Effect of Texel crossbreeding on productive traits, carcass and meat quality of Segureña lambs

Running title: Effect of Texel crossbreeding on Segureña productivity and lamb quality

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Abstract

Background: The aim of this work was to assess the effect of crossbreeding a local breed (Segureña, S×S) with Texel as sire line (Texel × Segureña crossbred, T×S) on productive traits and meat quality attributes. Sixty-eight lambs, males and females, from each genotype, weaned at about 45 days old and intensively fed with concentrates and cereal straw *ad libitum* until reaching 72 days old, were used to assess productive traits, and 10 animals from each genotype to assess meat quality.

Results: The crossbreeding with Texel improves productivity, with a greater weight at birth (+1 kg) and at slaughter (+3 kg) and a greater average daily gain (+29 g). T×S lambs had better conformation, less carcass fatness, and higher content of muscle (+45 g kg^{-1}) as opposed to a

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lower fat content (-50.6 g kg^{-1}). With regards to meat quality, the crossbreeding with Texel provided a meat with more protein content (+4 g kg^{-1}) and lower oleic acid content (21 % less), being the differences very scarce from the sensory point of view, and inexistent regarding the instrumental quality.

Conclusion: The crossbreeding could be a useful tool in the production of ovine meat in local breeds, such as Segureña, within the Mediterranean Area, and consequently, a way to increase the profitability of the farms.

INTRODUCTION

In recent years, statistics show a constant decline consumption of lamb meat in some Mediterranean countries like Spain.[1] In parallel, there is a decline in the number of farms and census.[1] On the other hand, Spain is the second country in the European Union in terms of heads,[1] being lamb a popular meat and the autochthonous sheep breeds the most frequently used,[2] probably because of the requirements of the Protected Geographical Indications and quality marks. Also, sheep represents a fundamental value in the development of rural areas and conservation of the natural environment, especially those unimproved breeds.[3]

In Mediterranean countries, the traditional production system implies that lambs are being slaughtered at early ages (30 to 90 days) with low live and carcass weights, producing meat highly rated by consumers.[4,5] Particularly, in the South-East region of Spain, the Segureña rustic-type breed is very well adapted to the severe conditions of the semi-arid Mediterranean climate, providing these light lambs.

Within this general context, some alternatives are currently being studied, with the ultimate aim of contributing to the maintenance of sheep farming, through the increase of profitability and the possibility of creating differentiated quality or value-added products. One available alternative is using the potential of different breeds through crossbreeding schemes and/or selection programs.[6] Crossbreeding has become more and more popular in an attempt to slaughter lambs earlier and with better carcass traits.[7] The industrial crossbreeding between a meat purpose male with local ewes was a technique widely studied in the past,[8] being its main objective to improve productivity and the carcass quality of local breeds. On the other hand, the market shows a trend toward leaner carcasses and a growing social interest in healthier fats.

The use of Texel as terminal sire has been studied under several conditions,[9,10,11,12,13] showing lower fat content, higher lean meat yield, and better carcass and leg conformation than other terminal sire breeds. Nevertheless, differences in meat quality have not been so clear.[14]

In this study, two genotypes, Segureña pure breed and Texel crossbred, were analyzed comparatively both as regards to productive yields, carcass and meat quality and consumer acceptability.

MATERIAL AND METHODS

Animals

The experiment was carried out in the experimental farm which belongs to Diputación Provincial of Castellón, located at Ares del Maestrat, Castellón, East of Spain. Data was available from 136 lambs born from 100 ewes. Two breeds of sires were used: Segureña and Texel. Five Segureña males were joined with fifty Segureña females (S×S, pure local breed) and five Texel males with fifty Segureña females (T×S) for 51 days. Lambs were born between March and April.

Productive traits and carcass quality

After birth, the number of lambs born alive (NL) and their birth weight were recorded. Animals were weighed fortnightly up to slaughter, and average daily gain (ADG) during the experimental period was calculated. Their husbandry conditions included: weaning at around 45 days of age and a concentrate-based diet (a mixture of wheat, maize, soya, with 171 g kg^{-1} crude protein and 50.3 g kg^{-1} ether extract) plus cereal straw *ad libitum* until slaughter at around 72 days of age. This husbandry system and diet is largely used for this type of animals in Spain.[1] Concentrate consumption per genotype was calculated in the last 27 days of the rearing period, after weaning in order to assess the profitability of the crossbreeding.

After the last weight control, ten entire males from each genotype with similar age, around 72 days, and average live weight of 23 kg were selected to be slaughtered at an EU licensed abattoir "Complejo Cárnico de La Plana", in Castellón. The following data were recorded: body weight at slaughter (BWS) and cold carcass weight (CCW), then carcass yield (CY) was calculated.

After 24 h, they were transported at 4ºC to the Department of Animal Production and Food Science (University of Zaragoza). Carcasses were graded for conformation using the light carcass standard system (1-5 points),[15] and assessed the fatness using a photo scoring system (1-4 points).[16] Also, morphometric measures were obtained: external carcass length (K), Chest depth (Th), leg length (F), buttock perimeter (BG), buttock width (G), and OS1 (maximum width of tarsus-metatarsus joint) and OS2 (the distance between the medial malleolus and the base of the calcaneus) measurements. Carcass compactness (CCW/K) and leg compactness (G/F) were calculated.[17]

At 24 h postmortem, the carcasses were divided in half along the back bone and the left side shoulder was separated,[15] vacuum packed, frozen and stored at -18ºC for subsequent dissection into muscle, bone, subcutaneous fat, intermuscular fat, and preescapular fat to calculate tissue composition percentage.[18] At the same time, the muscle/bone (M/B) ratio was determined.

