Spanish Journal of Agricultural Research
16 (3), e0609, 16 pages (2018)
eISSN: 2171-9292
https://doi.org/10.5424/sjar/2018163-13027
Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, O.A, M.P. (INIA)

RESEARCH ARTICLE

OPEN ACCESS

Performance, carcass characteristics, economic margin and meat quality in young Tudanca bulls fed on two levels of grass silage and concentrate

Emma Serrano[1], M. José Humada[1], Irma Caro[2], Ibán Vázquez[1], Ana M. Olaizola[3], Helena Resano[3], Sergio Soto[4] and Javier Mateo[2]

[1]Gobierno de Cantabria. D.G. Desarrollo Rural. Centro de Investigación y Formación Agrarias (CIFA), C/Héroes Dos de Mayo, 27, 39600 Muriedas (Cantabria), Spain. [2]Universidad de León, Dept. Higiene y Tecnología de los Alimentos. Campus Vegazana s/n, 24007 León, Spain. [3]Universidad de Zaragoza, Instituto Agroalimentario de Aragón-IA2 (Universidad de Zaragoza-CITA), Dept. Ciencias Agrarias y del Medio Natural. C/ Miguel Servet 177- 50013 Zaragoza, Spain. [4]Universidad Autónoma del Estado de Hidalgo, Instituto de Ciencias Agropecuarias. Ave. Universidad s/n km 1. 43600 Tulancingo (Hidalgo), Mexico.

Abstract

This study investigates the effect on performance, carcass and meat characteristics of increasing the forage level in the diet of fattening Tudanca young bulls using silage as the forage source as compared with a conventional *ad libitum* straw plus concentrate diet. Twenty two Tudanca young bulls were assigned to three different finishing diets: *ad libitum* grass silage plus *ad libitum* concentrate (GS-AC), *ad libitum* grass silage plus concentrate limited to a half of the intake of the *ad libitum* group (GS-LC), *ad libitum* barley straw plus *ad libitum* concentrate (Str-AC) and then slaughtered at around 11 months of age. GS-LC diet resulted in relation to GS-AC and Str-AC diets in lower ($p\leq0.05$) average daily weight gain (750 *vs* 1,059 and 991 g/animal/day, respectively), lower ($p\leq0.05$) carcass weight (133 *vs* 159 and 152 kg, respectively) and carcasses with slightly lower conformation scores. Although GS-LC diet allowed for a lower dependence on concentrate (372 *vs* 657 and 729 kg/animal, respectively), economic margin was similar for the two GS groups (-63.1 and -64.1 *vs* -91.8 €/head). The polyunsaturated/saturated fatty acid ratio was the lowest ($p\leq0.05$) in GS-AC meat (the group showing the highest IMF levels) and the ratio n-6/n-3 was the highest ($p\leq0.05$) in Str-AC meat. GS-LC meat showed higher collagen content and Str-AC meat presented higher cohesiveness, springiness and chewiness values. Results suggested that the substitution of straw by grass silage and the restriction of the concentrate level could be recommended for finishing young Tudanca bulls in indoors systems.

Additional keywords: rustic breed; beef; fat deposition; concentrate level; production efficiency; fatty acid; texture.

Abbreviations used: ADWG (average daily weight gain); BBU (bovine bulk unit); DM (dry matter); FAME (fatty acid methyl ester); GS-AC (*ad libitum* grass silage plus *ad libitum* concentrate diet); GS-LC (*ad libitum* grass silage plus limited concentrate diet); IMF (intramuscular fat); MUFA (monounsaturated fatty acids); PDI (protein truly digestible in the small intestine); PUFA (polyunsaturated fatty acids); SFA (saturated fatty acids); Str-AC (*ad libitum* barley straw plus *ad libitum* concentrate diet); TBARS (thiobarbituric acid reactive substances); UFL (Unités Fourragères Lait, or net energy for maintenance and gain expressed in milk feed units)

Authors' contributions: Conceived and designed the experiments: ES and MJH. Performed the experiments: ES, MJH, IC, SS, JM. Wrote the paper: ES, MJH, JM, IC, IV, AMO, HR. All authors analysed and interpreted the data, read and approved the final manuscript.

Citation: Serrano, E.; Humada, M. J.; Caro, I.; Vázquez, I.; Olaizola, A. M.; Resano, H.; Soto, S.; Mateo, J. (2018). Performance, carcass characteristics, economic margin and meat quality in young Tudanca bulls fed on two levels of grass silage and concentrate. Spanish Journal of Agricultural Research, Volume 16, Issue 3, e0609. https://doi.org/10.5424/sjar/2018163-13027

Received: 12 Feb 2018. **Accepted:** 01 Aug 2018.

Funding: Comunidad Autónoma of Cantabria, Spain; INIA (RTA2012-00084-C03-00 project); E. Serrano postdoctoral contract (DOC-INIA-CCAA 2008).

Competing interests: The authors have declared that no competing interests exist.

Correspondence should be addressed to Emma Serrano: emmaserrano@cifacantabria.org

Introduction

The Tudanca breed is an endangered breed (BOE, 2008) from Cantabria, Northern Spain, used for meat production, with a population of 11,148 breeding cows in 2015 (ICANE, 2017). Tudanca calves are usually sold at weaning (around 6 months of age) to units specialized in intensive fattening, located in other Spanish regions (Humada *et al.*, 2013). A traditional type of Tudanca production was based on young animals, slaughtered at approximately 10 months of age and suckled until slaughter, which, depending on the season and the availability of feeding resources, were raised grazing with their dams or receiving hay and small quantities of concentrate indoors. A number of Tudanca calves are still reared on local farms but most of the produced young Tudanca bulls are weaned at 4-6 months of age and finished with cereal straw and concentrate *ad libitum* until 10-11 months of age (Vázquez *et al.*, 2016).

The Tudanca is a rustic breed with low carcass yield and conformation scores and high capability of fat deposition, as much in the carcass as in the not carcass (Humada *et al.*, 2013). This fact leads to a reduction in the profitability of intensive finishing of Tudanca bulls on the one hand, while on the other hand, makes it possible to obtain acceptable results (*e.g.* enough intramuscular fat deposition) with forage based rations (Humada *et al.*, 2013).

In recent years there has been an increase in consumer demand for beef from cattle production systems not exhibiting negative effects on animal welfare and physiology (Bernués *et al.*, 2003; Maria, 2006) and contributing to improve the nutritional quality of beef, *i.e.*, a healthier fatty acid composition (Kallas *et al.*, 2014). In this context, increasing the forage/concentrate ratio of finishing diets to an appropriate level could be an interesting approach to meeting those consumer demands. Moreover, some ruminant meat quality labels, *i.e.*, organic beef (EC, 2007) establish a limit on the proportion of concentrates in ruminant rations during the finishing period.

Unlike dairy breeds, currently in Spain there are still relatively high censuses of beef cows of native breeds with rusticity characteristics similar to those in the Tudanca (MAPAMA, 2017a). Notwithstanding, the market penetration of differentiated beef produced with these native rustic breeds is still low. Despite fresh beef in Europe has been traditionally sold unbranded; a niche of market for differentiated beef has been detected within the literature (Resano & Sanjuán, 2017). In this sense, a more successful marketing policy may be achieved by developing quality labels based on a local breed and the use of natural resources by extensive or semiextensive systems (Bernués *et al.*, 2003; Olaizola *et al.*, 2012). Nevertheless, the availability of grazing surfaces and pasture characteristics of many farms make it difficult to set up grazing systems. Besides, there are periods of the year in which meteorological conditions make it necessary to stable animals, so alternative indoor systems should be considered.

Any alternative to reducing concentrate level in fattening rations implies replacing low quality forages (such as straw) with high quality ones. In the conditions of Cantabrian Cornice regions, the forage conservation system that yields higher quality forages is silage, and the most widespread silage method in beef farms is round bales, in spite of its higher cost (Martínez-Fernández *et al.*, 2014). The effects of the forage/concentrate ratio on carcass performance and carcass quality have been the subject of research. Some studies have found that increasing the levels of forage resulted in lighter carcasses with lower fat content and a more yellow fat colour (Sami *et al.*, 2004; Cerdeño *et al.*, 2006). In contrast, other studies report that increases in forage level exerts no or only slight effects on carcass characteristics (Blanco *et al.*, 2010; Daza *et al.*, 2014). However, different confounding factors, such as breed, age, plane of nutrition or forage type, make it difficult to compare between studies.

It is known that the amount of forage *vs* concentrate in diet can affect beef quality, *i.e.* intramuscular fat content, lipid composition, fat colour or sensory scores (Muir *et al.*, 1998; Resconi *et al.*, 2010; Humada *et al.*, 2012; Van Elswyk & McNeill, 2014). Several quality traits seemed to be hardly affected, *i.e.*, meat colour (Priolo *et al.*, 2001) or instrumental texture characteristics (Nuernberg *et al.*, 2005). The effects of high forage diets on beef quality depend on the forage *vs* concentrate ratio, so partial replacement of concentrate by forage would have less effect than a total replacement (Moloney & Drennan, 2013).

Taking into account all these considerations, the aim of this work was to evaluate the effect on growth, carcass characteristics, economic performance and meat quality of feeding young Tudanca bulls with finishing diets including two rates of silage versus the more conventional feeding system consisting of barley straw plus *ad libitum* concentrate.

Material and methods

Animal management, diet composition and feed sample collection

This study was conducted at the experimental farm “Finca Aranda” of the Cantabria Government (latitude: 43º23’15”N, longitude: 04º11’32”W; 84 m above sea level). The climate of this area is Atlantic with about 1,206 mm of annual rainfall and a 13.2 ºC mean temperature (mean values of 30 years).

