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The capability of alfalfa grazing- and concentrate-based feeding systems to produce homogeneous carcass quality in light lambs over time

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Abstract

The effects of grazing on the carcasses and meat of light lambs are unclear, mainly due to variations in weather conditions and pasture production, which affect the growth of lambs and the quality of their carcasses. The aim of this study was to evaluate the effect of feeding systems, which varied in intensification due to the use of concentrate, on the growth and carcass traits of light lambs and the capability of these feeding systems to produce homogeneous lamb carcasses over the course of several years. The average daily weight gain of grazing lambs, but not lambs fed indoors was affected over years. The colour of the *Rectus abdominis* muscle and the amount of fat were more variable in grazing lambs (from 2.7 to 6.3) than indoor lambs (from 4.5 to 5.1). Grazing feeding systems without concentrate supplementation are more dependent than indoor feeding systems on the year. This climatologic dependence could lead to slaughter of older grazing lambs (77 days) to achieve the target slaughter weight when temperatures are low or the rainfall great. All feeding systems evaluated produced light lambs carcasses with a conformation score from O to R$^-$ that is required by the market. Even the potential change in fat colour found in both grazing treatments was not enough to change the subjective evaluation of fat colour.

Additional key words: joint; classification; subjective; fat depot; zoometric measurement; lucerne,

Introduction

In most of Southern Europe, light lamb (18-24 kg live-weight, younger than 90 days old) meat producers keep lambs indoors, where they are fed concentrate and receive dams' milk until weaning (approximately 45 days old) and thereafter are fed only concentrate. Lamb's meat from these production systems is characterised by a pale pink colour and slight to average fatness, following the European Community scale for classification of carcasses of light lambs (EEC, 1992). The increasing demand for safe meat products, the cost of purchased feed (as concentrate) and the European Union (EU) Common Agricultural Policy are increasing market interest in pasture-based production systems, which also produce more healthy meat (Enser *et al.*, 1998; Demirel *et al.*, 2006; Scollan *et al.*, 2006). Grass-based systems may be a good alternative to indoor lamb production systems because the use natural resources and provide the meat desired by consumers (Grunert *et al.*, 2004). Additionally, forage-based sheep production systems have lower production costs than indoor systems (Woodward & Fernández, 1999). It has been demonstrated that light lambs can be raised by their dams in mountain pastures during spring (Álvarez-Rodríguez *et al.*, 2007; Joy *et al.*, 2008b; Carrasco *et al.*, 2009c) or in alfalfa pastures during the late spring, summer and early autumn (Álvarez-Rodríguez *et al.*, 2010) with minimal or no detrimental effect on lamb performance. However, the feeding system may modify the growth rate of lambs, which leads to potential changes in the

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Abbreviations used: ADG (average daily gain); CP (crude protein); DM (dry matter); EU (European Union); FS (fatness score); Ind (indoors); KKCF (kidney knob and channel fat); NDF (neutral detergent fiber).

pattern of tissue growth, especially adipose tissue. Grass-fed lambs may provide meat with a low degree of fatness (Priolo *et al.*, 2002b; Carrasco *et al.*, 2009b) and/or yellow fat and red meat colour (Priolo *et al.*, 2002a), which are the main reasons consumers reject this meat. The carcass and meat quality of light lambs in concentrate or grass systems may be different, mainly in their meat and fat colour (Ripoll *et al.*, 2012). However, when these traits were studied in light lambs instead of heavy lambs, differences in muscle and fat colour were barely detectable in subjective appraisals, although there were differences in CIE L*a*b* coordinates (Joy *et al.*, 2008b; Ripoll *et al.*, 2008). Despite these studies, the effects of grazing on the carcasses and meat of light lambs are unclear, mainly due to the variability in grazing systems. The variation in weather conditions, pasture production and animal grazing behaviour (Cacho *et al.*, 1999) affect the growth of lambs and their carcass quality. An analysis of the variability in the data is essential for decision-making (Cacho *et al.*, 1999) with the variability between years being especially important (Villalba *et al.*, 2010).

The aim of this study was to evaluate the effect of the feeding system, which varied in intensification due to the use of concentrate, on the growth and carcass traits of Rasa Aragonesa light lambs and the capability of these feeding systems to produce homogeneous lamb carcasses over years.

Material and methods

Animal management and diets

This experiment was conducted at the experimental facilities of a research centre in Zaragoza (north-eastern Spain, 41°62'N, 0°53'W, 210 m a.s.l.) over 3 consecutive years (2004, 2005 and 2006), referred to as year 1, year 2 and year 3. The pastureland in this experiment used an irrigation system, and water was always available for the alfalfa (*Medicago sativa* L., var. Aragón. The average weather conditions are shown in Table 1.

Table 1. Monthly average temperature and rainfall during the experimental period of the three studied years.

	April	May	June
Year 1 (2004)	12.2 ± 1.56°C (51.8 mm)	19.7 ± 3.19°C (18.2 mm)	22.9 ± 2.07°C (14.2 mm)
Year 2 (2005)	14.2 ± 3.42°C (9.6 mm)	18.8 ± 1.83°C (56.2 mm)	24.3 ± 1.45°C (46 mm)
Year 3 (2006)	14.1 ± 1.06°C (33.6 mm)	18.8 ± 1.99°C (10.2 mm)	21.5 ± 2.34°C (29.8 mm)

Ewes used in all three study years belonged to the same flock at the research center. The experimental trial involved 118 single, spring-born, male Rasa Aragonesa lambs. Ewes were mated during the early autumn (late September to mid-October) to have a concentrated spring-lambing period. One week prior to lambing, ewes were housed in barns and received an *ad libitum* total mixed diet with a forage:concentrate ratio of 40:60 (Table 2). After birth, lambs were kept with their dams indoors for a week to ensure maternal bonding. After this time, the pairs were randomly allocated to one treatment. Lambing dates, parity, body condition scores and live-weights of ewes and lambs were taken into account to balance the groups. The average live weight and body condition score of ewes at lambing were 57.6 ± 2.44 kg and 3.34 ± 0.1, respectively. The experimental treatments were as follows:

— *Grazing* (Gr): Ewes and lambs were continuously stocked in alfalfa pasture. No concentrate was available to the dams or lambs. Lambs suckled their mothers and grazed until slaughter at 22-24 kg live-weight (n = 31). No weaning was carried out.