Meat quality

The meat pH was measured at 24 h post-mortem, in the *Longissimus thoracis* (6th rib level) with a penetrating electrode connected to a portable Crison 507 pH-meter. Meat colour was measured at 24 h post-mortem on the surface of the section of the *Longissimus thoracis* (13th rib level) after 45 minutes of blooming with a reflectance spectrophotometer (Minolta CM-2002), with an illuminant D65 and a 10º standard observer, using the CIE L*a*b* system (CIE, 1986).[19] Blooming was performed with the muscle in a polystyrene tray covered with O_2 permeable transparent film without touching the muscle. The meat colour was assessed by the L* (lightness), a* (redness), b* (yellowness) as average of three measurements. Chroma (C*) and Hue (H*) values were calculated.

The *Longissimus dorsi* from the left half carcass was removed and divided into four portions and sealed into polyethylene bags under vacuum conditions. Samples were aged for 4 days at 4ºC, frozen and stored at -18ºC until further analysis.

Longissimus thoracis (5st-6th rib level) was used to determine fatty acid composition. Total lipids were extracted in chloroform:methanol,[20] methyl esters were obtained with KOH, and fatty acids were analysed by gas chromatography using an HP 6890 gas chromatograph (Hewlett-Packard, Waldbronn, Germany) and a SP2560 capillary column (100m x 0.25mm x 0.20 µm) with nitrogen as a carrier gas.[21] Fatty acids were expressed as percentage of total fatty acids.

The *Longissimus thoracis* (7th-8th rib level) was used to calculate chemical composition. Dry matter,[22] total fat,[23] protein with a conversion factor of 6.25,[24] and ashes,[25] were determined.

Between 9th-13th ribs, water holding capacity (WHC) and meat tenderness were assessed in *Longissimus thoracis*. Water losses were determined by calculating the difference in weight before and after storage under freezing conditions (thawing losses), before and after the immersion in a water bath at 75ºC until reaching an internal temperature of 70ºC and then cooled before weighing (cooking losses) and before freezing and after cooking (total losses). Meat tenderness was measured using an INSTRON 4301, equipped with a Warner-Bratzler cell. Cooked meat tenderness was assessed by means of a shear force test (test speed of 150 mm/min, force of 10 kg), taking the average of five to seven measurements on rectangular parallelepipeds per loin, (around 1x1 cm-thick and 3 cm-long, with the shear force perpendicular to the muscle fibres) without visible fat or connective tissue.

The *Longissimus lumborum* (1st-6th level) was used for the consumer study in a 'hall test'. One hundred consumers performed the sensory analysis in ten sessions of ten people each. The parameters inquired were: tenderness, flavour and overall acceptability. The scale used was structured in 9 points, where 1 and 9 were, respectively, dislike extremely and like extremely.[26] The intermediate level 'neither like nor dislike' was omitted to force consumers to decide on a liking category or a dislike category.[27] Meat samples were thawed at 4ºC for 24 h and grilled in an electric double grill (SAMMIC) preheated at 200ºC, wrapped between two foils of aluminium paper, until reaching an internal temperature of 70ºC. After cooking, the samples, excluding external fat and connective tissue, were cut into pieces and each piece was wrapped with aluminium foil, coded with 3-digit numbers and placed in a preheated oven at 50ºC until tasting. The order of tasting was designed to avoid the effect of order of presentation and first-order and carry-over effects.[28]

The right shoulder and right and left legs were used to study the acceptability by consumers from thirty families who live in Castellón in a 'home test'. Samples, aged for four days, packed and frozen at -18ºC, were sent to each family (leg or shoulders in each). Sensory test was carried out in two consecutive weeks. Each week, the family had to thaw the piece, cook with the same recipe and evaluate it. The recipe included cooking in an oven with only salt and olive oil. The order was designed, as previously, to avoid the effect of order of presentation and first-order and carry-over effects. The cook evaluated colour before cooking, amount of fat, smell during cooking, and aspect after cooking, on a 10-cm semi structured line, from dislike extremely (0) to like extremely (10). Consumers, including the cook, evaluated: tenderness acceptability, juiciness acceptability, flavour acceptability and overall liking, on a 10-cm semi structured line: from dislike extremely (0) to like extremely (10). Afterwards, consumers were asked to rate the sample that was assessed in comparison with other roasted lambs that they usually consume at home, on a 7-point category scale from much worse (1) to much better (7),

Statistical analysis

Statistical analyses were carried out using IBM SPSS (22.0) through analysis of variance. For productive parameters, the general linear model (GLM) included 'genetic group' (S×S, T×S),

’sex‘ (male or female), ’NL’ (single or twin), and their interactions as fixed effects. For carcass and meat quality traits, ’genetic group‘ (S×S, T×S) was included as fixed effect and ’animal‘ was fitted as a random effect. To analyse sensory acceptability, also ’session‘ as fixed effect and ’family‘ (home test) or ’consumer' (hall test) as random effects were used. The means and standard deviations were calculated.

RESULTS

Productive traits

The effect of genotype (G), sex (S) and number of lambs born alive (NL) on the birth weight (BW) slaughter weight (SW) and average daily gain (ADG) are shown in Table 1.

A highly significant difference in birth weight (P<0.001) between the genetic groups was observed, with animals from T×S showing heavier weights (+1 kg) compared with S×S lambs. This difference increased (P<0.001) at slaughter (+3 kg). Also, T×S lambs showed a higher ADG (+29 g) (P=0.002) needing 10 days less to reach the same SW than S×S lambs.

With regards to sex, no significant differences between males and females were found for BW, but for the SW and ADG variables, males exhibited significantly better results than females (P≤0.01). On the other hand, no significant interactions between sex and genotype were found (P>0.05).