Twenty two Tudanca young bulls (average birth date February 28) were used. Calves were raised on pasture with their mothers until weaning at 5 months of age. Then the animals were blocked according to age and live weight at weaning, allocated at random in three feedlot pens (age at weaning 150±20.1 days, p=0.997; live weight at weaning 129±23 kg, p=0.861) and fed on *ad libitum* hay and 1 kg/animal/day of commercial growing concentrate for 15 days. After this adaptation period, lots were assigned to three different diets:

ad libitum grass silage plus *ad libitum* commercial concentrate (GS-AC), *ad libitum* grass silage plus commercial concentrate limited to a half of the intake of the *ad libitum* group (GS-LC), *ad libitum* barley straw plus *ad libitum* commercial concentrate (Str-AC), until slaughter at around 11 months of age (323±16.3 days of age). All animals were individually weighed each 7 days at 9:00 a.m. before feed distribution and on the day before slaughter. Average daily weight gain (ADWG) was calculated by linear regression.

Silage was made in round bales. The grass used was 2nd year spring *Lolium perenne* growths obtained from two parcels cut at 16 April (1st batch) and 6 May (2nd batch) wilted to a dry matter (DM) content of approximately 30% and chopped to 12 cm length. Grass silage and straw were offered *ad libitum* (adjusted to allow a 10% refusal) once a day and group intakes were controlled 3 days a week. Concentrate was offered in a collective calf feeder to GS-AC and Str-AC groups, and group intake was calculated once a week. Half of the daily amount of concentrate ingested by GS-AC the previous week was offered daily to GS-LC and there were no refusals. Water and mineral blocks were always available to animals.

Feed samples (grass silage: 3 samples per bale; commercial concentrate and barley straw: 1 sample per feed) were analyzed to determine DM, crude protein, ether extract, ash (AOAC, 1990), crude fibre (Van Soest, 1982), acid detergent fibre (Goering & Van Soest, 1970) and neutral detergent fibre (Van Soest *et al.*, 1991). Net energy content (UFL/kg DM) of all feeds and bulk units (BBU/kg DM) of forages were calculated using the equations proposed by INRA (2007) (Table 1). Furthermore, fatty acid contents of straw, grass silage and concentrate were analysed in duplicate following the procedure described below for meat samples (Table 1).

Slaughter procedures and carcass characteristics

Animals were divided in two slaughter batches, January 14 (4 GS-AC, 4 GS-LC and 4 Str-AC) and

Table 1. Percentage of dry matter, chemical composition, net energy content and fatty acids content (expressed as percentage) of feeds and forage ingestibility.

	[1]Commercial concentrate	Grass silage		Barley straw
		[2]1st batch	[2]2nd batch	
[3]DM (%)	90.4	29.2 (20.1-35.9)	25.1 (18.6-37.2)	88.7
[4]CP (%DM)	14.5	8.0 (6.9-10.6)	12.3 (11.2-13.4)	4.4
[5]EE (%DM)	3.7	-	-	-
[6]CF (%DM)	11.1	34.2 (32.2-37.5)	28.3 (24.2-31.6)	-
[7]ADF (%DM)	13.0	35.1 (32.7-39.3)	29.7 (23.7-33.2)	49.8
[8]NDF (%DM)	24.1	61.0 (57.8-64.9)	57.5 (53.5-61.3)	80.8
Ash (%DM)	6.2	9.2 (8.2-11.0)	12.9 (9.6-21.0)	7.6
Net Energy ([9]UFL/kg DM)	0.99	0.76 (0.72-0.78)	0.74 (0.67-0.78)	0.43
Bulk units ([10]BBU/kg DM)	-	1.28 (1.26-1.30)	1.24 (1.20-1.26)	1.60
[11]PDIE (g/kg DM)	111	57 (55-58)	61 (59-64)	50
[12]PDIN (g/kg DM)	109	55 (50-68)	76 (71-82)	28
Fatty acids (g/100g of the total fatty acids identified)	**Commercial concentrate**	**Grass silage**		**Barley Straw**
C14:0	-	2.5		-
C16:0	17.7	23.9		25.7
C18:0	3.4	3.2		8.2
C18:1*cis-9*	20.1	5.7		13.8
C18:2*n-6*	55.9	14.8		23.5
C18:3*n-3*	2.9	49.9		28.8

[1]Concentrate composition: corn, 40%; barley, 25.2 %; toasted soybean meal, 11.7 %; sunflower meal, 5.1 %; dehydrated sugar beet pulp, 5 %; soybean husk, 4.4 %; sugar cane molasses, 3%; soybean oil, 2.6%; calcium carbonate, 1.4%; sodium bicarbonate, 0.7%; bicalcium phosphate, 0.38%; sodium chloride, 0.3%; magnesium oxide, 0.2%; vitamin A, 10000 UI/kg; vitamin D3, 2000 UI/kg; vitamin E 43.75 mg/kg; copper sulphate pentahydrate, 10 mg/kg. [2]Mean (range) of 9 analyses. [3]DM= dry matter. [4]CP= crude protein. [5]EE= ether extract. [6]CF= crude fibre. [7]ADF= acid detergent fibre. [8]NDF= neutral detergent fibre. [9]UFL= Unités Fourragères Lait: net energy for maintenance and gain expressed in milk feed units. [10]BBU= bovine bulk unit (Unités d'Encombrement Bovine). [11]PDIE= proteins truly digestible in the small intestine allowed by the energy content. [12]PDIN= proteins truly digestible in the small intestine allowed by the nitrogen content.

January 21 (3 GS-AC, 3 GS-LC and 4 Str-AC) according to age. The experimental period lasted 143±3.6 days. Slaughter took place in a commercial slaughterhouse located 35 km from the farm. The lairage period in the slaughterhouse lasted for 12 hours. The slaughter procedures comply with the Council Regulation (EC) No 1099/2009 (EC, 2009).

After slaughter, the perirenal fat and the hot carcass weight were obtained. Afterward, carcasses were split in two halves and then conformation and fatness carcass scores were determined according the European Union beef carcase classification grid (EC, 2006) with each score subdivided into high (+), medium (=) and low (-). This conformation scale ranged from 18 [(S+, very good) to 1 (P-, very poor)] and the fatness scale from 15 (5+, very high) to 1 (1-, very low). Carcass yield was calculated as the relation between hot carcass weight and slaughter weight. Right carcasses were weighed and stored immediately in a refrigeration room set to 1-2 ºC until 7 hours post-mortem and then in a refrigeration room set to 2-4 ºC following the routine refrigeration procedure used in the slaughterhouse. The left half-carcasses were assigned at random to two refrigeration procedures: room temperature or wrapping. In the room temperature treatment, carcasses were kept at room temperature (between 10 and 13 ºC) until 7 hours post-slaughter and then in a refrigeration room set to 2-4º C. In the wrapping treatment, carcasses were protected with a cotton cover and placed in the same refrigeration rooms as right ones.

At 24 hours post-mortem colorimetric variables of the CIE L*a*b* uniform colour space (CIE, 1976) were measured in triplicate on the loin subcutaneous fat area of right carcasses using a portable colorimeter Minolta CR-400 (D65 iluminant, 2º observer angle, 8 mm aperture size).

Meat sampling, sample preparation and analyses

Selected quality analyses were carried out at different anatomical locations and post-mortem time in order to assess the effect of diet on meat quality (Table 2).

At 24 hours post-slaughter, the pH of *Longissimus lumborum* muscle of left and right carcasses was measured in duplicate, between the 4th and 5th lumbar vertebrae (pHmeter Crison 507, Hach Lange Spain, L'Hospitalet de Llobregat, Spain). The loin portions from the limit between the 5th and 6th rib to the end of the loin were then removed from right and left carcasses, and a sample of *Rectus abdominis* muscle (750 g approximately; right side) was taken at the back area of the thin flank and stored at 4ºC. The loin section corresponding to the left 6th rib was used to determine tissue composition by dissection (Carballo *et al.*, 2005). A steak from the right *Longissimus thoracis* muscle was obtained from the 6th rib, minced and used to determine moisture, fat, protein and ash.

At 48 h post-slaughter another two 2 cm-thick steaks were cut at the level of the right side 8-11th rib. One steak was immediately used to determine colour and water holding capacity as drip loss and, and the other was frozen at -32 ºC until being tested for collagen content. Moreover, a 3 cm-thick steak was obtained from the left-side *Longissimus thoracis* muscle at the level of the 7-10th rib at 48 h post-slaughter. Steaks were then vacuum-packed and maintained at 4 ºC for 7 days (until 9 days post-slaughter) for ageing. Afterwards these steaks were frozen at -32 ºC until being used for cooking losses and texture profile analysis.

The *Rectus abdominis* samples, at 48 h post-slaughter were divided into two subsamples. One subsample was minced and used to determine fatty acid profile. The other half of the samples were stored for 7 days (until 9 days post-mortem) in hermetic trays at 4 ºC and then used for the determination of lipid oxidation.

Table 2. Experimental plan showing the analysis carried out, the muscles used and the post-mortem time elapsed before analysis.