— *Grazing with supplement for lambs* (Gr + S): Management was the same as for Gr, but the lambs also received concentrates *ad libitum* in lamb creep feeders. Lambs suckled their mothers and grazed until slaughter at 22-24 kg of live weight (n = 30). No weaning was carried out.

— *Indoors rationed grazing* (Ind – Gr): This treatment is the most typical livestock system in the area. Ewes grazed alfalfa on six hours a day (08:00 to 14:00 h) without their lambs and then remained indoors, receiving a total mixed ration. Lambs were kept indoors permanently, and fed with ewe's milk and concentrate *ad libitum* until weaning at 50 days old. Lambs had free access to concentrate and barley straw. After weaning, ewes were removed from the trial and lambs were fattened until they reached 22-24 kg live weight (n = 24).

— *Indoors* (Ind): Ewes and lambs were kept indoors permanently with *ad libitum* access to a total mixed ration and lambs were fed ewe's milk and concentrate *ad libitum* until weaning at 50 days old. Thereafter, as with the Ind – Gr treatment, ewes were removed from

Table 2. Feedstuff composition and chemical composition of ewes and lambs diets

Lamb concentrate composition		Total mixed ration		Barley straw
Ingredients (g kg^{-1} on as-fed basis)				
Corn grain	200	Cereal straw	400	—
Barley grain	403	Gluten feed	228	—
Soybean meal, 44%	21	Palm kernel	108	—
Wheat grain	10	Barley	81	—
Soya oil	12	Soybean hulls	60	—
Vegetal powdered serum	25	Citrus pulp	60	—
Vitamin and mineral	16	Cotton seeds	34	—
Calcium carbonate	24	Calcium carbonate	10	—
Sodium chloride	5	Sodium chloride	6	—
Ammonium chloride	5	Fatty acids salt	6	—
		Urea	7	—
Chemical composition (g kg^{-1} DM)				
Crude protein	185		120	49
Neutral detergent fiber	190		253	83.5
Metabolic energy (MJ kg^{-1} DM)	13.2		12.2	4.5

MJ: megaJoules; DM: dry matter.

the trial and lambs had free access to concentrate until slaughter at 22-24 kg live weight (*n* = 33). This feeding system was not tested in year 1.

The cultivated pastureland was sown with 25 kg per hectare of alfalfa in spring 2003 in loamy soil. The pastureland was divided into 5 paddocks of 843 m^2 and grazed using a rotational stocking method from April to June. Animals grazed in a paddock for 1 week and returned to the first paddock after 5 weeks with a stocking rate of 16.4 ewes (plus their lambs) per hectare per year. Herbage mass was measured weekly before and after grazing in the paddock using an electric mower to clip the herbage to 3 cm above ground level in 10 quadrats (1 m × 0.25 m) per paddock. The quadrats were the replicates within the paddock. Sward height was measured weekly before animals grazed the paddock, using 20 replicates evenly distributed throughout the paddock with a HFRO stick (Barthram, 1986).

Lamb concentrates, ewe total mixed ration and alfalfa samples were dried at 60°C until a constant weight was achieved and mill-ground. Dry matter and crude protein (CP) were determined according to AOAC (2000) methods. Neutral-detergent fibre (NDF) analysis was carried out following the sequential procedure with an Ankom 200/220 fibre analyser. Neutral-detergent fibre from concentrates was assayed using a heat stable amylase (Van Soest *et al.*, 1991).

The live-weight of lambs was recorded at weekly intervals and the lambs' average daily gain (ADG) was estimated using linear regression of live weight over time.

Slaughter, carcass measurements and muscle sampling procedures

Lambs that reached the target live weight of 22-24 kg every week were slaughtered in the experimental slaughterhouse of the CITA Research Institute at Zaragoza. The slaughter was conducted early in the morning without a fasting period. All procedures were conducted according to the EEC (1986) guidelines on the protection of animals used for experimental and other scientific purposes.

Lambs were weighed immediately before slaughter, hot carcass weights and omental and mesenteric fat weights were recorded. Carcasses were hung by the Achilles tendon and were chilled for 24 h at 4°C in total darkness and then, the cold carcass was weighed. The dressing percentage was calculated as cold carcass weight × 100/slaughter weight and carcass shrinkages was calculated as (hot carcass weight-cold carcass weight) × 100/hot carcass weight.

The conformation was scored using the EUROP system (E = excellent, U = very good, R = good, O = fair and P = poor) and these 5 categories were expanded to 15 points. So, carcasses were graded from 15 (E+) to 1 (P–) (Colomer-Rocher *et al.*, 1988). Fatness degree was carried out following the Community Scale for Classification of Carcasses of Ovine Animals (EEC, 1992) for light carcasses (< 13 kg) with grade values from 1 (1^-, very low) to 12 (4^+, very high) of the scale 1 (low), 2 (slight), 3 (average), 4 (high). Visual characteristics of fat (amount, consistency and color) and meat color were determined according to Colomer-Rocher *et al.* (1988). The values were as follows: amount of kidney knob and channel fat (KKCF) from 1 (very low) to 9 (very high); fat consistency from 1 (very hard) to 9 (very oily); fat colour from 1 (very white) to 9 (intensely yellow); and M. *Rectus abdominis* colour from 1 (very clear pink) to 9 (very dark) within clear pink (C), pink (P) and red (R). These evaluations were made by the same two assessors every year.