The NL had a strong effect (P≤0.001) in BW, SW and ADG. Single lambs obtained a higher BW (+1 kg), SW (+4.4 kg), and ADG (+46.6 g) compared with twin lambs. Genotype and type of birth interaction was significant (P≤0.001) in BW. Thus, the weight of T×S was higher than S×S, independently of the number of lambs born alive. When there were twins the difference was of

0.6 kg per animal (4.64 *vs*. 4.04 kg), but when there were singles the difference increased up to 1.97 kg (6.30 *vs*. 4.33 kg).

Animals were reared in independent groups without possibility of individual consumption control. However, each genotype was reared separately in different pens, so group consumption and feed conversion index have been calculated. TxS consumption per animal in the last 27 days of the feedlot period, just after weaning, was of 881,8 g d^{-1}, whereas SxS consumption in the same period was of 784,3 g d^{-1}. Considering the ADG of each genotype in this period, which was individually calculated (336 g in TxS and 289 g in SxS), TxS showed a feed conversion index of 2.62 and SxS showed an index of 2.71. In the last 27 days, TxS genotype increased 9.08 kg its live weight, and SxS genotype increased it in 7.81 kg. Since an animal between 19.1 - 23.0 kg of live weight in the reference market was worth 3.21€ kg^{-1}, [29] (SxS would have been included in this category) and between 23.1 - 25.4 kg was worth 3.09€ kg^{-1},[29] (TxS would have been included in this category), and considering that the concentrate price of the feed was 0.275 €/kg, the benefit obtained in the last 27 days was 21.51 € in TxS and 19.25 € in SxS.

Carcass quality

The results (Table 2) reported improvements in Texel crossbred lambs, with more conformation and less fatness scores, and a better butchery morphology. Conformation score showed an average value of 3.5 for T×S against 2.85 for purebred lambs (P=0.01). On the other hand, T×S showed, as expected less fatness score (P<0.001). The dressing percentage, about 45%, was not different among genotypes.

The morphology characteristics (Table 2) showed that purebred animals had longer leg length (P<0.001) and longer chest depth (P=0.039) than T×S lambs. On the other hand, Texel crossbred lambs had both longer buttock perimeter (*P*=0.05) and therefore, higher leg compactness index (G/F) (*P*=0.002), and higher OS2 value (*P*=0.016).

With regards to carcass composition (Table 3), the genotype had a highly significant influence (*P*<0.001) on the percentage of muscle, greater in Texel crossbred than in purebred lambs (+45 g kg^{-1}) as opposed to a lower percentage of fat (-50.6 g kg^{-1}). These differences in fat corresponded specially in subcutaneous fat (-33.2 g kg^{-1}) (*P*<0.001).

Meat quality

Differences have been very scarce from the point of view of chemical composition, and inexistent regarding the instrumental meat quality (Table 4), with normal pH, and no differences on meat colour, texture or WHC.

The crossbreeding with Texel (*P*=0.02) has provided a meat with slightly higher protein content (+4 g kg^{-1}) but no differences were observed in the other parameters, except for a tendency in the intramuscular fat (*P*=0.066) with S×S showing more fat than T×S.

There were few differences between the genotypes in the fatty acid profile (Tables 5, 6), with a tendency towards a lower content of monounsaturated fatty acids (MUFA, *P*=0.065) in TxS due to a lower amount of oleic acid in the muscle (*P*≤0.05). Although saturated (SFA) and polyunsaturated (PUFA) fatty acids were similar in both genotypes, the ratio PUFA/SFA was higher in T×S (0.44) than in S×S (0.33).

No significant differences were found between genotypes for overall acceptability, flavour acceptability and tenderness acceptability (Table 7), in the hall study, nor in the study of acceptability by cooks in the home study. However, there were significant differences between the genotypes for the study of acceptability in the home test by consumers, reporting more

(+0.40 points) flavour acceptability (*P*≤0.05) and more (+0.54 points) juiciness acceptability (*P*≤0.01) in purebred than in Texel crossbred lambs. Nevertheless, both genotypes obtained high values.

There were significant differences (*P*≤0.05) when home consumers compared the current samples with previously experienced roasted lambs. Samples from both genotypes were evaluated positively above the average value (3.5) getting purebred lambs 0.32 points more than crossbred lambs.

DISCUSSION

Productive traits

Texel crossbred lambs had higher birth (BW) and slaughter weight (SW) and growth (ADG), which are typical traits from meat purpose breeds, as Texel. The difference of weight between the genetic groups increased at slaughter. This may be explained by the higher ADG for T×S. Data found in the present work corroborate those related for other authors who observed differences on the BW of Texel×Santa Inês *versus* Santa Inês purebred (+ 0.82 kg more for Texel crossbreed lambs),[9] or in ADG of Texel×Pantaneiro *versus* Pantaneiro purebred and Santa Inês×Pantaneiro, 21 and 18% higher, respectively.[30]

With regards to sex, for the SW and ADG variables, males exhibited significantly better results than females in agreement with a study with Texel crossbred lambs.[31] TxS showed better performance during the fattening period corresponding to a better feed conversion index and higher economical return than SxS genotype.

Carcass quality

An improvement in Texel crossbred lambs, with more conformation and less fatness scores, and a better butchery morphology is consistent with previous studies.[32,33]

The similar dressing percentage among the different genotypes can be attributed to the fact that all animals were chosen with similar weight and age. This low percentage could be due to the use of a very fibrous food, such as the cereal straw typically used in Spain *ad libitum* as a fibre source, that could develop more quickly the digestive system. This system is not part of the carcass and is sold separately. Therefore, carcass yield would decrease. Also, a short fast period could increase the repercussion of the digestive system.

