned at 50 days and finished on concentrate and straw to an age of not more than 90 days. Lamb meat coming from this production system is characterised by a pale pink muscle colour and white subcutaneous and perirenal fat (B.O.E. 2006). In addition, the chilled carcass must weigh between 8.0 and 12.5 kg. The Ojinegra de Teruel lamb is one of the breeds included in the PGI, together with the Rasa Aragonesa and some minor breeds. However, Ojinegra de Teruel is an early maturing breed, and carcasses at the upper end of the accepted weight range are excessively fattened (B.O.A. 2016). The characteristics of the carcasses must meet the expectations of consumers. Mediterranean consumers have a clear preference for lamb meat from light animals (Font-i-Furnols *et al*. 2006) due to the pale muscle colour (Sañudo *et al*. 2007) and the white fat (Priolo *et al*. 2002*a*) of these animals. The Community scale for the classification of ovine animal carcasses (EEC 1992) for lambs with a carcass weight of less than 13 kg use carcass weight as the first criterion for classification. Then, there are two categories based on the rectus abdominis and subcutaneous fat colour. The *M. rectus abdominis* of the first category must have a clear pink colour and a degree of fatness between 2 and 3 on a 4-point scale.

The classification of carcasses using the colour of the *M. rectus abdominis* is preferred because the colour of that muscle is determined essentially by age (Colomer-Rocher 1988), although grazing increases the redness of this muscle (Ripoll *et al*. 2008*b*). In addition, fat colour can be used to trace the feeding of lambs, as carotenoid pigments are stored in fat deposits, modifying the fat colour (Priolo *et al*. 2002*b*; Prache *et al*. 2005; Ripoll *et al*. 2008*a*, 2012). However, the proposed system for classifying the colours of the *M. rectus abdominis* and fat are subjective and based on pictures. In Spain, market prices are not established on the basis of this classification standard (Miguel *et al*. 2007), perhaps due to this limitation.

The purpose of this experiment was to study the effect of the carcass weight of light male lambs on the colours of the

M. rectus abdominis and renal and subcutaneous fat, as well as the tissue composition of the thoracic limb and the fatty acid composition of intramuscular fat.

Materials and methods

Sampling and carcass measurements

Sixty-two carcasses of Ojinegra de Teruel male lambs were evenly selected over six consecutive weeks from the same commercial abattoir. All the lambs received concentrates *ad libitum* and barley straw as they were raised under the 'Ternasco de Aragón' GPI.

The hot carcass weight was recorded immediately after slaughter, and carcasses were randomly selected according to the hot carcass weight to cover the whole range of weights (>7 kg and <13 kg) of light lambs according to the Community scale for the classification of the carcasses of ovine animals (EEC 1992). Carcasses were hung by the Achilles tendon and transported at 4°C to the facilities of the CITA Research Institute at Zaragoza. Then, the carcasses were chilled for 24 h at 4°C in total darkness, and the cold carcasses were weighed. The degree of fatness was estimated following the Community scale (EEC 1992) as 1 (low), 2 (slight), 3 (average) or 4 (high), with each level of the scale expanded to three values (1−, 1, 1+; 2−, 2, 2+; 3−, 3, 3+; and 4−, 4, 4+). Hence, fatness was scored from 1 to 12 (Roche *et al*. 2012).

The *M. rectus abdominis* from the left half of the carcass was excised and stored until colour determination. The *M. rectus abdominis* colour was measured at three randomly selected locations on the internal face of each piece after the covering fascia was removed to obtain a mean value representative of surface colour (Carrasco *et al*. 2009). The colour was measured with a Minolta CM-2006d spectrophotometer (Konica Minolta Holdings, Inc., Osaka, Japan) in the CIELab space (CIE 1986) with the following parameters: specular component included, 0% UV, a D65 standard illuminant, an observer angle of 10° and zero and white calibration. The integrating sphere was 52 mm in diameter, and the measurement area (diameter of 8 mm) was covered with a CM-A149 dust cover (Konica Minolta Holdings, Inc., Osaka, Japan). The lightness (L*), redness (a*) and yellowness (b*) were recorded using the SpectraMagic NX software (Minolta Co. Ltd, Osaka, Japan). The hue angle (h_{ab}) and chroma (C^*_{ab}) indexes were calculated as $h_{ab} = \tan^{-1}\left(\frac{b*}{a*}\right) \cdot \frac{180^\circ}{\pi}$ expressed in degrees and $C^*_{ab} = \sqrt{(a*)^2 + (b*)^2}$. The colour difference between two stimuli (ΔE*) was calculated as $\Delta E* = \sqrt{(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2}$, where the various Δ quantities on the right represent the differences between the corresponding coordinates of the two stimuli (Brainard 2003).