Zoometric measurements of carcasses were also recorded: pelvic limb length, carcass internal length, hindquarter perimeter, hindquarter width, chest depth, and maximum carcass width. These measurements were used to calculate the following ratios: pelvic limb compactness (pelvic limb weight/pelvic limb length), chest roundness index (maximum carcass width/chest depth), hindquarter width/pelvic limb length index, hindquarter width/carcass internal length index and carcass compactness (cold carcass weight/carcass internal length) (Colomer-Rocher *et al.*, 1988; Carrasco *et al.*, 2009a).

The tail was removed, the carcass was carefully split longitudinally, and the two halves were weighed. Renal and pelvic fat from the two halves was removed and weighed to determine the contents of kidney knob and channel fat. The left side was cut into six standardised commercial joints following Panea *et al.* (2012): thoracic limb, breast, pelvic limb, neck, anterior-rib, and loin-rib. The joints were weighed and the joint proportions were calculated. The joints were categorised into 1st (anterior-rib, pelvic limb, loin-rib), 2nd (thoracic limb) and 3rd (breast and neck) commercial meat categories.

Statistical analysis

Statistical analyses were performed with SAS v.9.1. The GLM procedure was used for a two-way ANOVA (4 feeding systems × 3 years). A Duncan test was used to compare means. When $p > 0.05$, the differences between the means were not significant. The effect of slaughter weight was tested as a covariate, but not included in the final models because it had no influence on the principal effects. When the effect of year was not significant ($p > 0.05$) only the overall mean was shown. The GLM procedure was also used for a two-way ANOVA (grazing week × year) to analyse alfalfa crude protein and NDF, herbage mass and sward height.

Results

Alfalfa production and characteristics

Alfalfa mass and height throughout the spring stocking are shown in Figs. 1a and 1b. Alfalfa production was between 1,600 and 3,500 kg DM ha^{-1}, with the minimum at the beginning of the grazing period. The sward height was between 29 and 84 cm throughout the spring grazing period.

The crude protein and NDF evolution during the grazing period over the three years are shown in Figs. 1c and 1d. Crude protein (CP) decreased during the first 5 weeks of grazing and then increased for 2 weeks before decreasing throughout the following 5 weeks. As expected, NDF displayed an inverse pattern; as CP content decreased, NDF increased. The effect of year was significant for both parameters, CP ($p < 0.01$) and NDF ($p < 0.05$). Both amount and patterns of CP and NDF were similar in year 1 and 2. However, in year 3, the CP content was lower. It was observed that there was lower NDF content in year 3 than in years 1 and 2.

Animal performance and carcass characteristics

Lamb performance is shown in Table 3. The live weight at birth were not affected by the year or by the feeding system ($p > 0.05$). The ADG from birth to 50 days old (weaning of Ind and Ind-Gr) was only affected by year ($p < 0.001$). Gr and Gr + S had lower ADG in year 1 than year 2.When the ADG from 50 d to slaughter was studied, the effect of year disappeared ($p > 0.05$) and the effect of feeding system became significant ($p < 0.001$). When the ADG measured correspond to the full period (from birth to slaughter),

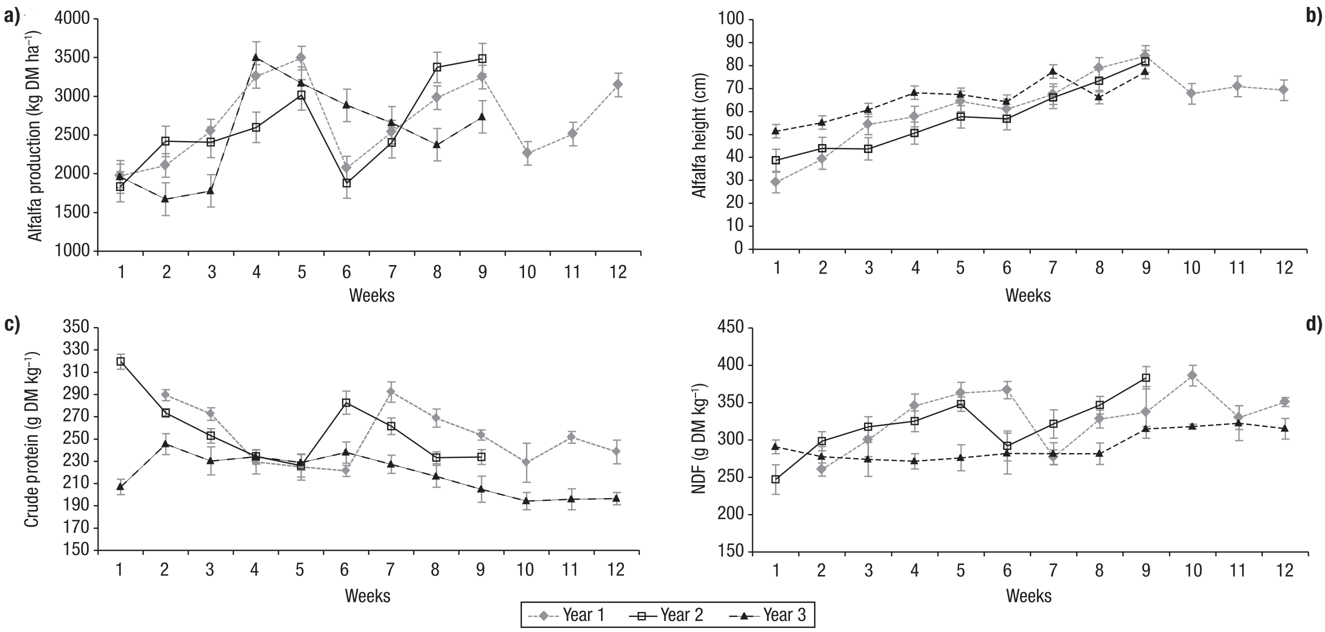

Figure 1. Production (a), height (b), crude protein (c) and neutral detergent fibre (d) of alfalfa from April to June of the three years studied.