Analysis	Anatomical location	Post-mortem time
Proximate and lipid composition		
Proximate composition	*Longissimus thoracis* (right side)	1 day
Fatty acid profile	*Rectus abdominis* (right side)	2 days
Technological quality traits		
pH	*Longissimus lumborum* (left and right side)	1 day
Drip loss	*Longissimus thoracis* (right side)	2 days
Collagen	*Longissimus thoracis* (right side)	2 days
Cooking loss and instrumental texture	*Longissimus thoracis* (left side)	9 days
Colour	*Longissimus thoracis* (right side)	2 days
Lipid oxidation	*Rectus abdominis* (right side)	9 days

Meat proximate composition and lipid composition

Proximate composition was carried out according to ISO, 1973 (Determination of total fat content; Standard R-1443); ISO, 1978 (Determination of nitrogen content; Standard R-937); ISO, 1997 (Determination of moisture content; Standard R-1442); ISO, 1998 (Determination of total ash; Standard R-936). Fatty acid composition was analysed in the intramuscular fat (IMF) from *Rectus abdominis* muscle as described in Domínguez *et al.* (2015). Fatty acid results were expressed as g/100g of the total fatty acids identified.

Technological meat quality traits

Total and heat-insoluble collagen were analysed according to AOAC (1999). For texture profile analysis of cooked meat, the corresponding meat steaks were thawed at 4 ºC for 24 h, weighed, placed into hermetic bags and cooked in a water bath at 80 ºC until a core temperature of 70 °C was reached. After cooling the cooked steaks under a running tap, the steaks were weighed again. Cooking losses were calculated as weight differences expressed in percentage on initial weight basis. Afterwards, the cooked steaks were wrapped in aluminium foil and held overnight at 4 ◦C. Subsequently, after tempering the samples for 1 h at room temperature (20 ºC), five 1 cm^3 cubes were cut with one of the axes being parallel to muscle fibre orientation. Instrumental texture profile analysis (TPA; Bourne, 1978) was performed with a texture analyser TA.XT2i and software Texture Expert, v1.20 (Stable Micro Systems, Godalming, Surrey, UK) with a 25 kg load cell and a 5 cm diameter cylindrical probe set to run at 1 mm/s. Cubes were compressed twice (80% of the thickness of the sample; parallel to fibre direction) with a 5-s elapse between the two compression cycles. Mean values for hardness, springiness, and cohesiveness were obtained from the force–time curves. Chewiness was calculated as the product of hardness multiplied by cohesiveness and springiness.

Regarding drip loss and colour, the steaks used for the determinations were placed on polystyrene trays immediately after being sliced, then wrapped with an oxygen permeable film and allowed to bloom for 1 h at 4 ºC. Next, the steaks were taken from the trays and colour parameters (lightness (L*), redness (a*) and yellowness (b*)) were registered on 3 homogenous zones of the steak surface using a Minolta CR-400 colorimeter (C illuminant, 2º standard observer angle and 8 mm aperture size, SCI mode). Thereafter, chroma (C*) and hue angle (Hº) values were calculated as $C^*_{a,b}=[(a^*)^2 + (b^*)^2]^{0,5}$ and $H^o_{a,b}=\arctan(b^*/a^*)$. Then, steaks were halved and the two slices (weighting approximately 100 g) were stored at 4º C for 24 h and drip loss was assessed according to Honikel (1998). Lipid oxidation in freshly meat samples was measured by the thiobarbituric acid reactive substances (TBARS) method (Nam & Ahn, 2003). Results were expressed as mg of malonaldehyde per kg of meat.

Economic analysis

The costs and incomes associated to each strategy of production were calculated to compare them in economic terms. Data on both input and output prices was based on the reference year 2014. The costs considered were: feeding (grass silage, straw, hay, vitamin-mineral supplements and concentrate); health and hygiene products and services (veterinarian products and services, cleaning and maintenance of feedlot pens); machinery [costs derived from the use of a tractor 1 hour per week, estimated from Márquez (2007) and considering the evolution of the consumer price index between 2005 and 2014 recorded in INE (2016)]; transport to slaughterhouse and slaughter cost (calculated considering the average value of prices of the three slaughterhouses operating in Cantabria in 2014 and the average value of prices of two livestock transport companies); interests of the working capital (opportunity cost calculated considering a legal interest rate of the money set at 4%; BOE, 2013). Grass silage cost was 0.034 €/kg of fresh matter and it includes grass purchase, grass mown and round bales elaboration. Straw and hay costs were calculated using the average price of barley straw and hay in the main cooperatives of Cantabria (0.072 €/kg and 0.11 €/kg of fresh matter, respectively) and include transport to the farm. Concentrate cost was calculated considering the average price of growing and finishing concentrate (0.399 and 0.366 €/kg of fresh matter, respectively). Total income achieved per animal at slaughter was calculated as carcass selling income (considering the selling price of 4.2 €/kg of carcass recorded in Vázquez *et al.* (2016) for Tudanca young bulls) plus coupled payment for calf fattening according to new CAP 2014-2020 (32.7 €/head; FEGA, 2017). The economic margin was calculated as the total income minus the above mentioned costs and minus the opportunity cost of a weaned calf (the market value of a 5 months old weaned Tudanca calf, 200 €/head) and the cost of family labour. Family labour was estimated as 2 h/day and the value of 1 hour of work was fixed at 4.95 €/h (MAPAMA, 2017b). In order to compare the economic margin under different scenarios a sensitivity analysis was carried out taking into account an increase of 25% in concentrate prices and a rise by 24% of carcass selling price up to the price suggested by local farmers as the price to overcome the threshold of profitability (5.2 €/kg of carcass; Vázquez *et al.*, 2016).

Statistical analysis

Data for performance and carcass characteristics were compared by means of analysis of covariance considering diet as a fixed effect and weight at weaning as a covariate. The covariate was removed from the statistical model when $p > 0.05$. Fat colour variables were compared by means of analysis of variance considering diet as the variation factor. Meat quality variables were statistically compared using a model including diet as a fixed factor and slaughter batch as a random factor. Values of 24 h pH, cooking losses and texture profile, determined in samples from left carcasses, were compared, in a first step, using a model including diet and refrigeration procedure (room temperature or wrapping) as fixed factors. Then, as refrigeration procedure effect was not statistically significant for any considered variable, data were analyzed, in a second step, considering diet as fixed factor and slaughter batch as random factor. When *p* was lower than 0.05 for the fixed factor, Bonferroni's test was used to separate treatment means. The above-mentioned analyses were carried out using the statistical package SPSS 17.0 (IBM Corp., Armonk, NY).

Results

Figure 1 shows the weekly evolution of average daily forage and concentrate intakes per animal. Daily grass silage intakes were on average 1.48 and 2.26 kg DM/animal for the GS-AC and GS-LC groups, respectively (total intakes of 215 and 329 kg DM/animal, respectively). Daily barley straw intake was on average 0.52 kg DM/animal for the Str-AC group (total intake of 77 kg DM/animal). Daily concentrate intakes were on average 4.56, 2.58 and 5.02 kg DM/animal/day for the GS-AC, GS-LC and Str-AC groups, respectively (total intakes of 657, 372 and 729 kg DM/animal). Figure 2 shows the evolution of UFL and PDI intakes from forage and concentrate expressed as total intake. Average total net energy intakes were 5.62, 4.25 and 5.19 UFL/animal/day for the GS-AC, GS-LC and Str-AC groups, respectively. Average total daily PDI intakes were 583, 411 and 562 g/animal for GS-AC, GS-LC and Str-AC groups, respectively.

The forage/concentrate ratios (on a DM basis) calculated for the three experimental diets, GS-AC, GS-LC and Str-AC, were respectively 25/75, 47/53 and 9/91. The concentrate substitution effect obtained by comparing forage and concentrate intake of GS-AC and GS-LC groups was 0.4 (a reduction of 0.4 kg de DM of