Purebred animals had longer leg length and longer chest depth than T×S lambs, which are characteristic of rustic breeds, in comparison with Texel crossbred lambs which had both longer buttock perimeter and therefore, higher leg compactness index (G/F), and better conformation with leaner carcasses,[30] variables which show a typical traits of specialized meat-type breeds, and higher OS2 value, in agreement with other studies.[34,35,36]

Meat quality

The results obtained in meat quality did not show important differences associated to the genotype.[37,38] In our work, T×S lambs showed only a slightly higher protein content. On the other hand, S×S show more visible fat than T×S, but was only a tendency in the intramuscular fat, as it could be expected in unimproved breeds, especially when they are slaughtered at the same age.[39] The rate of lipid deposition of the different depots is different, and subcutaneous or intermuscular fat are more precocious than intramuscular fat. The data of intramuscular fat in the current study are similar to those previously found in the crossbred between Texel×Scottish Blackface versus the Scottish Blackface purebred,[40] with a reduction from 3.28% to 2.52%.

The pH obtained in both genotypes suggest that all animals had the same non stress susceptibility.[41,42] Similar pH in lambs were found in Texel×Corriedale crossbred.[43] Also minimal differences among breeds have been reported by other authors.[44,45] The lack of differences in pH might partially explain the lack of differences in colour and water holding capacity, especially because the production conditions were identical for both genotypes. In fact, data found on meat colour were similar (L*=42.3; a*=7.12) to others on Segureña breed for similar weight and handling.[46] Nevertheless, some studies found higher lightness and lower redness in Texel×Santa Inês.[47] In any case, values are normal for young lambs (72 days) fed on concentrates.

In agreement with some authors who analyzed different genotypes,[48,49,50] no differences in WHC were reported. Nevertheless, our results are greater for thawing losses than those obtained who using an industrial freezing method of which minimizes losses,[51] but for cooking losses were similar to those reported in Texel.[50,51]

With regards to shear force, a result of less than 3 kg was reported to be desirable by consumers,[52] and both genotypes from the current study averaged less than 3 kg. Both set of animals were young, and samples were aged four days which might have influenced on these results.[53,54] Similar data were obtained on Texel×Corriedale crossbred lambs.[43] However, others authors have reported that Texel crossbred lambs were more tender.[47]

The composition of intramuscular fat is different to that of visible depots, since intramuscular fat has more phospholipids and polyunsaturated fatty acids that are incorporated into the membranes.[55] Phospholipid composition depends greatly on the feed composition. [55] Since both genotypes had access to the same concentrate, no differences have been found in *n*-6/*n*-3 PUFA composition, that showed a characteristic high content in *n*-6 PUFA due to the high content of cereals in the feed. However, the rate PUFA/SFA was higher in TxS coincidentally with the higher muscle (Table 3) and protein content (Table 4), corresponding to a meaty breed. Texel is less precocious than Segureña and, therefore, showed less intramuscular fat at a similar age. The higher fatness in SxS was mainly due to a significant higher oleic acid incorporation in the muscle.

With regards to consumer analysis significant differences were not found between breeds except for the study of acceptability in the home test by consumers, reporting more flavour acceptability and more juiciness acceptability in purebred than in Texel crossbred lambs. Some authors reported that flavour was related with carcass fatness, intramuscular fat content or fatty acid profile.[56,57,58] The differences in our study about fatness might have been related with the higher score on flavour acceptability for purebred lambs, especially because in the home test the whole cut, with intermuscular and subcutaneous fat, was cooked. Purebred lambs showed higher fat content, being parameters such as flavour and tenderness fat dependents. Sensory differences between the crossbred of Texel×Scottish Blackface and the Scottish Blackface purebred were found, with higher scores for acceptability in purebred animals, attributed to a higher intramuscular fat of the Scottish Blackface.[40] On the other hand, tenderness acceptability did not show differences between genotypes, as expected because there were not significant differences for WBSF.[52] Also, these authors reported that intramuscular fat content and WHC might be associated with juiciness acceptability, but in our work, there were not significant differences on these parameters.

CONCLUSION

The crossbreeding between Texel males and Segureña ewes can be a useful tool under certain conditions in the production of lamb meat and, consequently, a way to increase the profitability of the farms, by improving performances in crossbred animals, such as bigger birth and slaughter weights due to an increase in average daily gain. The crossbred with Texel also improves morphology, decreasing visual fatness.

With regards to meat quality, the differences have been very scarce from the point of view of sensory quality, and inexistent regarding the instrumental meat quality. However, the crossbreeding with Texel has provided a meat slighter with more protein and less oleic acid content.

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REFERENCES

1 MAPAMA.gob.es [homepage on the internet]. Spanish Ministry of Agriculture and Fishing, Food and Environment, official statistics. [2016 Nov 11]. Available from: http://www.mapama.gob.es/es/estadistica/temas/estadisticas-agrarias/ganaderia/

2 Juárez M, Alcalde MJ, Horcada A and Molina A. 2008. Southern Spain lamb types discrimination by using visible spectroscopy and basic physicochemical traits. Meat Sci. 80: 1249-1253.

3 Ripoll R, Joy M and Bernués A. 2014. Role of self-sufficiency, productivity and diversification on the economic sustainability of farming systems with autochthonous sheep breeds in less favoured areas in shouthern Europe. Animal. 8(8): 1229-1237.

4 Sañudo C, Sanchez A and Alfonso M. 1998. Small ruminant production systems and factors affecting lamb meat quality. Meat Sci. 49: 29-64.

5 D'Alessandro A, Maiorano G, Ragni M, Casamassima D, Marsico G and Martemucci G. 2013. Effects of age and season of slaughter on meat production of light lambs: Carcass characteristics and meat quality of Leccese breed. Small Rumin. Res. 114: 97-104.

6 Neto A, de Oliveira S, Faco O and Lobo R. 2010. Additive and non-additive genetic effects on growth, reproductive and maternal traits in sheep of Santa Ines, Brazilian Somali, Dorper and Poll Dorset breeds. Rev. Bras. Zoo. 39: 1943-1951.