Table 3. Effect of feeding system (FS) and year (Y) on growth of light lambs reared under grazing alfalfa (Gr), grazing with supplement (Gr + S), drylot with rationed grazing-dams (Ind – Gr) and drylot with dams fed in confinement (Ind)

	Year	Gr	Gr + S	Ind – Gr	Ind	SE	FS[1]	Y
n	1	7	7	9	—			
	2	13	12	12	13			
	3	11	11	12	11			
Live-weight at birth (kg)	Overall	4.0	3.9	4.1	4.1	0.063	NS	NS
ADG[2] (g d^{-1})								
Born to 50 d old[3]	1	215^x	205^x	279^y	—	5.23	NS	***
	2	299^y	282^y	291^y	267			
	3	251^x	269^y	238^x	227			
50 d old to slaughter	Overall	283^b	337^a	312^a	267^b	4.59	***	NS
Born-slaughter	Overall	278^{ab}	292^a	266^b	271^{ab}	4.59	***	NS
Age at slaughter (d)	1	77^x	72	76	—	1.6	NS	**
	2	67^y	65	72	71			
	3	71^{xy}	70	70	75			
Slaughter weight (kg)	1	22.9^x	22.7	22.7	—	0.15	NS	*
	2	23.7^y	23.4	23.1	22.9			
	3	22.8^x	23.4	22.5	22.9			

[1] FS: feeding system. [2] ADG: average daily gain. [3] Ind-GrE and Ind lambs were weaned at 50 d old. † Interactions were not significant ($p > 0.05$). Values in rows with different superscripts (^{a,b}) differ significantly ($p < 0.05$). Values in columns with different superscripts (^{x,y}) differ significantly ($p < 0.05$). SE: standard error. NS: no significant, $p > 0.05$; * $p \le 0.05$; ** $p \le 0.01$; *** $p \le 0.001$.

there was an effect of feeding system ($p < 0.001$), and the Gr + S treatment showed the greatest ADG, whereas the Ind – Gr treatment had the lowest ADG.

Slaughter weight and age were affected by the year ($p < 0.05$) but not by the feeding system ($p > 0.05$). Based on the greatest ADG from birth to weaning, year

Table 4. Effect of feeding system (FS) and year (Y) on light lambs carcass characteristics reared under grazing alfalfa (Gr), grazing with supplement (Gr+S), drylot lambs with rationed grazing-dams (Ind-Gr) and drylot lambs with dams fed in confinement (Ind)

	Year	Gr	Gr+S	Ind-Gr	Ind	SE	FS[1]	Y	FS × Y
Hot carcass weight (kg)	1	11.1^{x}	11.4	10.9^{x}	—	0.12	***	***	ns
	2	12.3^{ay}	12.0^{ab}	11.6^{by}	11.5^{b}				
	3	11.4^{x}	11.9	11.0^{x}	11.1				
Cold carcass weight (kg)	1	10.7^{x}	11.1	10.6^{x}	—	0.11	***	***	ns
	2	12.0^{ay}	11.7^{ab}	11.3^{by}	11.2^{b}				
	3	11.0^{ax}	11.6^{b}	10.6^{ax}	10.7^{a}				
Carcass shrinks (%)[2]	Overall	3.26	2.92	3.15	3.20	0.200	ns	ns	ns
Dressing percentage (%)[3]	1	46.93^{ax}	48.75^{a}	46.36^{bx}	—	0.342	***	***	ns
	2	50.85^{ay}	49.89^{a}	48.71^{by}	48.84^{bx}				
	3	48.15^{x}	49.45	47.41^{x}	46.75^{y}				
Conformation score[4]	1	5.2^{a} (O)	6.7^{bx} (R^{-})	5.9^{abxy} (O^{+})	—	0.24	ns	ns	*
	2	5.4 (O)	5.2^{y} (O)	6.2^{x} (O^{+})	5.3 (O)				
	3	5.2^{ab} (O)	6.4^{cx} (O^{+})	4.9^{ay} (O)	6.2^{bc} (O^{+})				
Fatness degree[5]	1	3.4 (1^{+})	4.1^{x} (2^{-})	4.8^{x} (2)	—	0.27	**	***	ns
	2	4.8^{a} (2)	6.2^{by} (2^{+})	6.4^{by} (2^{+})	6.4^{b} (2^{+})				
	3	4.3 (2^{-})	5.3^{xy}(2)	5.6^{xy} (2^{+})	5.7 (2^{+})				
KKCF[6]	1	2.7^{ax}	4.7^{bxy}	4.4^{bx}	—	0.26	ns	***	*
	2	4.5^{y}	4.0^{x}	4.3^{x}	4.5				
	3	6.3^{z}	5.4^{y}	5.7^{y}	5.1				
Fat consistency[7]	Overall	2.0^{b}	2.0^{b}	2.0^{b}	2.4^{a}	0.12	*	ns	ns
Fat colour[8]	Overall	2.1	2.0	2.1	1.9	0.06	ns	ns	ns
Rectus abdominis colour[9]	1	3.6^{ax} (C^{+})	5.9^{bxy} (P^{+})	3.6^{ax} (C^{+})	—	0.20	**	***	**
	2	5.1^{y} (P)	4.8^{x} (P)	4.6^{y} (P)	4.7 (P)				
	3	6.5^{az} (P^{+})	5.8^{aby} (P^{+})	5.2^{by}(P)	5.0^{b}(P)				