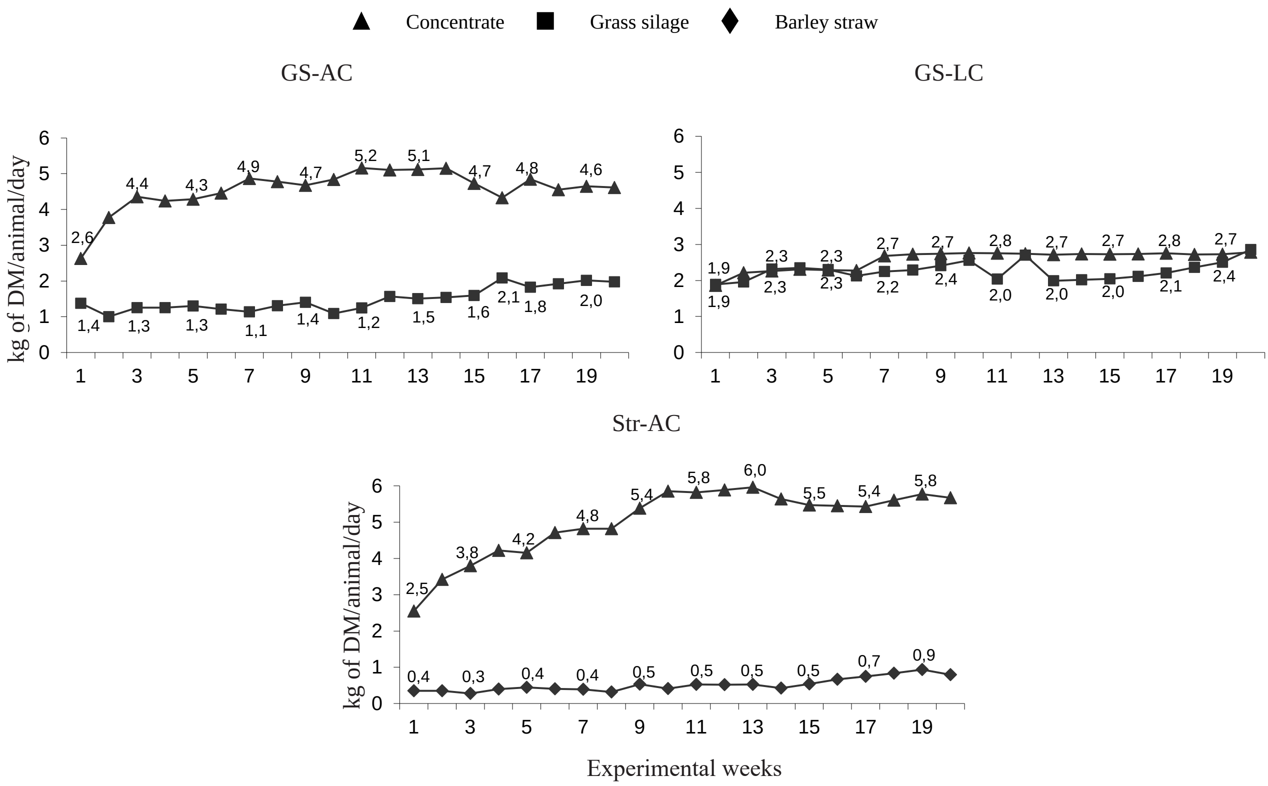

Figure 1. Evolution of voluntary intake in the three experimental groups (GS-AC= *ad libitum* grass silage plus *ad libitum* concentrate diet; GS-LC= *ad libitum* grass silage plus limited concentrate diet; Str-AC=barley straw plus *ad libitum* concentrate diet)

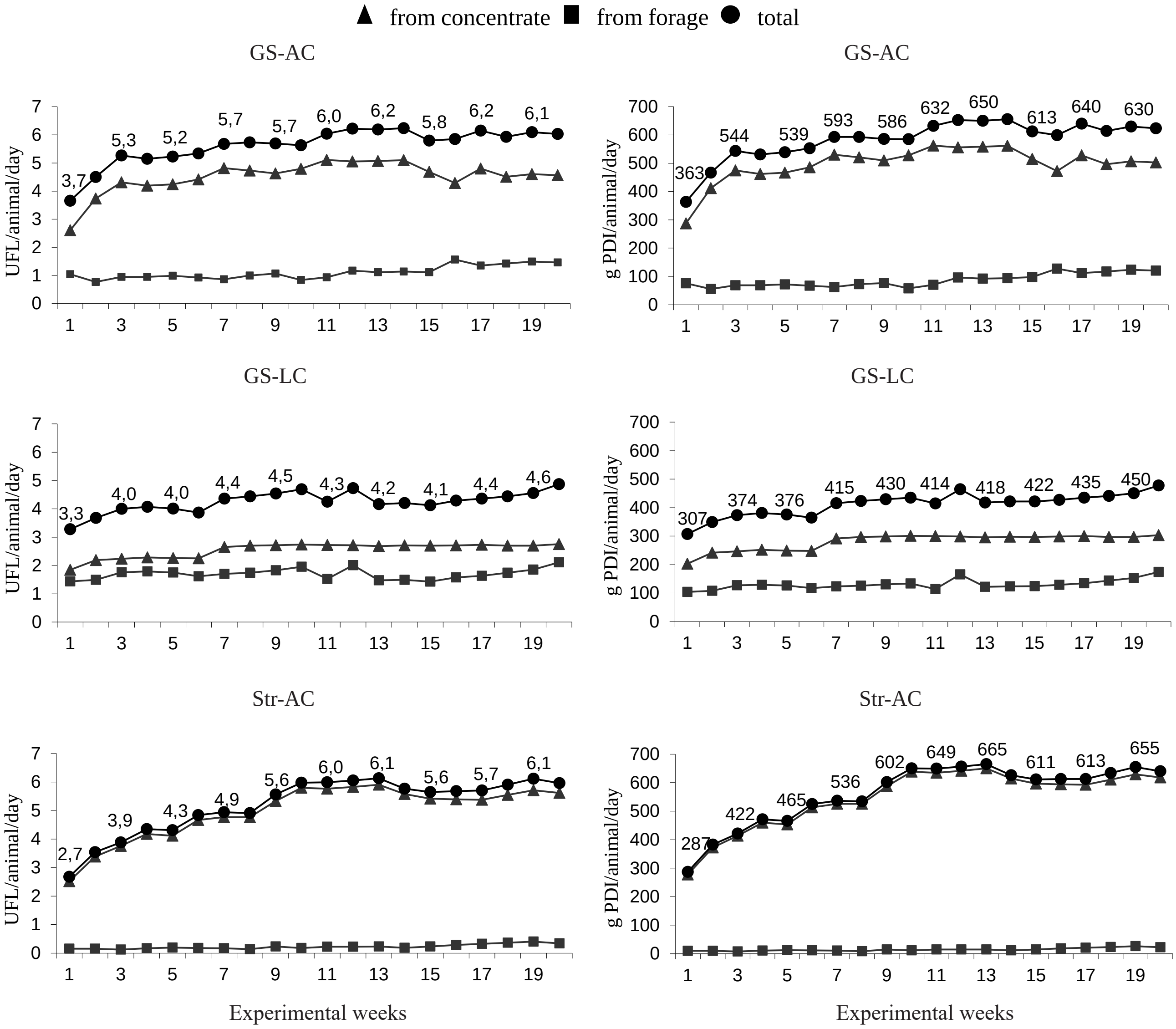

Figure 2. Evolution of net UFL (Unités Fourragères Lait: net energy for maintenance and gain expressed in milk feed units) and PDI (protein truly digestible in the small intestine) intake in the three experimental groups. GS-AC= *ad libitum* grass silage plus *ad libitum* concentrate diet; GS-LC= *ad libitum* grass silage plus limited concentrate diet; Str-AC= barley straw plus *ad libitum* concentrate diet.

forage intake per kg DM concentrate intake). The higher grass silage intake of GS-LC group was not enough to compensate the limitation in concentrate intake and it implied that total UFL and PDI intakes of GS-LC animals were lower than those of GS-AC animals (-1.37 UFL/animal/day and -172 g PDI g/animal/day). The GS-AC lot also showed higher values of UFL and PDI intake than the Str-AC lot, although differences were smaller (+0.43 UFL/animal/day and +21 PDI g/animal/day).

ADWG was significantly ($p\leq0.001$) affected by diet (Table 3). Significant differences ($p\leq0.05$) were observed between the three diets. GS-AC animals presented the highest values; Str-AC animals presented intermediate values and GS-LC the lowest ones. Differences in ADWG implied significant differences ($p\leq0.05$) in live weight at slaughter and hot carcass weight only between the two *ad libitum* concentrate groups (GS-AC and Str-AC) and the group with limited concentrate intake (GS-LC).

No significant differences ($p > 0.05$) were observed between the experimental groups in carcass yield and fatness score (Table 3); however, a significant effect of diet on conformation score (p=0.006) was observed. Conformation values for the GS-AC group were significantly higher than those of GS-LC group ($p \leq 0.05$), and the Str-AC group presented intermediate values with no significant differences to the other two groups ($p > 0.05$).

A significant effect of diet on the weight of perirenal fat was observed ($p \leq 0.001$). GS-AC animals presented

Table 3. Effect of diet [1](GS-AC, GS-LC and Str-AC) on animal performance and carcass characteristics.

	GS-AC n=7	**GS-LC n=7**	**Str-AC n=8**	**Standard deviation**	***p* value**	**[2]*p* value covariate**
[3]ADWG (g/animal/day)	1,059[a]	750[c]	991[b]	94.9	0.000	0.013
Slaughter live weight (kg)	299[a]	253[b]	285[a]	16.7	0.000	0.000
Hot carcass weight (kg)	159[a]	133[b]	152[a]	8.4	0.000	0.000
Carcass yield (%)	53.1	52.6	53.2	1.30	0.569	0.012
Conformation score (1-18)	3.9[a]	2.4[b]	3.1[ab]	0.75	0.006	0.001
Fatness score (1-15)	5.1	4.5	4.7	0.59	0.120	0.030
Perirenal fat weight (g)	4,597[a]	2,728[b]	3,330[b]	638.4	0.000	0.007
Tissue composition of the 6th-rib loin section (%):						
Intermuscular fat	13.49[a]	11.97[ab]	11.17[b]	1.548	0.031	0.053
Subcutaneous fat	3.06	2.15	2.82	0.880	0.158	-
Disectionable total fat	16.54	14.14	13.97	1.934	0.106	-
Muscle	67.90	68.45	70.23	1.989	0.084	-
Bone	13.60	15.61	13.90	1.485	0.061	-
Subcutaneous fat colour:						
L*	74.85	75.59	76.53	1.676	0.175	-
a*	0.92[b]	1.76[a]	0.53[b]	0.546	0.001	-
b*	7.93[b]	9.80[a]	6.85[b]	1.305	0.001	-

[1]GS-AC= *ad libitum* grass silage plus *ad libitum* concentrate diet, GS-LC= *ad libitum* grass silage plus limited concentrate diet, Str-AC= barley straw plus *ad libitum* concentrate diet. [2]Covariate= weight at weaning. [3]ADWG: average daily weight gain.

higher values ($p \leq 0.05$) than the other two groups, with these groups not differing from each other. Diet had not significant effect on % of total dissectionable fat of 6th rib-loin section, but a significant effect (p=0.031) on the percentage of intermuscular dissectionable fat was observed when intermuscular and subcutaneous fat were considered separately. The GS-AC group presented higher ($p \leq 0.05$) values than the Str-AC group, whilst the GS-LC group presented intermediate values not statistically different ($p>0.05$) to the other two groups.