The colour of the caudal subcutaneous fat between the 5th lumbar vertebra and the 1st coccygeal vertebra and the colour of the renal fat were measured with a spectrophotometer following the same procedure reported for muscle. Subcutaneous fat colour values were recorded at three randomly selected locations, avoiding blood blots, discolourations and less-covered areas. In addition to trichromatic coordinates, the proportion of reflected light at 10-nm increments between 450 and 510 nm was measured, and the absolute value of the summation of the translated spectrum (SUM) was calculated according to Priolo *et al*. (2002*b*). The reflectance spectrum was translated to make the reflectance value at 510 nm equal to zero (TR). On the translated spectrum, the integral value was calculated as follows:

$$\mathrm{SUM} = \left[\left(\frac{\mathrm{TR}_{450}}{2}\right) + \mathrm{TR}_{460} + \mathrm{TR}_{470} + \mathrm{TR}_{480} + \mathrm{TR}_{490} + \mathrm{TR}_{500} + \left(\frac{\mathrm{TR}_{510}}{2}\right)\right] \cdot 10$$

where TR_i was the reflectance value at i nm. A detailed explanation of the basis of the method is presented in Prache and Thériez (1999).

Then, the renal fat from the left half of the carcass was removed and weighed (Panea *et al*. 2012). The tail was removed, and the carcass was carefully split longitudinally into two half-carcasses. The thoracic limb of the left half of the carcass was cut and dissected into muscle, subcutaneous fat, intermuscular fat and bone plus waste (major blood vessels, ligaments, tendons and thick connective tissue sheets associated with some muscles) following Panea *et al*. (2012). The thoracic limb was defined by a polygon delimited by four imaginary lines and four points. The dorsal line went from the cranial side of the apophysis of the 4th cervical vertebra (V) to the caudal side of the apophysis of the 5th thoracic vertebra (D). The second line went from D to a point placed between the 5th and the 6th costochondral joints (E). The third line was parallel to the dorsal line and went from E to the *M. manubrium sterni*. Once the points were delimited, the shoulder was extracted with a knife following the described lines. The cartilage of the scapula was separated from the *M. serratus ventralis thoracis* and kept with the thoracic limb. The fat surrounding the prescapular lymph node was also kept with the thoracic limb.

Intramuscular fat and fatty acid analyses

To prepare the meat for fatty acid (FA) analysis, the *M. longissimus thoracis* of the left half of the carcass was minced and freeze-dried in a Virtiss Wizard 2.0 lyophilizer (Virtiss SP Scientific, Gardiner, NY, USA) for 7 days at −50°C and 13.332 Pa. Then, the meat was ground to a particle diameter of 0.5 mm. The intramuscular fat content content (IMF) was determined following the Ankom procedure (AOCS 2005) with an XT10 Ankom extractor (Ankom Technology, Madrid, Spain).

Fatty acids from the IMF of the *M. longissimus thoracis* were derivatised and extracted according to the method described by Lee *et al*. (2012). This method was developed specifically for freeze-dried meat. The determination of these FA methyl esters was carried out using a Bruker 436 Scion gas chromatograph equipped with a cyanopropyl capillary column (BR-2560, 100-m × 0.25-mm ID × 0.20-μm thickness, Bruker, Billerica, MA, USA), a flame ionisation detector and Compass CDS software. FA quantification was performed as described in the UNE-EN 12966–4 (ISO 2015), and identification was performed using the GLC 538 and GLC 463 standard references (Nu-Chek-Prep Inc., Elysian, MN, USA). FA contents are expressed as a percentage of the total amount of identified FA. After individual FA determination, total contents of saturated FA

(SFA), monounsaturated FA (MUFA), polyunsaturated FA (PUFA), PUFA n-6 and PUFA n-3 were calculated. PUFA n-6 : n-3 ratios were calculated. The Δ-9 desaturase activity index was calculated according to the ratio C18:1 : (C18:0 + C18:1) (Malau-Aduli *et al*. 1998).

