PAPER

Performance and carcass quality of forage-fed steers as an alternative to concentrate-based beef production

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Abstract

This paper studies the performance and carcass quality of Parda de Montaña cattle under different management systems to find alternatives to concentrate feed indoor beef production. Treatments were: i) Control, with 8 bulls (216±34.3 kg initial weight; 282±45.6 days) fed concentrate and straw *ad libitum* during winter housing period until reaching 500 kg; ii) G-supp, with 8 steers (204±31.2 kg initial weight; 271±47.5 days) fed a total mixed ration (TMR) (50% alfalfa hay, 10% straw, 40% corn) *ad libitum* during winter housing period (from mid-April steers rotationally grazed on a mountain meadow supplemented with 1.8 kg dry matter corn/d until reaching 500 kg); iii) TMR, with 8 steers (200±42.5 kg initial weight; 261±39.0 days) managed as G-supp steers until mid-July, when they were housed and fed TMR *ad libitum* until reaching 500 kg.Control bulls had 45% greater weight gain than TMR and G-supp steers during housing period (P<0.001). In the finishing period, TMR had 31% greater weight gain than steers finished on pasture (P<0.01). At slaughter, Controls were 97-127 days younger than others (P<0.001). Steers finished on TMR had worse conformed carcasses, greater fat and fewer edible meat proportions than G-supp and Control (P<0.01). Total cost of TMR and G-supp was greater than Control, with a similar income for G-supp and Control. TMR steers were paid less because of their worse carcass quality. Hence, finishing of steers on pasture with a supplement can be a feasible alternative to fattening bulls on concentrates, depending on the relative availability and price of feedstuff.

Introduction

Traditionally, in the dry mountain areas of Mediterranean countries, beef calves are raised with their dams until weaning at 5-8 months, when they are sold to be finished with concentrates and straw in feedlots in the valleys. In the last decades, several attempts have been made to finish them in the mountain areas (García-Martínez *et al*., 2009) in order to sustain or improve the returns of farmers. However, the success of such operations is highly dependent on cereal prices.

The uncertainty of cereal prices, the availability of feedstuffs and consumer preferences have increased the interest of farmers for forage-based systems in these areas. Low-input, self-sufficient pasture-based systems can satisfy societal demands such as landscape and biodiversity conservation or ethical concerns about food production and are less vulnerable to market changes (Bernués *et al*., 2011). Forage-based systems in cattle production have longer duration than concentrate-based fattening systems, thus, they require the prepubertal castration of the animals to reduce their sexual and aggressive behaviour.

Finishing steers in meadows after they had received a high-feeding level during the winter period is a feasible system in dry mountain areas, but it causes the scarcity of carcass fatness (Blanco *et al*., 2012). A narrow subcutaneous fat cover can have a negative impact on meat quality due to the cold shortening (Dolezal *et al*., 1982). Therefore, a finishing period would be advisable in order to improve carcass quality. Cattle are usually finished on concentrates after grazing, which improves subcutaneous fat (Blanco *et al*., 2010), but may change meat quality. If cattle were finished with a high-forage total mixed ration, however, carcass fatness could be improved without an increase of the use of cereals on-farm. The aim of this study was to analyse the performances and carcass quality of steers slaughtered from pasture and steers finished with a total-mixed ration after grazing, and then compare them with the control, concentrate-fed young bulls.

Materials and methods

All procedures were conducted according to the guidelines of the Council Directive 86/609/EEC (European Commission, 1986) for the protection of animals, used for experimental and other scientific purposes.

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Animals

This study was conducted in La Garcipollera Research Station, located in the Spanish Pyrenees (42º37'N, 0º30'W; 945 m asl) and in the Agrifood Research and Technology Centre of Aragon (CITA), located in the Ebro Valley (41°43'N, 0°48'W; 225 m asl). Twenty-four Parda de Montaña calves were born in La Garcipollera Research Station (average birth date: 4th March ±9.8 days). Calves remained with their dams indoors from birth to mid-June (age 102±8.8 d); they all grazed together in high mountain ranges until mid-September, when they were weaned (live weight 184±6.8 kg; age 200±9.8 d).