Diet significantly affected subcutaneous fat a* and b* colour values ($p \leq 0.001$). GS-LC animals presented higher values ($p \leq 0.05$) than the other two groups, which showed similar values ($p > 0.05$).

Table 4 shows feed energy and concentrate efficiency utilisation in the three experimental groups. The highest value of UFL/kg of live weight gain corresponded to the animals from the GS-LC group, indicating a lower efficiency of net energy utilization. However, if energy and feed utilisation are expressed per kg of carcass, the lowest average values of UFL and kg DM concentrate/kg carcass corresponded to the GS-LC group (5.09 UFL and 2.99 kg DM concentrate/kg carcass). These average values increased by 0.38 UFL and 1.31 kg DM concentrate per kg carcass for the GS-AC group and by 0.20 UFL and 1.94 kg DM concentrate for the Str-AC group.

Meat proximate composition and lipid composition

Proximate composition of *R. abdominis* and *L. thoracis* muscles (Table 5) showed some differences attributable to diet. Moisture was lower in the GS-AC meat whereas, in turn, intramuscular fat content of *R. abdominis* tended to be higher. Fatty acid profile of intramuscular fat of *R. abdominis* muscle was also significantly affected by diet (Table 5). The most relevant finding regarding the sums of saturated, monounsaturated and polyunsaturated fatty acids (SFA, MUFA and PUFA, respectively) percentages was a

Table 4. Feed energy and concentrate efficiency in the three experimental [1]groups.

	GS-AC n=7	**GS-LC n=7**	**Str-AC n=8**
[2]UFL/kg [3]LW gain	5.03	5.32	5.09
[2]UFL/kg of carcass	5.47	5.09	5.29
kg DM of concentrate/kg [3]LW gain	3.95	3.13	4.74
kg DM of concentrate/kg of carcass	4.30	2.99	4.93

[1]GS-AC= *ad libitum* grass silage plus *ad libitum* concentrate diet; GS-LC= *ad libitum* grass silage plus limited concentrate diet; Str-AC= barley straw plus *ad libitum* concentrate diet; [2]UFL= net energy for maintenance and gain expressed in milk feed units (Unités Fourragères Lait); [3]LW= live weight.

Table 5. Effect of [1]diet on meat quality.

	GS-AC n=7	GS-LC n=7	Str-AC n=8	Standard deviation	*p* value
Longissimus thoracis muscle					
pH at 24 h right side	5.70	5.71	5.65	0.09	0.213
Proximate composition (%)					
Moisture	74.59^{b}	76.49^{a}	75.56^{ab}	0.91	0.004
Protein	21.54	21.40	21.94	0.46	0.092
Intramuscular fat	3.50	2.27	2.72	1.15	0.259
Ash	1.12	1.10	1.10	0.03	0.586
[2]Colour (48 h)					
L*	37.20	35.56	37.38	2.010	0.208
a*	9.33	8.85	10.08	1.765	0.365
b*	14.83	14.97	14.45	1.631	0.984
Hue	57.46^{ab}	58.87^{a}	54.36^{b}	2.446	0.021
C*	17.55	17.45	17.74	2.285	0.792
[3]Drip loss (%)	0.34	0.32	0.36	0.10	0.667
[3]Cooking losses (%)	28.15	28.23	29.90	2.20	0.238
Total collagen (%)	0.668^{ab}	0.804^{a}	0.636^{b}	0.128	0.020
Total collagen (% of total protein)	3.10	3.76	2.88	0.630	0.186
Soluble collagen (% of total collagen)	29.4	32.1	30.1	7.56	0.643
pH at 24 h left side	5.58	5.71	5.59	0.13	0.209
Texture profile analysis					
Hardness (N)	20.44	19.34	20.19	2.05	0.599
Cohesiveness	0.43^{b}	0.44^{b}	0.46^{a}	0.02	0.004
Springiness	0.46^{ab}	0.44^{b}	0.49^{a}	0.03	0.021
Chewiness	4.13^{ab}	3.76^{b}	4.53^{a}	0.59	0.043
Rectus abdominis muscle					
Proximate composition (%)					
Moisture	75.52^{b}	76.82^{a}	76.58^{a}	0.62	0.002
Protein	21.27	20.81	21.44	0.58	0.129
Intramuscular fat	4.06	2.32	2.28	1.28	0.056
Ash	1.07	1.06	1.09	0.03	0.232
[4]Fatty acids (g/100 of the total fatty acids identified)					
SFA	47.31^{a}	46.99^{ab}	45.25^{b}	1.728	0.010
MUFA	44.83	43.76	43.88	1.484	0.068
PUFA	9.63^{b}	9.80^{b}	10.87^{a}	2.084	0.004
PUFA/SFA	0.147^{b}	0.210^{a}	0.241^{a}	0.051	0.000
n-6	6.05^{c}	8.16^{b}	9.77^{a}	1.894	0.000
18:2*n-6*	4.70^{c}	6.05^{b}	7.76^{a}	1.522	0.000
n-3	0.865^{b}	1.448^{a}	0.977^{b}	0.307	0.000
18:3*n-3*	0.413^{b}	0.591^{a}	0.401^{b}	0.111	0.000
n-6/*n-3*	6.99^{b}	5.67^{c}	10.03^{a}	1.968	0.000
[5]TBARS (9d)	0.743	0.759	0.890	0.365	0.583

[1]GS-AC= *ad libitum* grass silage plus *ad libitum* concentrate diet, GS-LC= *ad libitum* grass silage plus limited concentrate diet, Str-AC= barley straw plus *ad libitum* concentrate diet. [2]Steaks were cut from the muscle at 48 h post-slaughter. [3]Calculated as weight differences and expressed in percentage on initial weight basis. [4]SFA, MUFA and PUFA: saturated, monounsaturated and polyunsaturated fatty acids, respectively. [5]After 48 hours post-mortem meat was stored for 7 days into hermetic trays at 4ºC. [a–c]: Values in the same row with different letters are significantly different ($p<0.05$) by the Bonferroni's test.

higher PUFA content in Str-AC meat. Furthermore, this treatment resulted in the highest *n-6* (mainly C18:2*n-6*) fatty acid percentage followed by the GS-LC and then the GS-AC, while GS-LC meat showed the highest percentages of *n-3* (mainly C18:3*n-3*). Therefore, Str-AC treatment resulted in the highest n-6/n-3 ratio, followed by the GS-AC and then GS-LC group ($p \leq 0.05$).

Technological meat quality traits

No differences were found between diets for pH and water losses (Table 5). However, diet affected collagen content, which was higher in GS-LC meat, followed by GS-AC and finally Str-AC, with significant differences ($p<0.05$) between the former and the latter. However, the percentage of collagen per total protein did not show differences between treatments, although GS-LC meat showed again the highest mean value. As regards to texture profile, hardness was not affected by diet; however, cohesiveness, springiness and chewiness were affected. Str-AC meat showed the highest values, with significant differences being found for the three characteristics as compared to GS-LC, and for cohesiveness as compared to GS-AC and GS-LC. No differences were found in the meat texture between the groups of bulls fed on silage (GS-LC *vs* GS-AC). Str-AC meat was thus the most different group in texture.

The effect of the diets on meat colour (Table 5) was only observed for hue. Hue was significantly lower in Str-AC meat than in GS-LC meat, with GS-AC meat being in an intermediate position. Finally, lipid oxidation of the meat was not affected by diet.

Economic margin

The estimated economic margin from the three strategies presented negative values (Table 6). The estimated economic margin was similar for the GS-AC and GS-LC diets (-63.1 and -64.1 €/head, respectively). The higher feeding cost showed by the GS-AC group as compared to the GS-LC one was compensated with a higher carcass selling income in GS-AC with regard to GS-LC due to a higher carcass weight. The average value of economic margin of the Str-AC group was the lowest (-91.8 €/head), which is mainly a result of the relatively high feeding costs.

Discussion

The GS-LC animals presented the highest average value for UFL/kg of live weight gain and thus the lowest efficiency of energy utilisation. This agrees with the study by Blanco *et al.* (2011), who found lower energy utilization efficiency for a fattening diet based on lucerne supplemented with a restricted amount of barley with regards to an *ad libitum* concentrate diet in young Parda bulls. However, Serrano *et al.* (2007) observed no significant effect due to concentrate level (*ad libitum vs* the half of *ad libitum*) or forage type (hay or grass) in diet on the energy utilisation efficiency shown by young Salers bulls slaughtered at 10 months of age. On the contrary, Humada *et al.* (2013) obtained higher values of UFL/kg of live weight gain for intensive finished young Tudanca bulls (fed on concentrate and cereal straw) as compared to semi-extensive reared ones. The discrepancies could be related, at least partially, to differences in forage/concentrate ratios and in fat deposition between studies. In the study by Humada *et al.* (2013), the forage/concentrate ratio in the diet of the semi-extensive reared bulls was higher than that found in present study for the GS-LC group (64:36 *vs* 47:53, respectively) and carcass fat deposition was lower (total dissectionable fat of the 6th rib 7% in Humada *et al.* (2013) *vs* 14% in present work).