7 McManus CM, Paiva SP and Araújo RO. 2010. Genetics and breeding of sheep in Brazil. Rev. Bras. Zoo. 39: 236-246.

8 Esteban C (ed). 2003. Razas ganaderas españolas. II. Ovinas, 1st edn. Madrid: MAPA.

9 Springerplus.com [homepage on the internet]. Da Silva AF, McManus C, Paim TP, Dallago BS, Esteves GI, Louvandini H *et al.* Production traits in F1 and F2 crosses with naturalized hair breed Santa Inês ewes. [2014 Jun 15]. Available from: http://www.springerplus.com/content/3/1/66.

10 Furusho-Garcia IF, Costa TI, Almeida AK, Pereira IG, Alvarenga FA and Lima NL. 2010. Performance and carcass characteristics of Santa Inês pure lambs and crosses with Dorper e Texel at different management systems. Rev. Bras. Zoo. 39(6): 1313-1321.

11 García I, Perez J, Pereira I, Costa T and Martins M. 2009. Allometric study on carcass tissues from purebred Santa Inês lambs or crossbred with Texel, Ile de France and Bergamacia. Rev. Bras. Zoo. 38: 539-546.

12 Paim TP, Silva AF, Martins RF, Borges BO, Lima PM, Cardoso CC *et al*. 2013. Performance, survivability and carcass traits of crossbred lambs from five paternal breeds with local hair breed Santa Inês ewes. Small Rumin. Res. 112: 28-34.

13 Villarroel A, Lima L, De Oliveira S and Fernandes A. 2006. Weight gain and carcass traits of Texel and Santa Inês crossbred lambs in a semiintensive husbandry system. Ciência e Agrotec. 30: 971-976.

14 Johnson PL, McEwan JC, Dodds KG, Purchas RW and Blair HT. 2005. Meat quality traits were unaffected by a quantitative trait locus affecting leg composition traits in Texel sheep. J. Anim. Sci. 83:2729-2735

15 Colomer F, Morand-Fehr R, Kirton AH, Delfa R, and Sierra I (eds). 1988. Métodos normalizados para el estudio de los caracteres cuantitativos y cualitativos de las canales caprinas y ovinas, Vol 17. Madrid: Cuadernos INIA.

16 Publications.europa.eu [homepage on the internet]. COUNCIL REGULATION (EEC) No 2137/92 of 23 July 1992 concerning the Community scale for the classification of carcases of ovine animals and determining the Community standard quality of fresh

or chilled sheep carcases and extending Regulation (EEC) No 338/91. [Published 2004 May 01]. Available from: https://publications.europa.eu/en/home.

17 Ruiz de Huidobro F, Miguel E, Cañeque V and Velasco S. 2005. Conformación, engrasamiento y sistemas de clasificación de la canal ovina. In: Cañeque V and Sañudo C (eds). Estandarización de las metodologías para evaluar la calidad del producto (animal vivo, canal, carne y grasa) en los rumiantes, Serie ganadera 3, 1st edn. Madrid: Monografías INIA; 143-169.

18 Guía E and Cañeque V (eds). 1992. Crecimiento y desarrollo del cordero Talaverano. Evolución de las características de su canal. Serie. Área de Producción Animal. Toledo: Consejería de Agricultura de la Junta de Comunidades de Castilla-La Mancha.

19 CIE-Commission International du l´Eclairage Colorimetry. 1986. 15.2, 2nd edn. Vienna: Publication CIE.

20 Bligh EG and Dyer WJ. 1959. A rapid method of total lipid extraction and purification. Can. J. Biochem. Phys. 37: 911-914.

21 Carrilho MC, López M and Campo MM. 2009. Effect of the fattening diet in the development of the fatty acid profile in rabbits from weaning. Meat Sci. 83: 85-95.

22 ISO 1442. 1997. International standards meat and meat products - Determination of moisture content. International Organization for Standardization: Geneva, Switzerland.

23 ISO 1443. 1973. International standards meat and meat products - Determination of total fat content. International Organization for Standardization: Geneva, Switzerland.

24 ISO 937. 1978. International standards meat and meat products - Determination of nitrogen content. International Organization for Standardization: Geneva, Switzerland.

25 ISO 936. 1998. International standards meat and meat products - Determination of total ash. International Organization for Standardization: Geneva, Switzerland.

26 Sañudo C, Nute GR, Campo MM, Maria G, Baker A and Sierra I. 1998. Assessment of commercial lamb meat quality by British and Spanish taste panels. Meat Sci. 48: 91-100.

27 Guerrero L. 1999. Estudios de consumidores: análisis de los errores más habituales. In: Almeida TC Hough G Damasio MH and Da Silva MA (eds.). Sao Paulo: Avances En Análisis Sensorial; 121-129.

28 MacFie HJ and Thomson DM. 1988. Preference mapping and multidimensional scaling. In: Piggott JR (ed). Sensory analysis of foods. London: Elsevier Applied Science.

29 Oviespana.com [homepage on the internet]. Spanish Sheep Sector, national ovine reference price. [2014 Jun 18]. Available from: https://www.oviespana.com/informacion-de-ovino/cotizaciones-de-mercado/precios-nacionales-de-productos-de-ovino/lonja-de-albacete/lonja-agropecuaria-de-albacete-cotizaciones-de-ovino-semana-25-18-06-2014.

30 Vargas FM, Martins CF, Pinto GS, Ferreira MB, Ricardo HA, Leão AG *et al*. 2014. The effect of sex and genotype on growth performance, feed efficiency, and carcass traits of local sheep group Pantaneiro and Texel or Santa Inês crossbred finished on feedlot. Trop. Anim. Health Prod. 46: 869-875.