Statistical analyses

Statistical analyses were performed using XLStat (Addinsoft, Barcelona, Spain). A general linear model was used for carcass classification, and for IMF, FA, *M. rectus abdominis* colour and tissue composition in analyses of variance (ANOVA), with the carcass weight as a fixed effect. Additionally, linear, quadratic and cubic contrasts were tested. A general linear model procedure was used for fat colour variables in an ANOVA, with the carcass weight and location of fat depot as fixed effects. The *post hoc* Duncan test was used to compare means at the $\alpha = 0.05$ level.

Results

The four carcass weights studied were 8, 9, 10 and 11 kg because there were no carcasses weighing 12–13 kg. The carcasses were evenly distributed into the four carcass weight categories (Table 1). Fatness degree increased between 8 (5.1) and 10 kg (7.6) ($P < 0.05$) and then remained steady ($P > 0.05$). Renal fat weight increased nearly linearly with carcass weight ($P < 0.001$). The 8-kg carcasses had the lowest renal fat weight, the 9-kg and 10-kg carcasses had intermediate renal fat weights, and the 11-kg carcasses had the highest renal fat weight ($P < 0.001$).

The colour variables of the *M. rectus abdominis* are shown in Table 2. The colour variables were affected by carcass weight, except for redness. Lightness decreased linearly with increased carcass weight ($P < 0.001$). The 8-kg group had a lower yellowness index and hue angle than the other groups ($P < 0.05$). The 8-kg carcasses had the lowest chroma values, the 9-kg carcasses had intermediate chroma values and the 10-kg and 11-kg carcasses had the highest chroma values ($P < 0.001$). The largest ΔE* was between 8 kg and 9 kg, whereas the smallest ΔE* was between 10 kg and 11 kg. Hence, the ΔE* from 8 kg to 9 kg was approximately half that of the ΔE* from 8 kg to 10 kg. However, the ΔE* from 8 kg to 11 kg was very close to the ΔE* from 8 kg to 10 kg.

The significance of the effect of carcass weight and location of fat depot on the instrumental measurements of colour of fat is shown in Table 3. Lightness and SUM were only affected by location of fat depot ($P < 0.001$). Renal fat had greater values for lightness and SUM than did subcutaneous caudal fat (Fig. 1). Hue angle and chroma were affected by a magnitude interaction between the carcass weight and location of fat depot ($P < 0.05$). The hue angle of subcutaneous caudal fat was always greater than that of renal fat, irrespective of carcass weight. The hue angle of renal fat increased between 8 kg and 10 kg ($P < 0.05$)

Table 1. Means within the carcass-weight groups for carcass weight, fatness degree and renal fat weight
Means with different letters are significantly different ($P < 0.05$). s.e.m., standard error of the mean; CCW, cold carcass weight; RF, renal fat weight

	8 kg	9 kg	10 kg	11 kg	s.e.m.	Carcass-weight effect (*P*-value)[A]
n	16	16	16	14		
CCW, kg	8.01a	9.22b	10.23c	11.17d	0.094	0.0001 L
FD[B] (1–12)	5.1c	6.6b	7.6a	7.6a	0.25	0.0001 L[Q]
RF (g)	70.22c	100.26b	118.71ab	140.98a	7.638	0.0001 L

[A]L, Q, C letters indicate significant linear, quadratic and cubic contrasts at the 0.01 level.
[B]FD, fatness degree scored in a scale from 1 (low), 2 (slight), 3 (average) to 4 (high), each expanded to three values (1−, 1, 1+; 2−, 2, 2+; 3−, 3, 3+, 4−, 4, 4+). Hence, fatness degree was scored from 1 to 12.