Differences in energy and protein intake between the feeding groups of this experiment were detected. These differences, in turn, would be responsible for the significant differences found in the growth rates. The slowest growth rate was shown by the animals from the group fed on high forage and restricted concentrate diet, which showed the lowest efficiency of energy utilisation. In the study by Serrano *et al.* (2007) growth rates were also lower in half-*ad libitum*-concentrate fed bulls than in *ad libitum*-concentrate fed bulls. However, the difference found in that study for ADWG was lower than that found between the GS-AC and GS-LC groups (100 *vs* 260 g/animal/day).

Other works have also compared performance results of young bulls finished on straw and *ad libitum* concentrate or on a high quality forage and limited concentrate diet, in grazing systems (Blanco *et al.*, 2011; Humada *et al.*, 2013; Daza *et al.*, 2014) or in stall systems (Cerdeño *et al.*, 2006). Cerdeño *et al.* (2006) reported a significantly higher ADWG (increases of 600 g/animal/day) when Parda × Limousin young bulls (8 months old) were finished for 60 days on straw plus *ad libitum* concentrate than when the bulls were finished on lucerne hay and restricted concentrate diet. Blanco *et al.* (2011) and Daza *et al.* (2014) did not observe differences in ADWG in Parda and Avileña young bulls, respectively, finished on grazed grass plus a limited quantity of concentrate or with straw and *ad libitum* concentrate. Humada *et al.* (2013) found in a 220-280 day post-weaning period higher ADWG (around 180 g/day/animal) in young Tudanca bulls fed on straw and *ad libitum* concentrate than in those reared

Table 6. Economic performance (€/head) for the three strategies of [1]production.

	GS-AC	GS-LC	Str-AC
Total feeding cost	312.0	209.6	320.2
Concentrate	273.9	157.7	303.3
Conserved forages	32.4	46.2	11.2
Vitamin-mineral supplement	5.7	5.7	5.7
Health and hygiene costs	55.4	55.4	55.4
Veterinarian products and services	32.0	32.0	32.0
Cleaning and maintenance	23.4	23.4	23.4
Machinery cost	7.9	7.9	7.9
Transport and slaughter cost	88.1	78.5	86.1
Interest of working capital	9.1	7.5	8.5
Costs (€/head)	472.5	357.9	478.2
Carcass selling	654.6	540.0	631.6
[2]Fattening subsidy	32.7	32.7	32.7
Total income (€/head)	687.3	572.7	664.2
Total income – Costs	214.8	213.7	186.1
Family labour cost	77.9	77.9	77.9
[3]5-months old weaned calf value	200.0	200.0	200.0
Economic margin (€/head)	-63.1	-64.1	-91.8
Sensitivity analysis of economic margin			
Increase 25% concentrate cost			
Economic margin (€/head)	-131.5	-103.5	-170.4
Increase in carcass selling price to 5.2 €/kg			
Economic margin (€/head)	92.8	64.5	58.6
Increase 25% concentrate cost + increase carcass selling price to 5.2 €/kg			
Economic margin (€/head)	24.3	25.1	-17.2

[1]GS-AC= *ad libitum* grass silage plus *ad libitum* concentrate diet, GS-LC= *ad libitum* grass silage plus limited concentrate diet, Str-AC= barley straw plus *ad libitum* concentrate diet. [2]32.7 €/calf finished at the same exploitation of birth (FEGA, 2017). [3]Opportunity cost of weaned calf: average price of 5 month old weaned calves.

under a semi-extensive system (grass and restricted concentrate feeding). The ADWG found for the straw plus *ad libitum* concentrate bulls was similar to that found for the Str-AC animals in this study. However, when considering only the last 120 days of the finishing period, Humada *et al.* (2013) found a higher ADWG for the bulls reared under the semi-extensive system. In order to explain this apparent contradiction, the authors suggested that the growth rate depended not only on the levels of protein and energy in the ration but also upon a mix of animal physiological factors interrelated with those levels, *e.g.* compensatory growth or differences in fat deposition associated to age and growth rate. The higher ADWG of GS-AC animals with respect to Str-AC ones should be due to the higher energy and protein intakes of the former.

It is worth taking into account that the grass silage used in this experiment should be considered as a medium quality forage (INRA, 2007). It would have been expected that the use of higher-quality silage would have enabled an increase in forage and nutrient intakes in GS-LC cattle and thus an improvement in growth performance. The feeding value of grass silage can vary dramatically depending on several factors such as harvest season, botanical composition, growth, wilting, etc. (Martínez-Fernández *et al.*, 2014). Keady *et al.* (2008) observed that when high-feed value grass silage was offered to finishing steers, increasing concentrate level was not associated with an increase in metabolizable energy intake. They also observed that concentrate level showed greater effects on growth performance and carcass quality when animals were offered low-quality silage, than when they were offered high-quality silage. Increasing forage quality would be necessary too to meet limitations in the proportion of concentrates in the ration as that of the Standard Organic (minimum forage to concentrate ratio of 60:40 in DM basis; EC, 2007).

In this study it was found that feeding the animals with a relatively high level of forage (silage) and a restricted level of concentrate showed some negative effects on carcass conformation and perirenal fat amount – no other fatness characteristic was affected – as compared to feeding with the *ad libitum* concentrate diets. However, these effects would be expected to have a low impact on the commercial value of the young Tudanca bull carcasses. This is because the differences in conformation appeared to be slight, taking into account that following the European Union beef carcass classification grid (EC, 2006) the conformation score turned out to be the same for the carcasses from the three experimental groups (= P, poor conformation; EC (2006)), and the amount of perirenal fat is not used for carcass classification purposes. Furthermore, conformation and fatness of GS-LC carcasses might be improved by increasing the slaughter live weight of animals until reaching the weight of the animals fed on concentrate *ad libitum* or by decreasing the level of concentrate restriction. Moreover, when comparing the bulls fed on silage with those fed on straw (both using concentrate *ad libitum*; GS-AC *vs* Str-AC) no effect on carcass conformation was evidenced. However, with regard to fatness, perirenal fat amount and intermuscular dissected fat percentage were higher in the animals fed silage. This difference could be related with the higher ADWG in these animals, which could have resulted in higher fat deposition.

In studies comparing the carcass characteristics of young bulls fed on *ad libitum* concentrate *vs* restricted concentrate diets where bulls were slaughtered at a fixed live weight (Blanco *et al.*, 2010; 2011; Daza *et al.*, 2014) no differences in carcass weight, conformation and fatness were observed between diets. On the other hand, when bulls were slaughtered at a fixed age, as in the present study (Cerdeño *et al.*, 2006; Serrano *et al.*, 2007; Humada *et al.*, 2013) some significant differences were found between diets. Serrano *et al.* (2007), in agreement with our results, observed lower carcass weight (p<0.05) in animals receiving a restricted quantity of concentrate than in *ad libitum* concentrate fed animals and no significant effects of concentrate level on dressing percentage and carcass fatness score; however, unlike our results, they found no significant effect of concentrate level on carcass conformation. Cerdeño *et al.* (2006), in contrast, reported lower carcass fatness score and percentages of dissected fat from the 6th rib loin section for the carcasses of young bulls fed with a restricted concentrate diet regarding those from straw plus *ad libitum* concentrate fed bulls, and did not report differences in carcass conformation score. In agreement with this study, Humada *et al.* (2013) observed no differences in carcass conformation and fatness score between carcasses of Tudanca young bulls finished in a grazing system supplemented with restricted concentrate and those finished in a stall system fed on straw and *ad libitum* concentrate. However, and also in agreement with the present results, in spite of the lack of differences in carcass fatness score, the amount of perirenal fat was significantly higher in carcasses from the *ad libitum* concentrate fed animals. These authors attributed this increase to both a higher energy level of their diet and a more precocious development of perirenal fat than that of other fat depots, *i.e.*, intramuscular or subcutaneous fat. Discrepancies between studies on the effect of the concentrate restriction on young bull carcass fatness could be at least partially explained by animal breed- or age-related variability (Piedrafita *et al.*, 2003; Humada *et al.*, 2013).

Muscle pH values for all treatments were in the normal range and no differences were observed between diets. With regard to meat colour, the high forage (GS-LC) experimental diet resulted in a subcutaneous fat with a more yellow and red colour (higher a* and b*, respectively). These results can be attributed to differences in the levels of β-carotene in fat between the feeding treatments (Cerdeño *et al.*, 2006; Blanco *et al.*, 2010, 2011). This compound is the predominant carotenoid pigment in bovine fat and its colour is orange so it contributes to fat redness and yellowness (Yang *et al.*, 1992). Although carotenoids are partially destroyed as a consequence of forage conservation processes, ensiled forages presented a relatively high content of these compounds compared to straw and concentrates (Chauveau-Duriot *et al.*, 2005; Serrano *et al.*, 2006).

GS-AC showed a tendency to higher IMF content, this result agrees with the higher intermuscular fat content of the 6th rib and perirenal fat weight of this treatment. These effects would be associated with the higher ADWG in these animals resulting in a higher growth rate of fat depots. Perirenal and intermuscular fat depots have earlier development than intramuscular fat (Vernon, 1986; Arana *et al.*, 1998).

In the literature, the effect of forage type and concentrate level in the diet of young bulls on the IMF content is not consistent across studies. Cerdeño *et al.* (2006), Serrano *et al.* (2007) and Daza *et al.* (2014) observed no significant effect due to concentrate level or forage type. However, Blanco *et al.* (2010) and Humada *et al.* (2013) observed differences in the IMF content of meat. Differences among the studies might explained by for a range of confounding factors such as breed, age, forage quality, length of the finishing period or physical activity (Micol *et al.*, 1993).