31 Correa MP, Cardoso MT, Castanheira M., Landi A.V, Dallago BS, Louvandini H *et al*. 2012. Heat tolerance in three genetic groups of lambs in central Brazil. Small Rumin. Res. 104: 70-77.

32 Ellis M, Webster GM, Merrell BG and Brown I. 1997. The influence of terminal sire breed on carcass composition and eating quality of crossbred lambs. Animal Sci. 64: 77-86.

33 Sañudo C (ed). 2011. Atlas Mundial de Etnología Zootécnica. Zaragoza: Editorial Servet.

34 Vargas FM, Martins CF, Pinto GS, Ferreira MB, Ricardo HA, Leonardo AP *et al.* 2015. Carcass measurements, non carcass components and cut production of local Brazilian Pantaneiro sheep and crossbreeds of Texel and Santa Inês with Pantaneiro. Small Rumin. Res. 124: 55-62.

35 Galvani DB, Pires CC, Wommer TP, Oliveira F, Bolzan AM and François P. 2008. Carcass traits of feedlot crossbred lambs slaughtered at different live weights. Ciência Rural. 38(6): 1711-1717.

36 Jones HE, Lewis RM, Young MJ, Wolf BT and Warkup CC. 2002. Changes in muscularity with growth and its relationship with other carcass traits in three terminal sire breeds of sheep. Animal Sci. 74: 265-275.

37 Sañudo C, Delfa R, González C, Alcalde MJ, Casas M, Santolaria M *et al.* 1992. Calidad de la carne del ternasco, 88A. Zaragoza: Información Técnica Económica Agraria; 221-227

38 Hopkins DL and Fogarty NM. 1998. Diverse lamb genotype-2. Meat pH, colour and tenderness. Meat Sci. 49: 477-488.

39 Faria PB, Bressan MC, Vieira JO, Vicente-Neto J, Ferrão SP, Rosa FC *et al*. 2012. Meat quality and lipid profiles in crossbred lambs finished on clover-rich pastures. Meat Sci. 90: 733-738.

40 Gkarane V, Allen P, Gravador RS, Diskin MG, Claffey NA, Fahey AG *et al.* 2017. Effect of castration and age at slaughter on sensory perception of lamb meat. Small Rumin. Res. 157: 65-74.

41 Garrido MD, Bañón S and Álvarez D. 2005. Medida del pH. In: Cañeque V and Sañudo C (eds.). Estandarización de las metodologías para evaluar la calidad del producto (animal vivo, canal, carne y grasa) en los rumiantes, Serie ganadera 3, 1st edn. Madrid: Monografías INIA; 206-215.

42 Parvar R, Ghoorchia T, Kashfia H, and Parvarb K. 2018. Effect of Ferulago angulata (Chavil) essential oil supplementation on lamb growth performance and meat quality characteristics. Small Rumin. Res. 167: 48-54.

43 Bonacina MS, Osório MT, Osório JC, Corrêa GF and Hashimoto JH. 2011. Influência do sexo e do sistema de terminação de cordeiros Texel×Corriedale na qualidade da carcaça e da carne. Rev Bras. Zoo. 40(6): 1242-1249.

44 Hopkins DL, Stanley DF, Martin LC, Toohey ES and Gilmour AR. 2007. Genotype and age effects on sheep meat production 3. Meat quality. Aus. J. Expe. Agri. 47: 1155-1164.

45 Jandasek J, Milerski M and Lichovnikova M. 2014. Effect of sire breed on physico-chemical and sensory characteristics of lamb meat. Meat Sci. 96: 88-93.

46 Juárez M, Alcalde MJ, Horcada A and Molina A. 2008. Southern Spain lamb types discrimination by using visible spectroscopy and basic physicochemical traits. Meat Sci. 80: 1249-1253.

47 Bonagurio S, Pérez JR, Furusho-Garcia IF, Bressan MC and Lemos AL. 2003. Qualidade da Carne de Cordeiros Santa Inês Puros e Mestiços com Texel Abatidos com Diferentes Pesos. Rev. Bras. Zoo. 32(6): 1981-1991.

48 Hoffman LC, Muller M, Cloete WP and Schmidt D. 2003. Comparison of six crossbred lamb types sensory, physical and nutritional meat quality characteristics. Meat Sci. 65: 1265-1274.

49 Safari E, Fogarty NM, Ferrier GR, Hopkins LD and Gilmour A. 2001. Diverse lamb genotypes. 3. Eating quality and the relationship between its objective measurement and sensory assessment. Meat Sci. 57: 153-159.

50 Mousel MR, Notter DR, Leeds TD, Zerby HN, Moeller SJ, Taylor JB *et al*. 2014. Evaluation of Columbia, USMARC-Composite, Suffolk, and Texel rams as terminal sires in an extensive rangeland production system: VIII. Quality measures of lamb longissimus dorsi. J. Anim. Sci . 92: 2861-2868.

51 Muela E, Sañudo C, Campo MM, Clucel C, Nader C, Oliván A *et al*. 2010. Influencia del sistema de congelación en la calidad de la carne de cordero. I. Análisis Instrumental. Eurocarne. 183: 56-62.

52 Hopkins DL, Hegarty RS, Walker PJ and Pethick DW. 2006. Relationship between animal age, intramuscular fat, cooking loss, pH, shear force and eating quality of aged meat from sheep. Aus. J. Expe. Agri. 46:879-884.

53 Martinez-Cerezo S, Sañudo C, Panea B, Medel I, Delfa R, Sierra I *et al.* 2005. Breed, slaughter weight and ageing time effects on physico-chemical characteristics of lamb meat. Meat Sci. 69: 325-333.

54 Bianchi G, Betancur O and Sañudo C. 2006. La maduración de la carne de cordero como una herramienta para mejorar su terneza y calidad sensorial. Rev. Arg. Prod. Anim. 26: 39-55.