Animals were transported for 2 h (144 km) to a feedlot facility in CITA Research Station to be housed during the winter period. Upon arrival young bulls were randomly assigned to one of the three management strategies, according to the weaning weight and the average daily gains during grazing and lactation. Each group was allocated in a feedlot, in a separate pen, with concrete floor and straw as bedding material. One group of males remained intact (control; n=8) and the other two groups were castrated seven days after arrival. The animals were castrated by surgical removal of the testes using local anaesthesia and analgesia with xylazine (5 cc Rompún®;

Bayer, Leverkusen, Germany) and ketamine (5 cc Imalgene®; Mérial, Lyon, France) and local antibiotics with penicillin and posterior analgesia with flunixin-meglumine (Finadyne®; Schering-Plough, Kenilworth, NJ, USA). The experiment started 15 days after castration (29th November).

The intact young bulls were housed since the beginning of the experiment (29th November) until they reached the target slaughter weight (500 kg) (Figure 1). They received concentrate plus straw. Concentrate was offered once a day as 110% of the intake of the previous day. The concentrate was mainly composed by corn (32.0%), barley (23.5%), gluten feed (12.0%), sugar beet pulp (10.0) and soybean meal (9.4%). Water, barley straw and minerals were offered *ad libitum* in the pen.

The group G-supp steers (n=8) was housed from the beginning of the experiment until the grazing season started (18th April). Steers received a total mixed ration composed by alfalfa hay (50%), barley straw (10%) and corn (40%). The total mixed ration was offered once daily as 110% of the intake of the previous day. At the beginning of the grazing season (18th April), steers were transported to La Garcipollera Research Station to graze in natural valley meadows until they reached the target slaughter weight (500 kg). The meadow composed by *Graminaceae* (80%), *Leguminosae* (4%) and other families (16%) was divided in three 0.8 ha paddocks to allow a rotational grazing. Steers were changed to a new paddock fortnightly to ensure that stubble height was above 10 cm. At 08:00 a.m., 1.8 kg dry matter (DM) corn per head per day was delivered. Water and minerals were offered *ad libitum* in the plots.

The group of total mixed ration (TMR) steers (n=8) were identically managed as G-supp steers until the 12th July, when they were loose-housed to be finished until they reached the target slaughter weight (500 kg). Steers received a total mixed ration composed by alfalfa hay (50%), barley straw (10%) and corn (40%). The total mixed ration was offered once daily as 110% of the intake of the previous day. Water and minerals were offered in the pen.

Measurements

Individual live weight (LW) was obtained weekly for all the animals at 08:00 a.m. without deprivation of feed and water. Steers were also weighed before and after transportation. Live weights were used to calculate average daily gain (ADG) by linear regression of LW for the following periods: housing (control bulls: from 29th November to slaughter; TMR and G-supp steers: from 29th November to 18th April), steers grazing (from 25th April to 12th July) and steers finishing (from 12th July to slaughter).

The animals were bled monthly at 08:00 a.m. by puncture of the coccygeal vein. The samples were collected into test tubes containing ethylenediaminetetraacetic acid to obtain plasma. Afterwards, the blood samples were centrifuged at 2122 g for 5 min, the plasma was extracted and frozen at –20ºC for subsequent assay to determine urea, triglycerides (TG), β-hydroxybutyrate (BHB) and non-esterified fatty acids (NEFA).

Dorsal fat thickness and muscle depth were measured by ultrasonography with a multi-frequency probe (7.5 MHz; Aloka SSD-900; Aloka Co., Ltd., Tokyo, Japan) at the 13th thoracic vertebra perpendicularly to the backbone. Skin contact with the transducer was achieved using an ultrasound contact gel. The measurements were recorded the 17th April (the end of steers' housing period), 12th July (the starting day of the steers' finishing period), and the day before slaughter.