[1] FS: feeding system. [2] Carcass shrinks = (hot carcass weight – cold carcass weight) × 100/hot carcass weight. [3] Dressing percentage = cold carcass weight * 100/slaughter weight. [4] Conformation score: scale from 1 (P^{-}, poor) to 15 (E^{+}, Excellent) of the EUROP classification (E, excellent; U, very good; R, good; O, fair; and P, poor). [5] Fatness degree: scale from 1 (1^{-}: very low) to 12 (4^{+}, very high) of the scale 1 (low), 2 (slight), 3 (average), 4 (high). [6] Kidney knob and channel fat quantity: scale from 1 (without fat) to 9 (completely covered). [7] Fat consistency: scale from 1 (very hard) to 9 (very oily). [8] Fat colour: scale from 1 (very white) to 9 (intensive yellow) of white (W), cream (Cr), yellow (Y). [9] Muscle *Rectus abdominis* colour: scale from 1 (very clear pink) to 9 (red) of clear pink (C), pink (P), red (R). [†] Values in rows with different superscripts (^{a,b}) differ significantly ($p < 0.05$). Values in columns with different superscripts (^{x,y}) differ significantly ($p < 0.05$). SE: standard error; NS, $p > 0.05$; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

2 presented the greatest weight at slaughter and required a shorter time to reach slaughter, although the difference was only significant for the Gr treatment ($p < 0.05$; Table 3).

Carcass characteristics of the light lambs are shown in Table 4. Hot carcass weight, cold carcass weight and dressing percentage were significantly affected by both the year and the feeding system ($p < 0.001$). Carcasses from the second year were heavier for Gr and Ind – Gr treatments ($p < 0.05$). Dressing percentage was affected in the same way as hot and cold carcass weights. The percentage of carcass shrinkages was not affected by any of the factors studied ($p > 0.05$), with values between 3.0% and 3.3%.

There was a significant interaction between the year and the feeding system on conformation score (Table 4; $p < 0.05$). The fatness degree was significantly affected by the year ($p < 0.001$) and the feeding system ($p < 0.01$). Carcasses from year 2 had greater fatness values than the other years. Carcasses from grazing systems had lower values, despite all being classified as average-low (2 on a scale of 4). Kidney knob and channel fat (KKCF) showed an interaction between the feeding system and the year

Table 5. Effect of feeding system (FS) and year (Y) on zoometric carcass measurements and their ratios of light lambs reared under grazing (Gr), grazing with supplement (Gr+S), drylot lambs with rationed grazing-dams (Ind-Gr) and drylot lambs with dams fed in confinement (Ind).

	Year	Gr	Gr+S	Ind-Gr	Ind	SE	FS[1]	Y
Pelvic limb length (cm)	1	27.2	26.5^{x}	26.7^{x}	—	0.13	ns	***
	2	27.3^{ab}	26.8^{bcx}	27.5^{ay}	26.7^{cx}			
	3	27.7	27.6^{y}	27.6^{y}	27.6^{y}			
Carcass internal length (cm)	1	54.1^{a}	52.6^{bx}	53.5^{b}	—	0.21	ns	*
	2	54.0^{ab}	54.2^{by}	53.2^{a}	53.2^{a}			
	3	54.5	54.4^{y}	53.7	54.2			
Hindquarter perimeter (cm)	1	52.4^{x}	52.4^{x}	51.9^{x}	—	0.18	**	***
	2	53.8^{y}	53.9^{y}	53.2^{y}	52.9			
	3	53.0^{ay}	53.7^{ay}	52.1^{bx}	52.6^{b}			
Hindquarter wide (cm)	Overall	18.5	18.6	18.1	18.5	0.14	ns	ns
Chest depth (cm)	Overall	23.0^{a}	23.0^{a}	22.5^{b}	22.3^{b}	0.13	**	ns
Maximum width carcass (cm)	Overall	17.0^{b}	17.3^{b}	18.1^{a}	18.2^{a}	0.20	***	ns
Pelvic limb compactness[2] (g cm^{-1})	1	65.7^{x}	67.1^{x}	66.9^{xy}	—	0.73	*	***
	2	70.8^{aby}	71.4^{by}	68.1^{abx}	67.7^{a}			
	3	66.6^{abx}	69.3^{bxy}	64.6^{ay}	64.8^{a}			
Chest roundness index	Overall	0.74^{a}	0.75^{a}	0.81^{b}	0.81^{b}	0.013	***	ns
Hindquarter wide/pelvic limb length	Overall	0.68^{ab}	0.69^{a}	0.69^{a}	0.66^{b}	0.006	*	ns
Hindquarter wide/carcass internal length	Overall	0.34	0.35	0.34	0.35	0.003	ns	ns
Carcass compactness (g cm^{-1})	1	198.5^{bx}	211.3^{a}	197.9^{bx}	—	2.13	**	***
	2	223.3^{by}	215.4^{ab}	211.9^{ay}	210.1^{ax}			
	3	202.1^{abx}	213.3^{b}	198.3^{ax}	197.9^{ay}			

[1] FS: feeding system. [2] Pelvic limb compactness = Pelvic limb weight/Pelvic limb length; Chest roundness index = Maximum width carcass/Chest depth; Carcass compactness = cold carcass weight/Half carcass internal length. [†] Interactions were not significant ($p > 0.05$); Values in rows with different superscripts (^{a,b}) differ significantly ($p < 0.05$). Values in columns with different superscripts (^{x,y}) differ significantly ($p < 0.05$). SE: standard error; NS, $p > 0.05$; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

($p < 0.05$). In year 1, Gr had lower KKCF compared to other treatments ($p < 0.05$), but no differences between treatments were found in other years ($p > 0.05$). Feeding system affected fat consistency ($p < 0.05$), although fat was always classified within the hard fat category (Table 4). Fat colour did not change with the year or the feeding system ($p > 0.05$).