Table 2. Means within the carcass weight groups for *M. rectus abdominis* instrumental colour
Means with different letters are significantly different ($P < 0.05$). s.e.m., standard error of the mean; CWG, cold carcass weight group

	8 kg	9 kg	10 kg	11 kg	e.e.	Carcass-weight effect (P value)[A]
L* (Lightness)	46.50a	44.58ab	42.42bc	40.95c	0.863	0.0001 L
a* (Redness index)	11.41	10.84	11.63	10.72	0.428	0.411
b* (Yellowness index)	12.57b	15.46a	17.47a	16.38a	0.899	0.001 LQ
h_{ab} (Hue angle), degrees	46.17b	53.98a	56.14a	55.69a	2.524	0.015 L
C^*_{ab} (*Chroma*)	17.46c	19.08b	21.15a	19.83ab	0.606	0.001 LQ
$\Delta E^*_{(CWGn - CWGn - 1)}$[B]	–	3.5	3.1	2.0		
$\Delta E^*_{(CWGn - CWG8\ kg)}$[C]	0.00	3.5	6.4	6.8		

[A]L, Q, C letters indicate significant linear, quadratic and cubic contrasts at the 0.01 level. Q letter indicates a significant quadratic contrast at the 0.05 level.
[B]Difference in colour between carcass weight groups differing 1 kg.
[C]Difference in colour between the 8-kg carcass weight group and the other groups.

but remained steady from 10 kg to 11 kg ($P > 0.05$). However, the hue angle of subcutaneous fat increased more gradually between 8 kg and 10 kg ($P < 0.05$). The chroma of renal fat was greater than the chroma of subcutaneous fat between 8 kg and 10 kg ($P < 0.05$), but there were no differences in chroma between fat depots at 11 kg ($P > 0.05$). The chroma of subcutaneous fat increased from 8 kg to 10 kg ($P < 0.05$), whereas the chroma of renal fat remained similar ($P > 0.05$).

The tissue composition of the thoracic limb is shown in Table 4. Carcass weight did not affect the percentages of lean meat or subcutaneous fat ($P > 0.05$), but it did affect the percentages of intermuscular fat and bone ($P < 0.001$). The percentages of intermuscular fat for 8-kg and 9-kg carcasses were similar ($P > 0.05$), but the percentage increased in 10-kg and 11-kg carcasses ($P < 0.05$), which had similar percentages. The percentage of bone decreased almost linearly with increasing carcass weight ($P < 0.001$). Muscle : bone ratios were greater for 9-kg, 10-kg and 11-kg carcasses than for 8-kg carcasses ($P < 0.001$).

The IMF content and the percentages of most of the FA were not affected by carcass weight ($P > 0.05$) (Table 5). Some individual saturated FA (C12:0, ΣC13:0, ΣC15:0 and C20:0) were affected by carcass weight ($P < 0.05$) but without a clear pattern. The percentages of C12:0 and C13:0 were highest in 8-kg carcasses ($P < 0.05$). However, the percentage of ΣC15:0 was higher in 8-kg and 10-kg carcasses than in 9-kg and 11-kg carcasses ($P < 0.05$). The percentage of ΣCLA was higher in 8-kg than in 9-kg carcasses, with 10-kg and 11-kg carcasses presenting intermediate values. The percentage of C20:0 was higher in 8-kg and 9-kg carcasses than in 10-kg carcasses ($P > 0.05$). There were no differences in the calculated sums and ratios of FA due to carcass weight ($P > 0.05$).

Table 3. Significance (indicated by *P*-values) of the effects of carcass weight and location of fat depots (renal and subcutaneous) on instrumental colour of fat

Means are shown in Fig. 1. SUM, estimator of fat carotenoid pigments

	L*	h_{ab}	C^*_{ab}	SUM
Carcass weight	0.140	0.003	0.107	0.335
Location of fat depot	0.0001	0.0001	0.0001	0.0001
Carcass weight × Fat depot	0.869	0.016	0.040	0.436

Discussion

The moderate milk production of the Ojinegra de Teruel breed results in lambs reaching the age limit for weaning in the 'Ternasco de Aragón' GPI system (50 days) with low bodyweights (Ripoll-Bosch *et al.* 2012*a*). Therefore, when