During the housing and finishing periods, the feedstuffs offered and refusals were recorded daily to estimate the daily intake on a group basis. During the grazing period, forage mass in each paddock was measured fortnightly before (pre-grazing) and after grazing (post-grazing) by clipping with an electrical mower all plant material 2 cm above ground level in 20 quadrates of 0.25 m^2 randomly located in the paddock. Forage intake was estimated as proposed by Smit *et al*. (2005), considering the difference between pre- and post-grazing mass plus forage growth between measurements, according to the estimated daily growth rate proposed by Álvarez-Rodríguez *et al*. (2006), obtained in the same conditions.

Chemical analyses

Feedstuffs

Samples of the different feedstuffs were collected weekly throughout the experimental period and pooled at fortnight intervals to determine their chemical composition. Samples were dried at 60°C until constant weight and mill-ground (1 mm screen). Moisture and ash were determined by gravimetric method. Moisture was determined at 103°C and ash content was determined after ignition in a muffle for 3 h (AOAC, 1999). Crude protein content was determined following the Dumas Procedure (AOAC, 1999) using a Nitrogen and Protein analyser (Model NA 2100; CE Instruments, Thermoquest S.A., Barcelona, Spain). Fat content was quantified using the Ankom Procedure (AOCS Am 5-04) with an Ankom extractor (Model XT10; Ankom Technology, Madrid, Spain). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) analyses were carried out following the sequential procedure of Van Soest *et al*. (1991), with the Ankom fibre analyser (Model 200/220; Ankom Technology). Metabolisable energy (ME) was estimated using the equations proposed by Mertens (1983):

$$ME\ (MJ/kg\ DM)=(2.5-0.0351\times ADF)\ 6.83$$

Blood metabolites

Plasma concentration of TG (GPO-PAO enzymatic-colorimetric method), BHB (enzymatic-colorimetric method) and urea (GlDH method, kinetic UV test) were determined with an automatic analyser (Bitalab Selectra; Merck, Darmstadt, Germany). Reagents for TG and urea were provided by Diagnostica Merck (Merck KGaA 64271) and for BHB by Sigma Diagnostics (St. Louis, MO, USA). Plasma NEFA concentration was determined with a commercial enzymatic colorimetric kit (Randox Laboratories Ltd., Crumlin, Co. Antrim, UK). Intra- and inter-assay coefficients of variation were 9.1 and 10.3% for BHB, 5.6 and 4.0% for urea, 3.1 and 2.5% for TG, and 9.1 and 11.3% for NEFA concentration analyses.

Carcass quality

When the animals belonging to one treat-

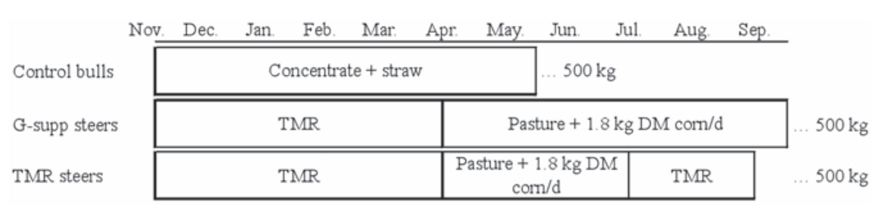

Figure 1. Description of the management strategies throughout the experiment.

ment reached on average the target slaughter weight (500 kg), all of them were slaughtered in a commercial abattoir (MercaZaragoza, Zaragoza, Spain). Slaughtering took place immediately upon arrival to minimize pre-slaughter stress. Cattle were stunned by captive bolt pistol and dressed according to standard commercial practices. Carcasses were weighed immediately after slaughter to record hot carcass weight and chilled during 24 h at 4ºC. Then, left half carcasses were graded using the European grading system (EEC Directives nº 1208/81 and nº 1026/91). Carcass conformation was based on a visual assessment (SEUROP classification) of the development of carcass profiles, in particular the essential parts (round, back, shoulder). Conformation was scored on an 18-point scale, from 1 for *all profiles concave to very concave and poor muscle development* to 18 for *all profiles extremely convex and exceptional muscle development (double-muscled carcass type)*. The degree of fat cover takes into account the amount of fat on the outside of the carcass and in the thoracic cavity. Fat cover was scored on a 15-point scale, from 1 for *none up to low fat cover* to 15 *entire carcass covered with fat and heavy fat deposits in the thoracic cavity*.