The subjective M. *Rectus abdominis* colour classification (Table 4) categorised all carcasses with colours ranging from clear pink to pink (C^{+}, P^{+}). Nevertheless, there was a significant interaction ($p < 0.01$) between the year and the feeding system ($p < 0.01$) for M. *Rectus abdominis* colour classification. In year 2, all treatments were classified as pink (P) without significant differences among treatments; however, in year 1, Gr and Ind – Gr were classified as clear pink (C^{+}) and Gr + S as dark pink (P^{+}). In year 3, both grazing treatments (Gr and Gr + S) were also classified as P^{+}, whereas the indoors treatments (Ind – Gr and Ind) were classified as P. Within treatments, Gr lambs presented a wider variation range of M. *Rectus abdominis* colour (from 3.6 in year 1 to 6.5 in year 3). For instance, within years the greatest range between feeding systems was in year 1 with 2.3 points.

Zoometric carcass measurements

There was no significant interaction between the feeding systems and the year for any zoometric carcass measurement (Table 5; $p > 0.05$). The effect of the year was significant for carcass internal length ($p < 0.05$), pelvic limb length, hindquarter perimeter, pelvic limb

Table 6. Effect of feeding system (FS) and year (Y) on quantity of internal fat depots in Rasa Aragonesa light lambs reared under grazing (Gr), grazing with supplement (Gr+S), drylot with rationed grazing-dams (Ind-Gr) and drylot with dams fed in confinement (Ind).

	Year	Gr	Gr + S	Ind – Gr	Ind	SE	FS[1]	Y	FS × Y
KKCF[2], g	1	177.2[by]	300.2[a]	272.3[a]	—	23.99	ns	**	*
	2	301.6[x]	253.0	276.7	291.4[x]				
	3	211.0[y]	248.8	220.8	214.7[y]				
Pelvic, g	Overall	68.8	81.0	76.7	81.1	3.63	ns	ns	ns
Renal, g	1	117.9[by]	207.7[a]	191.8[ax]	—	23.73	ns	***	*
	2	222.8[ax]	173.5[b]	195.3[bx]	201.1[ax]				
	3	143.6[y]	164.2	145.0[y]	132.8[y]				
Mesenteric, g	1	228.7[xy]	242.9[x]	257.0	—	12.98	ns	***	ns
	2	203.2[y]	199.0[y]	202.3	182.7[x]				
	3	240.9[x]	251.8[x]	261.6	284.4[y]				
Omental, g	1	201.5[by]	309.9[a]	262.6b	—	26.57	ns	**	ns
	2	296.4[x]	275.4	261.0	280.0[x]				
	3	224.4[y]	260.7	210.3	217.6[y]				

[1] FS: feeding system. [2] KKCF: kidney knob and channel fat. † Values in rows with different superscripts ([a,b]) differ significantly ($p < 0.05$). Values in columns with different superscripts ([x,y]) differ significantly ($p < 0.05$). SE: standard error; NS, $p > 0.05$; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

compactness and carcass compactness (p <0.001). Year 2 presented greater pelvic limb compactness and carcass compactness than the other years across all treatments. The feeding system had an effect on hindquarter perimeter ($p < 0.01$), chest depth ($p < 0.01$), maximum carcass width ($p < 0.001$), pelvic limb compactness ($p < 0.05$), chest roundness index ($p < 0.001$), hindquarter width to pelvic limb length ratio ($p < 0.05$) and carcass compactness ($p < 0.01$).

Internal fat depots

The internal fat depots of light lambs are shown in Table 6. There was an interaction between the feeding system and the year for KKCF and renal fat ($p < 0.05$). However, pelvic fat had no variation due to the year or feeding system. Gr and Ind lambs had the greatest differences in KKCF and renal fat amounts ($p < 0.05$) between years, although the Gr treatment produced more extensive variation among years while the other treatments did not produce any significant differences ($p > 0.05$). No effect was observed on internal fat depots due to the feeding system ($p > 0.05$).

Year had an effect on KKCF, renal, mesenteric and omental fat depots. Year 2 presented greater KKCF, renal and omental fat than the other years ($p < 0.05$) for the Gr and Ind treatments. The subjective degree of carcass fatness was significantly correlated with renal fat ($r = 0.43$, $p < 0.001$), pelvic ($r = 0.29$, $p < 0.01$), and omental fat ($r = 0.35$, $p < 0.001$).

Joint proportions and commercial meat categories

The proportions of joints obtained from the left halves of carcasses are presented in Table 7. The thoracic limb, pelvic limb and loin-rib had the highest percentages in carcasses from all treatments, while the neck and anterior-rib had the lowest. The feeding system and the year had a significant interaction on thoracic limb, pelvic limb and loin-rib percentages in carcasses ($p < 0.05$). The Gr treatment resulted in a greater thoracic limb and pelvic limb percentage and lower loin-rib percentage in year 1 than in the other years ($p < 0.05$) and treatments ($p < 0.05$). The feeding system only affected the anterior rib ($p < 0.001$), with a greater percentage in carcasses from both grazing treatments than in both groups raised indoors ($p < 0.05$).