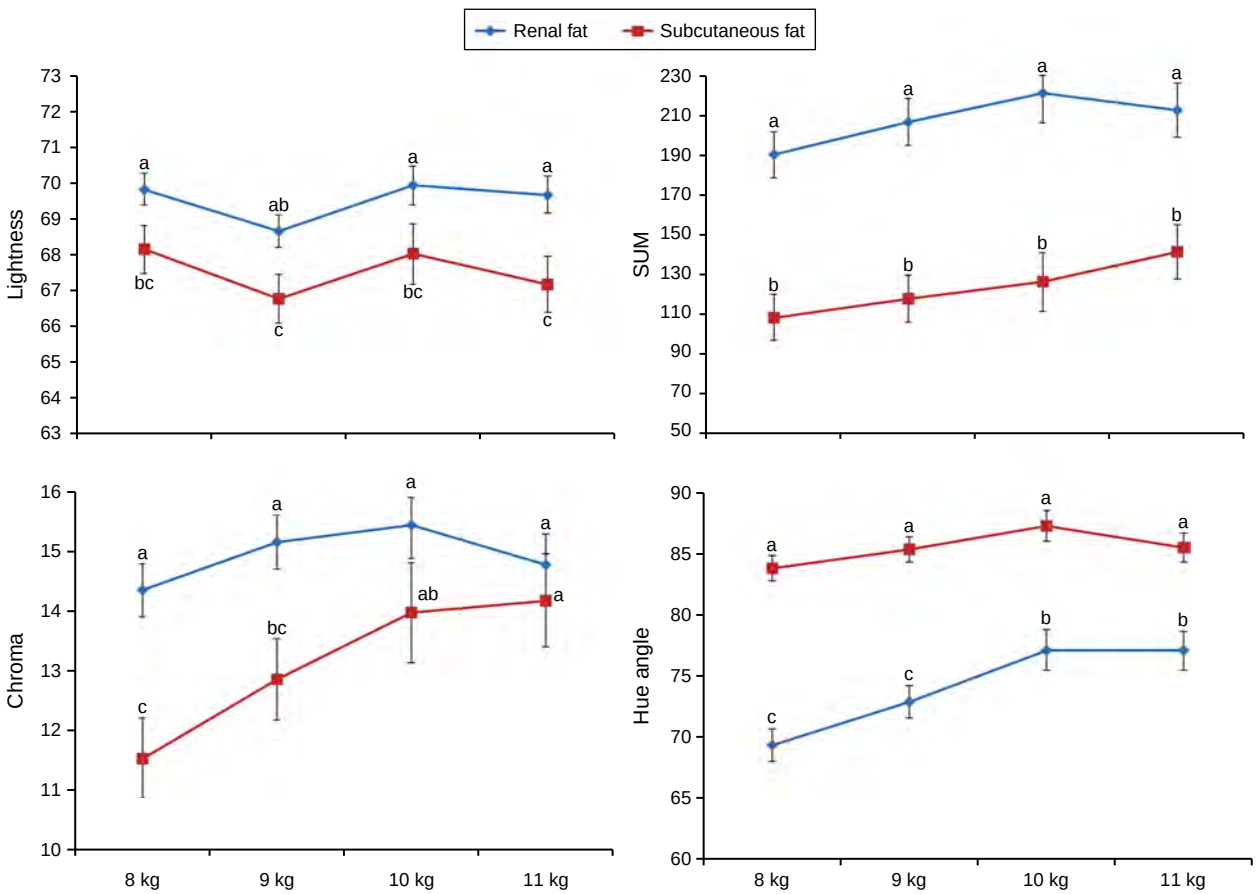

Fig. 1. Lightness, SUM, chroma and hue angle of renal and subcutaneous caudal fat. Significance levels are given in Table 3. SUM, estimator of fat carotenoid pigments. The error bars are the standard error. Means with different superscripted letters are significantly different ($P < 0.05$).

Table 4. Means within the carcass weight groups for the tissue composition of the thoracic limb
Means with different letters are significantly different ($P < 0.05$). s.e.m., standard error of the mean

	8 kg	9 kg	10 kg	11 kg	s.e.m.	Carcass-weight effect (P-value)[A]
Lean meat (%)	62.89	63.25	61.88	61.18	0.646	0.116
Subcutaneous fat (%)	3.61	3.05	3.07	3.80	0.442	0.535
Intermuscular fat (%)	9.93b	11.39b	13.88a	14.69a	0.752	0.0001L
Bone and others (%)	23.57a	22.32b	21.17bc	20.34c	0.388	0.0001L
Muscle : bone ratio	2.8b	3.0a	3.1a	3.1a	0.06	0.0001L