The effect of the dietary treatments on the fatty acid profile could be attributed to two interrelated factors, *i.e.*, fatty acid content in the diet and IMF content in meat. On the one hand, the corresponding intake of grass silage, rich in *n-3* fatty acids, and concentrate, rich in *n-6*, by the young bulls from the different experimental feeding groups (Table 1), would be mainly responsible for the highest *n-3* proportion (and lowest *n-6*/*n-3* ratio) in the GS-LC meat and the highest *n-6* proportion (and *n-6*/*n-3* ratio) in the Str-AC meat, GS-AC meat being at an intermediate position with regards to that ratio. On the other hand, it is well known that higher contents of IMF in meat involve higher neutral lipids and lower phospholipid rates, and, in turn, higher SFA and lower PUFA proportions (Wood *et al.*, 2008); this effect would mainly account for the lower PUFA/SFA in GS-AC meat (showing the highest IMF content; p=0.056). A healthy dietary fat source should contain a high proportion of PUFA compared with SFA and a high proportion of *n-3* fatty acids within the PUFA (Simopoulos, 2002). According to this statement, the fat of GS-LC meat should be the most valuable, because it shows the highest PUFA/SFA ratio (together with Str-AC meat) and the lowest *n-6*/*n-3*. On the other hand, the disadvantage of GS-AC meat would be its comparatively low PUFA/SFA ratio and that of Str-AC meat its high *n-6*/*n-3* ratio.

The higher amount of collagen in GS-LC meat (Table 5) could be explained at least partially by a lower growth rate at slaughter of GS-LC animals, due to lower concentrate intake. However, as collagen solubility (soluble collagen to total collagen) was not affected by diet, the reported positive effect of growth rate on collagen solubility (Miller & Cross, 1987; Muir *et al.*, 1998) was not observed in the present study, which could be justified by the young age of bulls at slaughter.

The results of the texture profile analysis regarding hardness were in partial agreement with Moloney & Drennan (2013), who did not find effect of grass silage *vs* concentrate based diets on this characteristic, although in that study hardness was assessed as the shear force value. The lack of effect of total collagen content on collagen solubility and hardness could be attributed to high collagen solubility and relatively small variation in collagen content, due to the young and similar age of animals at slaughter (Gerrard *et al.*, 1987; Purslow, 2005).

With regard to colour, the present results confirm the statement of Moloney & Drennan (2013), that there seems to be a lack of effect (or hardly any) due to grass silage-based rations being supplemented with concentrates, as compared to concentrate plus straw-based rations on meat colour (as well as other meat quality traits such as pH and sensory characteristics). TBARS levels were under the threshold of 2 mg of malondialdehyde per kilogram of meat, considered as the acceptable oxidation level of raw beef (Campo *et al.*, 2006).

The economic margin calculated in this study presented negative values for the three strategies of production. Moreover, if family labour costs are not considered for calculations, only silage using strategies (GS-AC and GS-LC) would reach positive net profits. However, an increase of 24% of carcass selling price from the market value to 5.2 €/kg of carcass (price suggested by the local farmers as the price to overcome a threshold of profitability) would lead to positive net profits in the three groups.

The higher amount of concentrate consumed by the Str-AC animals considerably reduced the economic margin of this group with regard to the other two groups, which presented similar profitability. Under the assumption of an economic context with increased concentrate prices (sensitivity analysis), which could be especially relevant considering its current trend subject to strong volatility, the GS-AC and Str-AC would be the most affected feeding strategies. On the other hand, in a context with increased carcass prices, the economic margin of the GS-AC group would be increased to values higher than that estimated for the GS-LC group (Table 6). In agreement, Blanco *et al.* (2011) and Humada *et al.* (2013) also reported greater profitability from the rearing of young bulls finished on pasture and restricted concentrate allowance as compared to feeding alternatives using concentrate *ad libitum*. They also pointed out a higher robustness of low concentrate systems in a situation of high concentrate prices.

The higher forage (GS-LC) finishing diet as compared with the *ad libitum* concentrate finishing diets (GS-AC and Str-AC) has resulted in animals showing lower ADWG; moreover, GS-LC-carcasses tended to have slightly lower conformation. On the other hand, high-forage feeding has demonstrated a relatively high profitability and lower dependence on concentrate. When *ad libitum* concentrate diets were compared, the carcass characteristics obtained from the animals fed on the GS-AC and Str-AC diets were very similar; however, the GS-AC diet resulted in higher ADWG and a greater economic margin. Decreasing the concentrate levels has had an effect on fatty acid profile attributable to both a decrease of intramuscular fat deposition and a dietary change in the fatty acid profile, *i.e.*, higher levels of *n-3* fatty acids. This has resulted in a tendency for the *ad libitum* grass-silage and restricted concentrate diet to produce the most favourable fatty acid composition. The study confirms that in indoor feeding systems, technological meat quality traits, such as texture, colour and lipid oxidative stability of raw meat, are not negatively affected by the inclusion of silage as forage source with regard to straw and the reduction in concentrate level. The results suggest that both substitution of straw by grass silage and restriction of the concentrate level in the finishing diets could be recommended for finishing young Tudanca bulls and for the establishing of Tudanca beef quality labelling schemes. In order to generate further recommendations regarding more appropriate high-forage finishing diets, further studies are recommended using additional concentrate levels to those of this study and higher quality grass silage; the latter because increasing forage quality could be essential to increase forage consumption and nutrients intake when using restricted concentrate diets. Those further studies should consider the effect of diet on sensory characteristics of meat and the effect of live weight at slaughter as an additional experimental factor on both, carcass quality and economic performance.

Acknowledgments

The authors thank César Cimadevilla, the personnel at the *Finca Aranda*, Carlos Murga, Patricia Manrique, Sara Jiménez and Irene Velasco, the *Laboratorio Agrícola del CIFA*, the *Cooperativa Agrocantabria*, *GESCANORSA* staff and the Official Veterinarian staff for their assistance.

References

AOAC, 1990. Official Methods of Analysis of the Association of Official Analytical Chemistry. AOAC, Virginia, USA.

AOAC, 1999. Official Methods of Analysis of the Association of Official Analytical Chemistry. AOAC, Virginia, USA.

Arana A, Soret B, Mendizabal JA, Corroza M, Eguinoa P, Purroy A, 1998. Changes in adipose tissue accumulation in Rasa Aragonesa breed lambs during growth and fattening. Anim Sci 66: 409-413. https://doi.org/10.1017/S1357729800009553

Bernués A, Olaizola A, Corcoran K, 2003. Extrinsic attributes of red meat as indicators of quality in Europe: An application for market segmentation. Food Qual Prefer 14: 265-276. https://doi.org/10.1016/S0950-3293(02)00085-X

Blanco M, Casasús I, Ripoll G, Panea B, Albertí P, Joy M, 2010. Lucerne grazing compared with concentrate-feeding slightly modifies carcase and meat quality of young bulls. Meat Sci 84: 545-552. https://doi.org/10.1016/j.meatsci.2009.10.010

Blanco M, Joy M, Ripoll G, Sauerwein H, Casasús I, 2011. Grazing lucerne as fattening management for young bulls: technical and economic performance and diet authentication. Animal 5: 113-122. https://doi.org/10.1017/S1751731110001461

BOE, 2008. Royal decree 2129/2008, of 26 December, that established the National Programme of Preservation, Improvement and Fostering of Livestock Breeds. Boletín Oficial del Estado (Spain) No. 23, 27/1/09.

BOE, 2013. Law 22/2013, of 23 December, General State Budget for 2014. Boletín Oficial del Estado (Spain) No. 309, 26/12/13.

Bourne MC, 1978. Texture profile analysis. Food Technol 32: 62-6.

Campo MM, Nute GR, Hughes SI, Enser M, Wood JD, Richarson RI, 2006. Flavour perception of oxidation in beef. Meat Sci 72: 303-311. https://doi.org/10.1016/j.meatsci.2005.07.015

Carballo JA, Monserrat L, Sánchez L, 2005. Composición regional y tisular de la canal bovina. In: Estandarización de las metodologías para evaluar la calidad del producto (animal vivo, canal, carne y grasa) en los rumiantes; Cañeque V, Sañudo C (eds.) pp: 120-140. Monografías INIA: Ganadera Nº 3, Madrid.

Cerdeño A, Vieira C, Serrano E, Lavín P, Mantecón AR, 2006. Effects of feeding strategy during a short finishing period on performance, carcass and meat quality in previously-grazed young bulls. Meat Sci 72: 719-726. https://doi.org/10.1016/j.meatsci.2005.10.002

Chauveau-Duriot B, Thomas D, Portelli J, Doreau M 2005. Effet du mode de conservation sur la teneur en caroténoïdes des fourrages. Renc Rech Rum 12: 117.

CIE, 1976. Colour System. Commission Internationale de l'Eclairage, Paris. Publication 36.