The right half of the carcass was dissected into edible meat in different commercial cuts (Carballo *et al*., 2005), fat and bone. The commercial cuts were grouped into 3 anatomical muscle groups based on their anatomical site: thoracic limb, trunk and pelvic limb. Before the carcass was dissected, the 10th rib of each carcass was removed. The rib was dissected into muscle, subcutaneous fat, intermuscular fat, bone and others (tendons and noticeable blood vessels).

Economic analysis

The economic analysis considered only the estimated costs and income that were different between management strategies. The costs considered were: i) veterinary costs, which were different because both groups of steers had castration costs (45 EUR); ii) costs of the housing period such as feeding concentrate (0.23 EUR/kg) or total mixed ration (0.19 EUR/kg) and yardage expenses (0.21 EUR/d), which include management and fixed costs; iii) costs associated with grazing (0.03 EUR/kg DM grass; Chambre d'Agriculture de la Creuse, 2010) and corn supplementation (0.23 EUR/kg). Additionally, the forage produced during finishing in the paddock where TMR steers had been grazing in the previous period was destined to hay production, which produced extra costs associated to harvesting and transport of lucerne (0.06 EUR/kg DM; Chambre d'Agriculture de la Creuse, 2010). Income achieved per animal at slaughter was calculated according to carcass weight and conformation. Furthermore, TMR steers generated an economic return from hay production in the meadow during their finishing period. The economic margin was calculated as the income achieved minus the abovementioned costs. Actual selling prices of products and labour during 2005 and 2006 were used.

Statistical analyses

The statistical analyses were performed using SAS v.9.1 (SAS, 2004). Before further analyses, the normality of the residues of all the variables was tested with the Shapiro-Wilk test. Live weight, weight gains, ultrasound measures and serum metabolite concentrations were analysed using mixed models based on Kenward-Roger's adjusted degrees of freedom solution for repeated measures including the management strategy, sampling date, time, or period and their interaction as fixed effects, and animal as the random effect. A first-order autoregressive structure with heterogeneous variances for each date was used to model heterogeneous residual error.

Carcass traits were tested by analysis of variance using the GLM procedure of SAS with the management strategy as fixed effect. Conformation score was tested with management strategy as fixed effect and slaughter weight as covariate. Least square means were estimated and differences were tested with a t-test. Pearson's correlation coefficients between variables were calculated. For all tests, the level of significance was set at 0.05. Trends were discussed when $P<0.10$.

Results and discussion

Feedstuffs

The chemical composition of the feedstuffs offered in the experiment is presented in Table 1. Concentrate, corn and TMR composition did not change throughout the experimental period ($P>0.05$) but pasture quality changed during the grazing season ($P<0.001$). Pasture had minimum NDF (45.8%) and ADF (22.0%) contents during the first month of the grazing season. These contents did not change during the 3 following months (average 495 and 221 g/kg DM for NDF and ADF contents, respectively) but increased in the last month of the grazing season reaching their maximum contents (568 g/kg DM 246 g/kg DM for NDF and ADF respectively) (Figure 2). Crude protein, however, did not change throughout the grazing season ($P>0.05$). Forage availability also changed throughout the grazing season ($P<0.001$). Pasture availability did not change during the first 2 months of the grazing season (1240 and 1512 kg DM/ha, respectively), increased in the third month (2279 kg DM/ha), decreased to initial values (1624 kg DM/ha) in the fourth month and increased again to the maximum availability (2538 kg DM/ha) in the last month of the grazing season (Figure 2).

Live weight, weight gains and intake

Live weight did not differ among management strategies at the beginning of the experimental period ($P>0.05$; Table 2) but Control bulls were 24.2% heavier than both groups of steers on 18th April ($P<0.001$), the end of the steers' housing period (Figure 3). The housing period lasted 159 and 138 days for Control bulls and both groups of steers, respectively. During the housing period, Control bulls had 45% greater weight gains than both groups of steers ($P=0.001$; Table 2). The differences in performance during the housing period between Control bulls and both groups of steers could be attributed to the different energy and protein content of diets. Including forage in the beef diets reduces average daily

Table 1. Chemical composition of feedstuffs offered throughout the experiment. Results are means±standard error.