[A]L letter indicates significant linear contrasts at the 0.01 level.

lambs are slaughtered at 90 days, they yield carcasses lighter than 12 kg. However, these carcasses have a similar degree of fatness and renal fat content compared with values for Manchega suckling lamb carcasses between 10 kg and 12 kg (Miguel *et al*. 2007). Suckling lambs of the same breed with a carcass weight of 6 kg had a fatness score of 4 on a 5-point scale (Ripoll-Bosch *et al*. 2012*b*), whereas 5-kg, 10-kg and 11-kg carcasses of Rasa Aragonesa lambs had lower degrees of fatness (Martínez-Cerezo *et al*. 2005; Roche *et al*. 2012). Early maturing breeds, such as Ojinegra de Teruel, reach a certain high degree of fatness early in their development. However, these breeds cannot easily increase in fatness from this point according to the present results. However, 11-kg Rasa Aragonesa carcasses had greater amounts of renal fat (Roche *et al*. 2012; Ripoll *et al*. 2014) than did Ojinegra de Teruel carcasses in the present study. This increase in subcutaneous fat but not in renal fat is convenient since the subcutaneous fat protects the carcass from cold shortening, and renal fat is not an edible part of the lamb.

All the carcasses in the present experiment were classified as pale pink according to the UE classification of the *M. rectus abdominis*. The 10-kg and 11-kg carcasses of Rasa Aragonesa were classified as pink because they had high lightness and low chroma values (Ripoll *et al*. 2012, 2014; Roche *et al*. 2012; Lobón *et al*. 2017). When the range of carcass weights is wide, there is a clear change in the visually detectable colour of the *M. rectus abdominis* (Sanz *et al*. 2008). When the carcass weights of Ojinegra de Teruel animals decrease, the *M. rectus abdominis* L* increases, and the h_{ab} and C^*_{ab} decreased. According to these results, carcasses weighing ~6 kg from suckling male Ojinegra de Teruel lambs had higher lightness, lower h_{ab} and lower C^*_{ab} values (Ripoll-Bosch *et al*. 2012*b*). However, the effect of small increases in carcass weight on the *M. rectus abdominis* is not negligible. When ΔE* is greater than 1.8, changes in colour are visually detectable (Ripoll *et al*. 2012). Thus, from our results, increases of 1 kg in carcass weight lead to noticeable changes in the *M. rectus abdominis* colour, except for an increase from 10 kg to 11 kg.

The subcutaneous fat of 10-kg carcasses of Rasa Aragonesa lambs fed with concentrates in a previous study had L* and C^*_{ab} values (Ripoll *et al*. 2012; Roche *et al*. 2012) similar to the ones reported here, and these values correspond to white fat according to the EU classification. Renal fat has higher L* and lower h_{ab} values and is more prone to the deposition of carotenoid pigments than subcutaneous fat, as reported by Ripoll *et al*. (2012). Estimators of carotenoids in fat depots are often greater in renal than in subcutaneous fat. According to estimates, both types of fat store low levels of carotenoids (Priolo *et al*. 2002*b*; Ripoll *et al*. 2008*a*). However, C^*_{ab} depends on the carotenoid pigments contained in the feedstuffs (Ripoll *et al*. 2012). According to Priolo *et al*. (2002*b*), when carotenoid concentrations are high, as occurs in grazing lambs, b* and C^*_{ab} are similar in all fat depots. However, when carotenoid concentrations are low, as in lambs raised indoors, carotenoids accumulate to a greater degree in subcutaneous caudal fat (Priolo *et al*. 2002*b*). The use of C^*_{ab} instead of b* to classify carcasses is recommended because it more accurately represents adipose tissue colour (Rigg 1987). In addition, the C^*_{ab} of fat is easily visually perceived by consumers and meat graders (Dunne *et al*. 2006). Camacho *et al*. (2017) found that the colour of subcutaneous fat in two breeds of lamb fed milk and forage did not change when the carcass weight increased from 8 kg to 12 kg.