Daza A, Rey AI, López-Carrasco C, López-Bote CJ, 2014. Influence of feeding system on growth performance, carcass characteristics and meat and fat quality of Avileña-Negra Ibérica calves' breed. Span J Agric Res 12: 409-418. https://doi.org/10.5424/sjar/2014122-4096

Domínguez R, Crecente S, Borrajo P, Agregán R, Lorenzo JM, 2015. Effect of slaughter age on foal carcass traits and meat quality. Animal 9: 1713-1720. https://doi.org/10.1017/S1751731115000671

EC, 2006. Council Regulation 1183/2006/EC concerning the Community scale for the classification of carcasses of adult bovine animals (codified version). 24 July 2006 [LEX-32006R1183]. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006R1183&from=EN:PDF

EC, 2007. Council Regulation 2007/834/EC organic production and labelling of organic products and repealing Regulation 2092/91/EC. 28 June 2007 [LEX-32007R0834]. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007R0834&from=EN:PDF

EC, 2009. Council Regulation (EC) 1099/2009 on protection of animals at the time of killing. 24 september 2009 [Lex-32009R1099]. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R1099&from=EN

FEGA, 2017. Ayuda asociada para las explotaciones de vacuno de cebo. España Peninsular. Campaña 2015. Fondo Español de Garantía Agraria, Gobierno de España. https://www.fega.es/sites/default/files/Ayuda_Asociada_Vacuno_de_Cebo_Espana_Peninsular_2015-2016.pdf

Gerrard DE, Jones SJ, Aberle ED, Lemenager RP, Diekman MA, Judge MD, 1987. Collagen stability, testosterone secretion and meat tenderness in growing bulls and steers. J Anim Sci 65: 1236-1242. https://doi.org/10.2527/jas1987.6551236x

Goering HK, Van Soest PJ, 1970. Forage fiber analysis. In: Agricultural Handbook Nº 379. pp. 1-20. USDA.

Honikel KO, 1998. Reference methods for the assessment of physical characteristics of meat. Meat Sci 49: 447-457. https://doi.org/10.1016/S0309-1740(98)00034-5

Humada MJ, Serrano E, Sañudo C, Rolland DC, Dugan MER, 2012. Production system and slaughter age effects on intramuscular fatty acids from young Tudanca bulls. Meat Sci 90: 678-685. https://doi.org/10.1016/j.meatsci.2011.10.013

Humada MJ, Sañudo C, Cimadevilla C, Serrano E, 2013. Efecto del sistema de producción y la edad de sacrificio sobre parámetros productivos, calidad de la canal y rendimiento económico de la producción de terneros y añojos de raza Tudanca. ITEA - Inf Tecn Econ Agr 109: 183-200.

ICANE, 2017. Censo de las principales razas de ganado vacuno. Instituto Cántabro de Estadística, Gobierno de Cantabria. http://www.icane.es/data/cattle-major-breeds#-timeseries

INE, 2016. Cálculo de variaciones del índice de precios al consumo (enero 2005-diciembre 2014). Instituto Nacional de Estadística, Gobierno de España. http://www.ine.es/varipc/index.do

INRA, 2007. Alimentation des bovins, ovins et caprins. Quae Editions, Versailles, France.

Kallas Z, Realini CE, Gil JM, 2014. Health information impact on the relative importance of beef attributes including its enrichment with polyunsaturated fatty acids (omega-3 and conjugated linoleic acid). Meat Sci 97: 497-503. https://doi.org/10.1016/j.meatsci.2014.03.015

Keady TWJ, Lively FO, Kilpatrick DJ, Moss BW, 2008. The effects of grain treatment, grain feed level and grass silage feed value on the performance of and meat quality from finishing beef cattle. Animal 2: 149-159. https://doi.org/10.1017/S1751731107000948

MAPAMA, 2017a. Catáloto Oficial de Razas. Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente, Gobierno de España. http://www.mapama.gob.es/es/ganaderia/temas/zootecnia/razas-ganaderas/razas/catalogo/

MAPAMA, 2017b. Publicación de Precios e Índices Percibidos, Pagados y Salarios Agrarios (IPPAS enero 2014-septiembre 2016). Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente, Gobierno de España. http://www.mapama.gob.es/es/estadistica/temas/estadisticas-agrarias/ippasenero2014-septiembre2016_tcm7-432019.pdf

Maria GA, 2006. Public perception of farm animal welfare in Spain. Livest Sci 103: 250-256. https://doi.org/10.1016/j.livsci.2006.05.011

Márquez L, 2007. Los tractores en la agricultura española. Parte 2: Costes de utilización. Revista Agrotécnica Junio: 69-73.

Martínez-Fernández A, Argamentería A, de la Roza B, 2014. Manejo de forrajes para ensilar. Servicio Regional de Investigación y Desarrollo Agroalimentario del Principado de Asturias, España. 280 pp.

Micol D, Robelin J, Geay Y, 1993. Composition corporelle et caractéristiques biologiques des muscles chez les bovins en croissance et à l'engrais. INRA Prod Anim 6: 61-69.

Miller MF, Cross HR, 1987. Effect of feed energy intake on collagen characteristics and muscle quality of mature cows. Meat Sci 21: 287-294. https://doi.org/10.1016/0309-1740(87)90065-9

Moloney AP, Drennan MJ, 2013. Characteristics of fat and muscle from beef heifers offered a grass silage or concentrate-based finishing ration. Livest Sci 152: 147-153. https://doi.org/10.1016/j.livsci.2012.12.001

Muir PD, Deaker JM, Bown MD, 1998. Effects of forage- and grain-based feeding systems on beef quality: A review. New Zeal J Agr Res 41: 623-635. https://doi.org/10.1080/00288233.1998.9513346

Nam KC, Ahn DU, 2003. Combination of anaerobic and vacuum pack-aging to control lipid oxidation and off-odour volatiles of irradiatedraw turkey breast. Meat Sci 63: 389-395. https://doi.org/10.1016/S0309-1740(02)00098-0

Nuernberg K, Dannernberger D, Nuernberg G, Ender K, Voigt J, Scollan ND, Wood JD, Nute GR, Richardson RI, 2005. Effect of a grass-based and a concentrate feeding system on meat quality characteristics and fatty acid composition of *longissimus* muscle in different cattle breeds. Livest Prod Sci 94: 137-147. https://doi.org/10.1016/j.livprodsci.2004.11.036

Olaizola A, Bernués A, Blasco I, Sanz A, 2012. Perspectivas de una carne de calidad diferenciada: análisis exploratorio para la carne de vacuno "Serrana de Teruel". ITEA-Inf Tecn Econ Agr 108: 546-562.

Piedrafita J, Quintanilla R, Sañudo C, Olleta JL, Campo MM, Panea B, Renad G, Turin F, Jabet S, Osoro K, *et al.* 2003. Carcass quality of 10 beef breeds of the southwest of Europe in their typical production systems. Livest Prod Sci 82: 1-13. https://doi.org/10.1016/S0301-6226(03)00006-X

Priolo A, Micol D, Agabriel J, 2001. Effects of grass feeding systems on ruminant meat colour and flavour. A review. Anim Res 50: 185-200. https://doi.org/10.1051/animres:2001125

Purslow PP, 2005. Intramuscular connective tissue and its role in meat quality. Meat Sci 70: 435-447. https://doi.org/10.1016/j.meatsci.2004.06.028

Resano H, Sanjuán AI, 2017. The role of beef brands for consumers. A cross-regional analysis. ITEA-Inf Tecn Econ Agr 113: 267-286.

Resconi VC, Campo MM, Font i Furnols M, Montossi F, Sañudo C, 2010. Sensory quality of beef from different finishing diets. Meat Sci 86: 865-869. https://doi.org/10.1016/j.meatsci.2010.07.012

Sami AS, Augustini C, Schwarz FJ, 2004. Effects of feeding intensity and time on feed on performance, carcass characteristics and meat quality of Simmental bulls. Meat Sci 67: 195-201. https://doi.org/10.1016/j.meatsci.2003.10.006

Serrano E, Prache S, Chauveau-Duriot B, Agabriel J, Micol D, 2006. Traceability of grass-feeding in young beef using carotenoid pigments in plasma and adipose tissue. Anim Sci 82: 909-918. https://doi.org/10.1017/ASC200698

Serrano E, Pradel P, Jailler R, Dubroeucq H, Bauchart D, Hocquette J-F, Listrat A, Agabriel A, Micol D, 2007. Young salers suckled bull production: effect of diet on performance, carcass and muscle characteristics and meat quality. Animal 1: 1068-1079. https://doi.org/10.1017/S1751731107000225

Simopoulos AP, 2002. The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomed Pharmacother 56: 365-379. https://doi.org/10.1016/S0753-3322(02)00253-6

Van Elswyk MR, McNeill SH, 2014. Impact of grass/forage feeding versus grain finishing on beef nutrients and sensory quality: The U.S. Experience. Meat Sci 96: 535-540. https://doi.org/10.1016/j.meatsci.2013.08.010

Van Soest PJ, 1982. Nutritional ecology of the ruminant animal. C.U.P., Ithaca, USA.

Van Soest PJ, Robertson JB, Lewis BA, 1991. Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci 74: 3583-3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Vázquez I, Olaizola AM, Resano H, Serrano E, Gómez F, Domínguez M, 2016. Perspectivas del cebo de ternero de la raza Tudanca en Cantabria: Aplicación del método Delphi. Proc Raças Autóctones no Espaço Ibérico: Um Recurso Sustentável, Vila Real (Portugal), Nov 6-7. pp: 187-192.

Vernon RG, 1986. The growth and metabolism of adipocytes. Proc 43th Nottingham Easter School in Agricultural Science; pp: 67-83. Butterworths, London.

Wood JD, Enser AV, Fisher GR, Nute PR, Sheard RI, Richarson SI, Hughes SU, Whittington FM, 2008. Fat deposition, fatty acid composition and meat quality: A review. Meat Sci 78: 343-358. https://doi.org/10.1016/j.meatsci.2007.07.019

Yang A, Larsen TW, Tume RK, 1992. Carotenoid and retinol concentrations in serum, adipose tissue and liver and carotenoid transport in sheep, goats and cattle. Aust J Agric Res 43: 1809-1817. https://doi.org/10.1071/AR9921809