	Concentrate	Corn	Total mixed ration		Meadow
			Winter	Finishing	
DM, %	84.8±0.65	88.1±0.12	83.3±0.78	87.6±0.40	21.9±3.96
CP, %	14.5±1.46	12.4±3.88	10.2±0.80	11.3±1.15	18.6±2.45
Fat, %	4.1±0.71	3.2±0.35	1.7±0.34	2.4±0.29	nd
NDF, %	29.3±5.61	29.2±6.31	51.5±3.52	46.8±2.74	51.3±7.29
ADF, %	6.1±0.72	2.5±0.01	28.1±2.50	22.5±2.08	23.2±2.27
Ash, %	6.4±0.30	1.51±0.03	8.1±0.37	6.7±0.37	10.9±1.07
ME, MJ/kg DM	15.6±0.17	16.5±0.01	10.3±0.60	11.7±0.50	11.5±0.54

DM, dry matter; CP, crude protein; NDF, neutral detergent fibre; ADF, acid detergent fibre; ME, metabolisable energy; nd, not detected.

gain and feed efficiency (Dieguez Cameroni *et al*., 2006; Patterson *et al*., 2000), depending on the proportion forage:concentrate (Nuernberg *et al*., 2005) mainly due to the lower energy concentration of forages. Furthermore, the different gender could enlarge the differences in weight gains because it affects both intake and feed efficiency for growth (Andersen and Ingvartsen, 1984). Previous studies have reported that bulls had greater weight gains than steers even when they had similar dry matter intake (Bruckmaier *et al*., 1998; Mach *et al*., 2009). Throughout the housing period, the daily intake of Control bulls was 83 g DM concentrate/kg $LW^{0.75}$, and that of G-supp and TMR steers was 115 and 110 g DM of TMR/kg $LW^{0.75}$, respectively.

Live weight of TMR and G-supp steers did not differ at turnout to pasture (P=0.68), which was 38 kg (standard error 9 kg) lower than that observed at the end of the housing period. The weight loss between the last record of the housing period and the first one of the grazing period (10.5% LW) was a consequence of transport and adaptation to grazing conditions, which agrees with previous results (Blanco *et al*., 2012). In the current experiment, weight loss due to transportation was on average 6.8%, similar to what Arthington *et al*. (2003) reported in weaned calves transported for 3 h. In the present study the steers needed 30 days to attain the weight previous to transportation, but Phillips *et al*. (1987) reported shorter periods to recover pre-transportation weight. Besides of the transportation losses, when cattle are turned-out to pasture they loose weight and may need 10-18 d to recover the loss (Nams and Martin, 2007), which could extend the recovery period. From 25th April to 12th July (78 days), they had an estimated daily intake of 124 g DM pasture+corn/kg $LW^{0.75}$. Weight gains of G-supp and TMR steers did not differ (P=0.30; Table 2), consequently LW at the end of the grazing period did not differ (P=0.77).

From 12th July to slaughter, G-supp steers with an intake of 95.8 g DM pasture+corn/kg $LW^{0.75}$ had 31% lower ADG than TMR steers (P<0.01; Table 2), with an intake of 102.4 g DM TMR /kg $LW^{0.75}$. The finishing period on the TMR improved weight gains compared with finishing on pasture with supplement. Similar results were reported by Duynisveld *et al*. (2006). It could be suggested that the mobility of the pasture finished steers could have decreased the energy available for growth. Moreover, the low intake (80 g DM pasture+corn/kg $LW^{0.75}$) of G-supp steers from mid-August to slaughter might have impaired their growth during the last 45 days. Thus the