Santos *et al*. (2015) studied Churra Galega Mirandesa lambs with carcass weights of 6.1 kg and 8.3 kg. In accordance with the results of our study, they reported a similar percentage of lean meat on the shoulder at all of the carcass weights. The percentage of lean meat in Churra Galega Mirandesa animals was slightly lower than the corresponding percentage of Ojinegra de Teruel animals. Additionally, these authors reported a decrease in the percentage of bone with an increase in carcass weight. However, they found an increase in subcutaneous fat and no differences in intermuscular fat. Both studies reported an increase in fat with an increase in weight. Similar results were reported by Abdullah and Qudsieh (2008), who also did not find differences in lean meat and subcutaneous fat when studying Barbarine carcasses with cold carcass weights of 8.3 kg and 13.6 kg. D'Alessandro *et al*. (2013) compared 7.3-kg and 8.06-kg Leccese carcasses and reported that the total fat content of the shoulder for the heavy carcasses was similar to or even lower than that of the light carcasses, depending on the season of lamb rearing. Miguel *et al*. (2007) did not find any differences in the tissue composition of the shoulder of Manchega suckling lambs with carcass weights of 10 kg and 12 kg.

Oleic, palmitic and stearic acids are the most abundant MUFA and SFA in the IMF of small ruminants (Horcada *et al*. 2014; Camacho *et al*. 2017). The FA composition of meat is more affected by slaughter weight than by sex or breed (Camacho *et al*. 2017). However, in the current experiment, there were minor changes but no clear trend. Cañeque *et al*. (2001) reported that an increase in carcass weight from 11 kg to 13 kg did not affect SFA levels but increased MUFA and decreased PUFA levels. However, when carcass weight increased from ~16 kg to

Table 5. Means within the carcass-weight groups for intramuscular fat (IMF) and fatty acids (mg FA/100 mg FAME)
Means with different letters are significantly different ($P < 0.05$). s.e.m., standard error of the mean

	8 kg	9 kg	10 kg	11 kg	s.e.m.	Carcass-weight effect (*P*-value)[A]
IMF (% DM)	10.76	9.56	9.32	9.87	0.709	0.522
C10:0	0.27	0.21	0.22	0.23	0.018	0.074
C10:1	0.06	0.05	0.05	0.04	0.005	0.061
C12:0	0.68a	0.46b	0.50b	0.49b	0.042	0.001
C12:1	0.01	0.01	0.01	0.01	0.003	0.245
ΣC13:0[B]	0.18a	0.13b	0.14b	0.13b	0.010	0.007L
ΣC14:0	5.33	4.63	4.92	4.85	0.242	0.170
C14:1 n-9*cis*	0.15ab	0.14b	0.18a	0.17a	0.100	0.044Lc
ΣC15:0	0.91a	0.79b	0.89a	0.79b	0.031	0.007
C15:1	0.04	0.03	0.03	0.03	0.004	0.669
ΣC16:0	25.03	24.88	25.39	25.17	0.263	0.583
Σ16:1	3.07b	3.15b	3.36a	3.30ab	0.071	0.040
C17:0	1.26	1.29	1.31	1.23	0.044	0.668L
C17:1 n-9*cis*	1.24	1.31	1.33	1.23	0.036	0.144
Σ18:0	11.35	11.35	10.90	11.03	0.169	0.262
Σ18:1	36.12	37.60	36.95	36.96	0.499	0.157
Σ18:2	7.83	7.73	7.86	8.04	0.299	0.900
CLA	0.57a	0.50b	0.53ab	0.53ab	0.020	0.039L
Σ18:3	0.62	0.60	0.58	0.60	0.018	0.675
C20:0	0.09a	0.09a	0.08b	0.09ab	0.003	0.035
C20:1 n-9	0.00	0.00	0.00	0.00	0.001	0.844
C20:2 n-6	0.09	0.09	0.10	0.10	0.006	0.586
Σ20:3	0.47	0.46	0.44	0.45	0.022	0.825
C20:4 n-6	2.68	2.55	2.44	2.64	0.153	0.713
C20:5 n-3	0.30	0.31	0.30	0.32	0.022	0.894
C22:0	0.05	0.05	0.05	0.04	0.003	0.697
C22:1	0.01	0.02	0.02	0.02	0.003	0.947
C22:3 n-3	0.00	0.00	0.00	0.00	0.001	0.853
C22:4 n-6	0.14	0.14	0.13	0.13	0.009	0.742
C22:5 n-3	0.54	0.51	0.45	0.49	0.027	0.208
C22:6 n-3	0.23	0.23	0.22	0.25	0.015	0.659
C24:0	0.01	0.01	0.01	0.01	0.001	0.935
C24:1 n-9	0.01	0.00	0.00	0.02	0.006	0.480
SFA	45.81	44.56	45.00	44.69	0.462	0.202
MUFA	40.71	42.32	41.93	41.76	0.516	0.122
PUFA	13.48	13.12	13.06	13.55	0.501	0.856
n-6	10.97	10.71	10.75	11.14	0.452	0.893
n-3	1.65	1.61	1.51	1.62	0.068	0.599
n-6/n-3	6.89	6.78	7.52	7.03	0.307	0.389
Δ-9 desaturase	0.76	0.77	0.77	0.77	0.004	0.212