55 Wood JD, Richardson RI, Nute GR, Fisher AV, Campo MM, Kasapidou E *et al*. 2004. Effects of fatty acids on meat quality: a review. Meat Sci. 66: 21-32.

56 Fisher AV, Enser M, Richardson RI, Wood JD, Nute GR, Kurt E *et al.* 2000. Fatty acid composition and eating quality of lamb types derived from four diverse breed x production systems. Meat Sci. 55: 141-147.

57 Sañudo C, Alfonso M, Sánchez A, Delfa R and Teixeira A. 2000. Carcass and meat quality in light lambs from different fat clases in the EU carcass classification system. Meat Sci. 56: 89-94.

58 Sañudo C, Enser ME, Campo MM, Nute GR, María G, Sierra I *et al*. 2000. Fatty acid composition and sensory characteristics of lamb carcasses from Britain and Spain. Meat Sci. 54: 339-346.

Table 1.

Effect of genotype (G), sex (S) and number of lambs born alive (NL) on productive traits (mean ± standard deviation)

Productive traits	Effects						P						
	Genotype		Sex		Number of lambs		*G*	*S*	*NL*	*GxS*	*GxNL*	*SxNL*	*GxSxNL*
	T×S	S×S	M	F	S	T							
n	68	68	72	64	39	97							
Birth weight (kg)	5.1 ±1.1	4.1 ±0.7	4.8 ±1.0	4.5 ±1.0	5.3 ±1.2	4.3 ±0.8	<0.001	0.323	<0.001	0.376	<0.001	0.333	0.259
Slaughter weight (kg)	24.9 ±5.6	21.9 ±4.3	24.7 ±5.1	21.9 ±5.0	26.5 ±5.3	22.1 ±4.6	<0.001	0.005	<0.001	0.458	0.197	0.764	0.735
Slaughter age (d)	72.2 ±5.4	72.4 ±5.9	73.0 ±5.2	71.5 ±6.0	72.4 ±5.8	72.2 ±5.6	0.376	0.439	0.821	0.986	0.169	0.121	0.704
ADG (g)	271.9 ±60.0	243.1 ±45.9	271.3 ±55.9	241.8 ±50.3	290.7 ±57.1	244.1 ±48.5	0.002	0.002	<0.001	0.475	0.252	0.747	0.900

T×S= Texel×Segureña; S×S= Segureña×Segureña; M=male; F=female: S=single; T=twin; ADG; Average Daily Gain from birth to slaughter

Table 2.

Effect of genotype on carcass quality (mean ± standard deviation)

	T×S	**S×S**	***P***
n	10	10	
Cold Carcass Weight (kg)	11.00 ±0.57	11.34 ±0.63	0.230
Carcass Yield (kg)	45.3 ±1.6	45.4 ±1.5	0.865
Conformation[1]	3.50 ±0.47	2.85 ±0.53	0.010
Fatness score[2]	2.25 ±0.54	3.45 ±0.28	<0.001
External carcass length (cm)	47.40 ±1.26	50.90 ±1.31	<0.001
Leg length (cm)	25.95 ±0.81	27.53 ±0.93	0.001
Buttock width (cm)	18.44 ±0.53	18.20 ±0.58	0.345
Buttock perimeter (cm)	54.22 ±1.04	53.08 ±1.37	0.050
Chest depth (cm)	21.45 ±0.69	22.32 ±1.03	0.039
OS1 (cm)	2.48 ±0.09	2.41 ±0.13	0.157
OS2 (cm)	3.66 ±0.09	3.54 ±0.11	0.016
Carcass compactness index (kg/cm) [3]	0.23 ±0.01	0.22 ±0.01	0.130
Leg compactness index (cm/cm) [4]	0.71 ±0.03	0.66 ±0.02	0.002

T×S= Texel×Segureña; S×S= Segureña×Segureña; [1] Range: 1, poor-5, excellent; [2] Range: 1, low-4, important; [3] Cold Carcass Weight/External carcass length; [4] Buttock width/Leg length;

Table 3.

Effect of genotype on tissue composition (g kg^{-1}) from the dissection of the shoulder (mean ± standard deviation)

	T×S	**S×S**	***P***
n	10	10	
Muscle	661 ± 18	616 ± 18	<0.001
Preescapular fat	15.7 ± 3.3	24.8 ± 3.4	<0.001
Subcutaneus fat	49.5 ± 12.2	82.7 ± 13.5	<0.001
Intermuscular fat	52.8 ± 8.8	61.2 ± 11.1	0.076
Total fat	118.1 ± 15.5	168.7 ± 19.9	<0.001
Bone	212.4 ± 8.9	205.2 ± 8.2	0.078
Others	9.02 ± 2.82	10.6 ± 3.45	0.274
Muscle/bone ratio	3.12 ± 0.19	3.00 ± 0.19	0.140

T×S= Texel×Segureña; S×S= Segureña×Segureña;

Table 4.

Effect of genotype on meat quality (mean ± standard deviation)

Traits	**TxS**	**S×S**	***P***
n	10	10	
pH and Chemical			
pH	5.39 ± 0.05	5.34 ± 0.04	0.042
Moisture (g kg^{-1})	764.6 ± 8.0	761.6 ± 8.2	0.402
Protein (g kg^{-1})	197.7 ± 6.5	193.7 ± 5.1	0.020
Fat (g kg^{-1})	26.8 ± 9.9	33.7 ± 9.8	0.066
Ashes (g kg^{-1})	10.9 ± 1.4	10.9 ± 1.2	0.555
Meat colour			
L*	42.33 ± 2.94	41.85 ± 1.51	0.918
a*	8.32 ± 2.48	8.97 ± 1.04	0.583
b*	14.26 ± 1.03	13.90 ± 1.15	0.380
C*	16.62 ± 1.80	16.55 ± 1.43	0.747
Hº	60.26 ± 7.16	57.20 ± 2.04	0.289
Texture			
Shear force (kg)	2.45 ± 0.75	2.73 ± 0.52	0.325
Water holding capacity			
Thawing losses (%)	9.66 ± 1.86	9.21 ± 1.22	0.592
Cooking losses (%)	18.60 ± 3.39	15.32 ± 4.28	0.121
Total water losses (%)	27.06 ± 3.93	23.68 ± 4.46	0.139

T×S= Texel×Segureña; S×S= Segureña×Segureña;

Table 5.