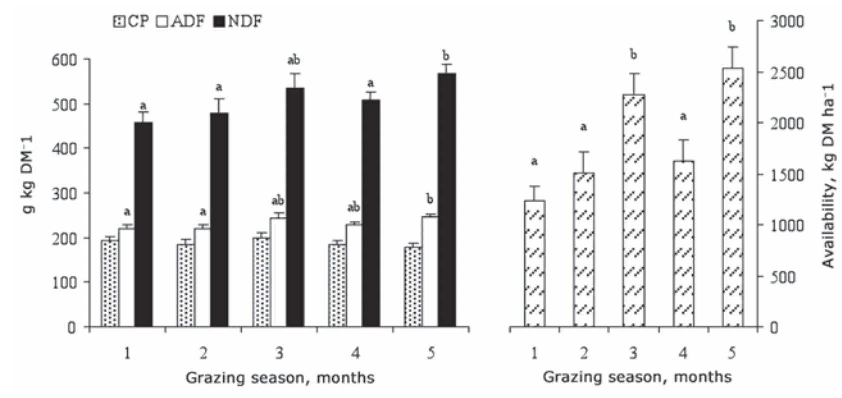

Figure 2. Pre-grazing forage mass crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) as g kg^{-1} dry matter (DM) and availability throughout the grazing season. Within a parameter, means with different letters differ at P<0.05. Vertical bars represent the standard error.

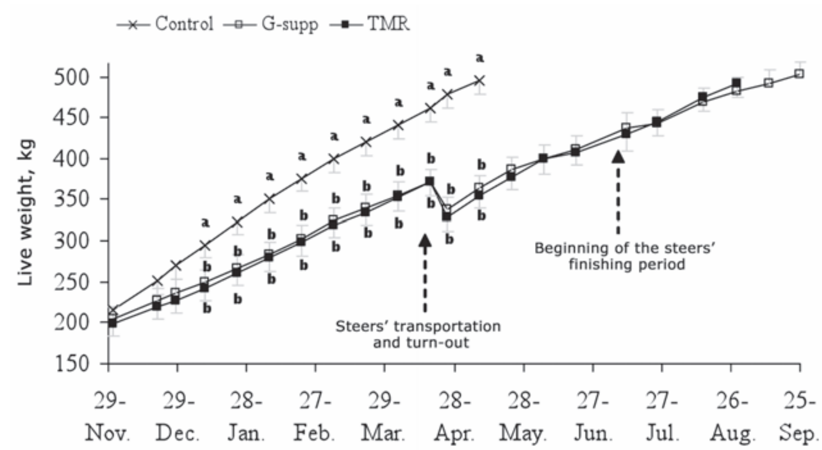

Figure 3. Live weight throughout the experimental period according to the management strategy. Control: concentrate-fed bulls; G-supp: steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg dry matter (DM) corn/d; TMR: steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg DM corn/d and finished on a total mixed ration. Within a date, means with different letter differ at P<0.05. Vertical bars represent the standard error.

Table 2. Effect of the management strategy on live weight and weight gains in the different periods.

	Control	G-supp	TMR	SEM	Pr>F
Live weight, kg					
Initial	216	204	200	3.2	0.75
End of the steers' housing period	461^a	371^b	371^b	3.5	0.001
Initial grazing period	-	337	328	3.5	0.68
Initial finishing period	-	437	429	8.9	0.77
Slaughter	495	502	501	3.5	0.94
Weight gains, kg/d					
Housing period	1.772^a	1.204^b	1.244^b	0.093	0.001
Grazing period	-	1.084	1.168	0.090	0.37
Steers' finishing period	-	0.942^b	1.371^a	0.1232	0.004
Age at slaughter, days	442^b	569^a	539^a	27.0	0.001

Control, concentrate-fed bulls; G-supp, steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg dry matter (DM) corn/d; TMR, steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg DM corn/d and finished on a total mixed ration. [a,b]Different letters in the same row denote significant differences (P<0.05) among parameters.

time needed to attain the target slaughter weight was prolonged 20 days in the steers finished on pasture (75 *vs* 55 days, for G-supp and TMR steers, respectively). Therefore, Control bulls were 97 to 127 days younger than their counterparts at slaughter (P<0.001; Table 2).