[A]L letter indicates significant linear contrasts at the 0.01 level. l,c letters indicate significant linear and cubic contrasts at the 0.05 level.

[B]The symbol Σ indicates a summation of isomers of a fatty acid, when isomer levels were not affected ($P < 0.05$) by the carcass weight. ΣC13:0 = a-C13:0 + C13:0; ΣC14:0 = a-C14:0 + C14:0; ΣC15:0 = a-C15:0 + i-C15:0; ΣC16:0 = a-C16:0 + i-C16:0 + DMA-C16:0; ΣC18:1 = C18:1 t11 + 18 : 1 c9 + C18:1 t15 + C18:1 c11 + C18:1 c12 + C18:1 c13 + C18:1 t16 + C18:1 c15; ΣC18:2 = C18:2 n6 t9,12 + C18:2 n6; ΣCCLA = C18:2 t9 c11 + C18:2 t10 c12 + C18:2 t11 c9; ΣC18:3 = C18:3 n6 + C18:3 n3; ΣC20:3 = C18:3 n6 + C20:3 n9.

23 kg, SFA and PUFA levels did not change (Al-Suwaiegh and Al-Shathri 2014). These changes in FA composition according to slaughter weight are related to the physiological condition and digestive ability of the animals, which changes as a result of their growth and development (Marino *et al*. 2008). In addition, the FA composition is also strongly affected by the IMF. Hence, when meat has a low fat content, it is rich in PUFA, and when the amount of IMF increases, the amount of SFA increases (Kosulwat *et al*. 2003). In fact, Cañeque *et al*. (2005) reported no differences in levels of SFA, PUFA and MUFA and most individual FA when the amounts of IMF were similar, regardless of whether carcass weights were 5, 6 or 7 kg.

The enzyme Δ-9 desaturase is responsible for the synthesis of oleic acid (C18:1) from stearic acid (C18:0). However, it has been reported that the activity of Δ-9 desaturase is related to an increase in fatness. Hence, in this study, without differences in the IMF, Δ-9 desaturase activity did not change with increases in carcass weight.

Conclusions

Ojinegra de Teruel has been shown to be an early maturing breed that quickly reaches a high degree of fatness, but fatness does not increase easily with an increase in carcass weight. The increase in fatness with carcass weight was not concomitant with an increase in renal fat. Renal fat weight doubled as carcass weight increased from 8 kg to 11 kg, but the degree of fatness increased slowly, with 10-kg and 11-kg carcasses having the same degrees of fatness. It is advisable to slaughter lambs at light weights because renal fat is not a valuable part of the carcass, and the percentage of lean meat did not increase with an increase in carcass weight. Moreover, IMF, which improves the flavour and juiciness of meat, did not change in either quantity or quality. However, when selling carcasses at heavier weights is preferred, achieving carcasses of 11 kg, rather than 10 kg, is advisable because the deposition of fat was similar at both weights. Moreover, changes in *M. rectus abdominis* colour from carcass weights of 10 kg to 11 kg were not noticeable.

For other breeds that have an earlier deposition of fat than the breed used in this study but that are raised in similar production systems, the use of less-energetic concentrates to avoid high levels of fat deposition in heavier carcasses is proposed. This feeding strategy could also be considered if fat deposition differs between sexes.

Conflicts of interest

The authors declare no conflicts of interest.

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