Effect of genotype on fatty acid composition (mg kg^{-1} of muscle) (mean ± standard deviation)

Fatty Acids	**T×S**	**S×S**	***P***
n	10	10	
SFA			
C8:0	52.6 ± 51.2	56.5 ± 41.8	0.856
C10:0	30.3 ± 12.3	31.7 ± 7.8	0.761
C12:0	56.1 ± 34.6	45.5 ± 16.2	0.396
C14:0	617 ± 260	737 ± 221	0.281
C15:0	78.1 ± 26.7	77.4 ± 19.8	0.953
C16:0	5009 ± 1137	5559 ± 1232	0.314
C17:0	217 ± 55	239 ± 51	0.364
C18:0	2859 ± 443	3290 ± 691	0.114
C20:0	25.5 ± 4.4	25.5 ± 6.1	0.982
C22:0	82.4 ± 25.2	58.9 ± 13.7	0.018
MUFA			
C14:1	20.9 ± 10.7	27.0 ± 11.3	0.229
C16:1	301 ± 106	387 ± 113	0.097
C17:1	102 ± 30.7	122 ± 29.4	0.159
tC18:1 *n*-9	1159 ± 471	1250 ± 369	0.638
C18:1 *n*-9	6539 ± 1405	8316 ± 1803	0.024
tC18:1 *n*-11	401 ± 140	335 ± 128	0.287
C20:1	40.2 ± 11.3	37.7 ± 9.9	0.604
C22:1 *n*-9	3.46 ± 1.82	3.12 ± 1.82	0.682
PUFA			
tC18:2 *n*-6	43.7 ± 11.2	58.6 ± 14.3	0.018
C18:2 *n*-6	2367 ± 623	1974 ± 660	0.188
C18:3 *n*-6	25.0 ± 7.5	21.6 ± 4.8	0.234
C18:3 *n*-3	60.8 ± 15.5	57.5 ± 16.5	0.655
C20:2 *n*-3	15.6 ± 5.28	12.0 ± 3.59	0.094
CLA	135 ± 20.5	206 ± 86.1	0.021
C20:2 *n*-6	25.7 ± 9.3	21.9 ± 7.2	0.322
C20:3 *n*-3	11.1 ± 12.4	4.77 ± 1.81	0.125
C20:3 *n*-6	66.2 ± 20.6	50.7 ± 17.8	0.088
C20:4 *n*-6	1026 ± 372	800 ± 264	0.135
C20:5 *n*-3	118 ± 40.9	87.0 ± 31.5	0.073
C22:2 *n*-6	3.09 ± 1.61	2.38 ± 1.17	0.268
C22:6 *n*-3	30.7 ± 14.3	28.1 ± 11.4	0.650

T×S= Texel×Segureña; S×S= Segureña×Segureña; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsatutated fatty acids; CLA: total conjugated linoleic acid

Table 6.

Effect of genotype on the composition of groups of fatty acids (mg kg^{-1} of muscle) (mean ± standard deviation)

	T×S	**S×S**	***P***
n	10	10	
SFA	9027 ± 1771	10120 ± 2134	0.229
MUFA	8567 ± 2079	10477 ± 2259	0.065
PUFA	3928 ± 1069	3325 ± 1053	0.220
***n*-3 PUFA**	3557 ± 1002	2930 ± 948	0.168
***n*-6 PUFA**	236 ± 72.7	189 ± 59.8	0.132
PUFA/SFA	0.44 ± 0.13	0.33 ± 0.07	0.024
***n*-6/*n*-3**	15.32 ± 1.68	15.47 ± 0.74	0.796

T×S= Texel×Segureña; S×S= Segureña×Segureña; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids

Table 7.

Effect of genotype on sensory acceptability (mean ± standard deviation)

Traits	T×S	S×S	*P*
Hall test [1]			
n	100	100	
Tenderness acceptability	7.11 ±1.48	6.84 ±1.87	0.171
Flavour acceptability	7.42 ±1.30	7.28 ±1.20	0.369
Overall acceptability	7.27 ±1.26	7.05 ±1.31	0.169
Home test – Cook appraisal [2]			
n	29	29	
Colour before cooking	8.31 ±1.23	8.43 ±1.45	0.600
Amount of fat	7.23 ±1.72	7.49 ±1.69	0.442
Smell during cooked	8.56 ±1.24	8.29 ±1.53	0.295
Aspect after cooking	8.68 ±1.31	8.69 ±1.42	0.977
Home test [2]			
n	114	114	
Tenderness acceptability	7.87 ±1.67	8.13 ±1.52	0.206
Flavour acceptability	7.90 ±1.54	8.30 ±1.35	0.038
Juiciness acceptability	7.60 ±1.81	8.14 ±1.49	0.010
Overall acceptability	8.12 ±1.45	8.15 ±1.46	0.847
n	109	109	
Compared with other roasts [3]	5.19 ±1.35	5.51 ±1.17	0.040

T×S= Texel×Segureña; S×S= Segureña×Segureña; [1] Range 1, dislike very much -9, like very much; [2] Range 0, dislike extremely-10, like extremely; [3] Range 1, significantly worse-7, significantly better