When the joints were classified according to commercial meat categories, no effect of treatment was observed ($p > 0.05$). More than 60% of commercial meat was placed into the first category for all treatments.

Table 7. Effect of feeding system (FS) and year (Y) on proportion of joints and commercial meat categories of light lambs reared under grazing (Gr), grazing with supplement (Gr + S), drylot lambs with rationed grazing-dams (Ind – Gr) and drylot lambs with dams fed in confinement (Ind)

	Year	Gr	Gr + S	Ind – Gr	Ind	SE	FS[1]	Y	FS × Y
Thoracic limb (%)	1	20.65[ax]	19.59[b]	19.83[b]	—	0.108	ns	ns	*
	2	20.04[y]	19.88	20.10	19.67				
	3	19.81[y]	20.01	20.19	20.14				
Pelvic limb (%)	1	34.20[ax]	31.85[bx]	33.59[a]	—	0.208	*	ns	*
	2	32.88[y]	33.47[y]	33.83	33.27				
	3	33.44[y]	33.14[y]	33.98	33.91				
Loin-rib (%)	1	19.19[ax]	21.59[bx]	20.73[b]	—	0.233	ns	ns	*
	2	20.98[y]	20.64[y]	20.14	21.05				
	3	20.03[y]	20.05[y]	20.08	20.03				
Anterior-rib (%)	Overall	7.45[a]	7.47[a]	6.99[b]	6.98[b]	0.100	***	ns	ns
Neck (%)	Overall	7.94	7.86	7.59	7.55	0.122	ns	ns	ns
Breast (%)	Overall	10.89	11.19	11.26	11.44	0.156	ns	ns	ns
Commercial meat categories[2]									
1st category (%)	Overall	61.06	61.09	61.09	61.13	0.218	ns	ns	ns
2nd category (%)	1	20.65[ax]	19.59[b]	19.83[b]	—	0.108	ns	ns	*
	2	20.04[y]	19.88	20.10	19.67				
	3	19.81[y]	20.01	20.19	20.14				
3rd category (%)	Overall	18.84	19.05	18.86	19.00	0.193	ns	ns	ns

[1] FS: feeding system. [2] 1st category (loin-rib, pelvic limb, anterior-rib), 2nd category (thoracic limb) and 3rd category (breast and neck) † Values in rows with different superscripts (a,b) differ significantly ($p < 0.05$). Values in columns with different superscripts (x,y) differ significantly ($p < 0.05$). SE: standard error; NS: no significant; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

Discussion

Alfalfa production and characteristics

The short sward height at the start of the grazing period was related to the bud stage, which is typical at the first cut in a 1-month interval harvest management plan in irrigated Mediterranean areas (Delgado *et al.*, 2005). CP and NDF showed a cycle of 5 weeks, in agreement with the alfalfa growth pattern reported by Delgado *et al.* (2011). The lowest NDF content in year 3 may be due to stricter control of the phonological stage of alfalfa in this year, meaning that plant maturity and the leaves to stalk ratio may be the source of these differences (Joy *et al.*, 2012b).

Animal performance and carcass characteristics

The similar live weight between the years and feeding systems reflects the comparable conditions of ewes (live weight, body condition score) among the years. Differences between the years in temperature and rainfall in April (lambing and beginning of trial) may have affected the growth of newborn lambs under grazing conditions, while indoors lambs were not affected. During the suckling period, all feeding systems provided sufficient energy for milk-production requirements leading to similar growth across treatments. Joy *et al.* (2012b) studied two forage types (hay *vs*. green mountain pasture) and concluded that the lack of differences in milk yield suggests that the dietary energy content of both treatments was sufficient to meet the nutritional requirements of dams to support their milk production potential. When the ADG from 50 d to slaughter was studied, the influence of climatology disappears and the effect of feeding system becomes more important. In this phase, lambs are able to eat solid food and do not depend exclusively on dam's milk. In the indoor systems (Ind – Gr and Ind), the lambs were weaned and had free access to concentrate, whereas in the other treatments lambs were not weaned and kept suckling while they had access to alfalfa (Gr) or grazing alfalfa plus concentrate (Gr + S). When the ADG measured is the full period (from birth to slaughter) the effect of the feeding system is in agreement with the findings of several authors (Zervas *et al.*, 1999; Joy *et al.*, 2008b). In the present study treatment Gr + S showed the greatest ADG. Similarly Carrasco *et al.* (2009c) studied another sheep breed, and concluded that when lambs grazing on permanent mountain pastures were supplemented with concentrate the ADG increased significantly regardless of stocking management.

The best lamb productive performance in year 2 may also be related to the greatest dry matter (DM) yield and quality of the second year alfalfa crop when it was sown in spring (Lloveras, 1999). In summary, grazing systems are dependent on external factors such as climatology and provided more heterogeneous lambs at slaughter than either indoor lamb or alfalfa-grazing-plus-concentrate systems; although in all feeding systems studied lambs are able to reach the slaughter target weight at ages younger than 90 d, which is the maximum age accepted for these light lambs.

Grazing treatments (Gr and Gr + S) had greater dressing percentage in years 2 and 3 than indoors treatments. Álvarez-Rodríguez *et al.* (2010) reported that the entire digestive tract of light lambs is not influenced by alfalfa grazing but by weaning, and unweaned lambs have a lighter digestive tract than lambs fed concentrates. The percentage of carcass shrinkage was similar to that found by other authors (Joy *et al.*, 2008a, 2012a; Carrasco *et al.*, 2009c).