Blood metabolites

Serum urea concentrations were affected by the interaction between the management strategy and the date (P<0.001; Figure 4). Both groups of steers had slightly higher urea concentrations in the first sampling (P<0.10) and in the two following samplings (P<0.05) than in Control bulls. Urea concentrations did not differ, however, between management strategies during the last part of the housing period (P>0.05). Concentrate fed bulls had lower plasma urea concentration than both groups of steers during two months of the housing period. A high urea concentration could be related with a high protein content in the diet or to the endogenous protein catabolism (Cunningham and Klein, 2007; Kaneko *et al.*, 1997). The greater urea concentration of the steers during the housing period could not be explained by a high protein intake as protein content of the total mixed ration was lower than that from the concentrate. The low urea concentration in Control bulls could be due to a reduction of amino acid catabolism for muscle deposition in fast growing animals (Cabaraux *et al.*, 2003). Furthermore, the different gender could have enlarged the differences as, according to Bruckmaier *et al.* (1998), bulls had lower urea concentration than steers from 180 to 330 kg reflecting enhanced protein utilisation and accretion. Besides, the degradability of crude protein of lucerne is high, which could contribute to the higher urea concentration of the steers compared to Control bulls.

Urea concentrations in both groups of steers in the first sampling after the turn-out to the meadows were greater than those of the housing period (P<0.01). The increase in urea concentration in the first sampling after turn-out to pastures could be ascribed to the stress of transport (Phillips *et al.*, 1987), as it alters protein metabolism (Buckham Sporer *et al.*, 2008). Moreover, the greater protein content of pasture than that of the TMR offered to steers in the housing period could have contributed to sharpen the increase in urea concentration. Urea concentrations did not differ in both groups of steers thereafter, except for the last sampling before slaughter, when G-supp steers had greater urea concentration than TMR steers (P<0.001). The greater urea concentration of the steers finished on pasture compared to those finished on the total mixed ration would be related to their greater protein intake, and also to their lower energy intake between the last two sampling dates, which could result in higher muscle catabolism, being in agreement with the lower weight gains.

Serum NEFA concentrations were only affected by the sampling date (P<0.001) (Figure 4). Other authors reported that serum NEFA concentrations in young bulls fed a fattening diet to allow rapid growth and those receiving a diet restricted in energy did not differ (Ellenberger *et al.*, 1989; Hornick *et al.*, 1998). Serum NEFA concentrations remained more or less stable during the housing period but increased drastically from the end of it to the beginning of the grazing season (P<0.001), as observed in urea concentrations. The first sampling after turn out to the pasture serum NEFA concentration increased sharply to values near 0.5 mmol/L, the threshold defined by Hachenberg *et al.* (2007) as indicative of limited adaptive performance. An increase in NEFA concentration reflects the activation of the sympathetic adrenomedullary system due to stress of transport (Tarrant and Grandin, 2000), that increases adrenaline, prolactin, endorphins, renin, fatty acids and glycogenolysis. Moreover, the change of feeding system from the total mixed ration to pasture could have contributed to this increase as in the short term there is a negative energy balance, which according to Emery *et al.* (1992) mobilises fat and consequently, increases NEFA concentrations in blood. Thereafter, NEFA concentrations decreased sharply (P<0.001) and remained unchanged until slaughter. During the finishing period, serum NEFA concentrations did not differ between the steers finished on pasture and those fed the TMR, which had different growth rates. According to previous studies, bulls under compensatory growth had lower serum NEFA concentrations than continuously grown bulls (Ellenberger *et al.*, 1989; Hornick *et al.*, 1998). However, the response may be dependent on the extent of restriction in the previous period, and while in the current experiment