Lambs conformation scores were within the typical range for the light lamb category (Sanz *et al.*, 2008; Carrasco *et al.*, 2009a). This results did not support the idea that lambs raised in a grazing system without any supplementation have an inferior conformation score (Murphy *et al.*, 1994; McClure *et al.*, 1995; Priolo *et al.*, 2002b; Joy *et al.*, 2008b). Similarly, fatness degree was influenced by the year and carcasses from grazing systems had lower values. However, all were classified as average-low, which is a requirement of the light lamb market. Similar results were found by other authors rearing similar local breeds (Peña *et al.*, 2005; Joy *et al.*, 2008b; Carrasco *et al.*, 2009c).

The low temperature and high rainfall in April of year 1 suggest a greater requirement for energy for maintenance of Gr lambs, which agrees with the low ADG registered from birth to slaughter in this year. These observations may also explain the low development of KKCF and carcass fatness degree. The rest of the studied body fat depots studied also were low in the Gr treatment (Joy *et al.*, 2008a). Joy *et al.* (2008a) and Carrasco *et al.* (2009c) did not find an effect of feeding management (permanent mountain pasture *vs*. concentrate) on fat colour. The potential change in fat colour for both grazing treatments, resulting from the presence of carotenoids in subcutaneous fat was not enough to modify the subjective scores of light lambs (Blanco *et al.*, 2005; Joy *et al.*, 2008b; Carrasco *et al.*, 2009c).

The subjective M. *Rectus abdominis* colour classification categorises meat with colours ranging from clear pink to pink (C^+, P^+), within the range of consumer preferences for light lamb (Font i Furnols *et al.*, 2006). In grazing systems, the effect of physical activity is often confused with the effect of feeding level and/or feed ration (Vestergaard *et al.*, 2000). The muscle of lambs raised on pasture is darker in relation to stall-fed lambs due to a greater concentration of haeminic pigments in muscles as a result of exercise (Renerre, 1986). However in light lamb carcasses the M. *Rectus abdominis* colour is influenced by diet and age, but not by physical activity (Colomer-Rocher *et al.*, 1988). In agreement, Blanco *et al.* (2005) concluded that muscle colour of lamb light carcasses showed slight differences between feeding systems, although carcasses from grazing lambs had more vivid colour than indoor lambs. Light lambs slaughtered at 22-24 kg of live weight were classified as pink regardless of the feeding system (Horcada *et al.*, 1998; Beriain *et al.*, 2000; Sanz *et al.*, 2008). However when heavy lambs were studied there was no consistent effect of diet on muscle colour (Young *et al.*, 1997; Hopkins *et al.*, 1998).

Zoometric carcass measurements

According to Díaz *et al.* (2002), carcasses with small pelvic limb length and high hindquarter perimeter are well conformed. In this study, grazing lambs had greater hindquarter perimeters and also greater pelvic-limb lengths, concomitantly with conformation score, showing an inconsistent effect of feeding system on conformation-related variables. However when grazing was supplemented with concentrate, carcasses presented greater carcass compactness and pelvic-limb compactness, which agrees with the conformation score from the visual classification. Similar results were found by Carrasco *et al.* (2009c), in the Churra Tensina breed and Osório *et al.* (1999) using Polwarth lambs. Conversely, Díaz *et al.* (2002) and Santos-Silva *et al.* (2002) did not find any effect of feeding system on this parameter. Both carcass and pelvic-limb compactness indexes had a greater range between years within the Gr feeding system than between feeding systems within years.

Internal fat depots

Several authors reported lower amounts of internal fat depots in grazing lambs (Murphy *et al.*, 1994; Carrasco *et al.*, 2009c). However, if feeding systems provide enough energy for acceptable lamb growth, they lead to similar development of fat depots (Chestnutt, 1994), which is in agreement with the current findings.

Joint proportions and commercial meat categories

Thoracic limb, pelvic limb and loin- rib had the highest percentages in carcasses from all treatments, while the neck and anterior- rib had the lowest (Peña *et al.*, 2005; Carrasco *et al.*, 2009a). The first category accounted for more than 60% of commercial meat from light lambs (Cañeque *et al.*, 2004; Díaz *et al.*, 2006; Carrasco *et al.*, 2009c), showing that the feeding system does not influence the proportion of meat in each commercial category. Carrasco *et al.* (2009a) concluded that proportions of joints are affected more by slight variations in the slaughter weight (within the range of 22-24 kg) than by the feeding system**.**

Feeding systems based on alfalfa grazing often provide similar lamb growth and carcasses compared to indoors concentrate-feeding systems. However in general terms, grazing feeding systems without concentrate supplementation are more dependent on the year. This climatologic dependence may lead to the slaughter of older grazing lambs to achieve the target slaughter weight when temperatures are low or the rainfall is great. The best feeding system for producing light lambs in irrigated Mediterranean areas was alfalfa grazing plus concentrates, which produced the greatest ADG and the best carcass classification.

All feeding systems evaluated produced light lambs with the carcass characteristics required by the market. Even the potential change in fat colour found in both grazing treatments was not enough to change the subjective evaluation of fat colour. In the present study, the effect of year was important in the period from birth to weaning, as the lambs depend on the milk production of dams, and several environmental factors can affect ewe dietary intake. After lambs reach 12-14 kg of live weight at weaning, the effect of the feeding system becomes significant because grazing- and concentrate-based diets can differ in their energy and protein content. Year and feeding system also affect some characteristics of carcass classification, which may reflect the influence of inter-annual variation of dietary feed quality, especially grazed alfalfa, on lambs' growth patterns. This study showed the utility of subjective assessment of the degree of fatness in carcasses using a uniform EU scale to predict the other fat deposits in the lamb.

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