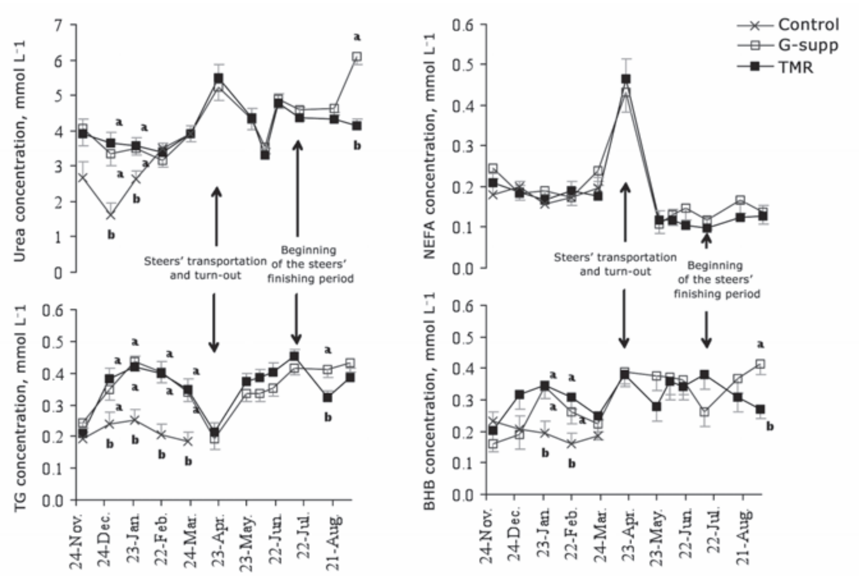

Figure 4. Effect of the management strategy on the plasmatic urea, non-esterified fatty acids (NEFA), triglycerides (TG) and β-hidroxi-butirate (BHB) concentrations throughout the experimental period. Control: concentrate-fed bulls; G-supp: steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg dry matter (DM) corn/d; TMR: steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg DM corn/d and finished on a total mixed ration. Within a metabolite and a date, means with different letters differ at P<0.05. Vertical bars represent the standard error.

previous growth rates of steers were above 1.0 kg/d, in the abovementioned studies reported lower weight gains (below 0.5 kg/d).

Serum TG and BHB concentrations were affected by the interaction between the management strategy and the sampling date (P<0.01; Figure 4). Except for the initial value, both groups of steers had greater TG concentrations than Control bulls (P<0.05). In steers, TG concentrations increased in the first and second months (P<0.05) and remained unchanged the rest of the housing period (P>0.05) while in Control bulls kept steady throughout this period (P>0.05). Serum BHB did not differ until the second and third months of the housing period, when both groups of steers had greater concentration than Control bulls (P<0.05). The lower serum TG and BHB concentrations of Control bulls than those of both groups of steers during the housing period was unexpected because fat content of the bulls diet was greater than that of the total mixed ration. Dairy cows given a high-fat ration had greater TG concentration than those given a control ration (Bauchart *et al*., 1987). However, the lower TG and BHB concentrations in Control bulls could be due to the fact that muscle deposition was taking place at a greater rate than in both groups of steers. This would require a great amount of energy which proceeds from glucose but also from other energy substrates such as BHB (Boisclair *et al*., 1993; Herdt, 2003) or TG (Hocquette and Bauchart, 1999), and therefore there would be an uptake from blood at a fast rate. Moreover, the gender might have affected TG metabolism, as Bong *et al*. (2012) reported that castration increases lipogenic gene expression of both acetyl-CoA carboxylase and fatty acid synthase while downregulating lipolytic gene expression of both adipose triglyceride lipase and monoglyceride lipase in the *Longissimus* muscle.

As previously explained in urea and NEFA concentrations, the stress caused by transport and turn-out to the meadows reduced BHB (P<0.05) and increased TG concentrations. After a month in the pastures TG increased (P<0.05) and BHB concentrations decreased, showing no differences between both groups of steers enduring the rest of the grazing period. One month after the finishing period started, TMR steers had lower TG concentrations than G-supp steers (P<0.05) but at slaughter TG concentration did not differ again. Serum BHB concentrations did not differ in both groups of steers until slaughter, when G-supp steers had greater BHB concentration than TMR steers (P<0.01). These differences in BHB and TG concentrations between the steers finished on pasture and those finished on TMR reflect the differences in growth rates.

Muscle depth and subcutaneous fat thickness

Ultrasound measurements of subcutaneous fat thickness and *Longissimus dorsi* area in live cattle can be an accurate estimator of these parameters in the carcass (Greiner *et al*., 2003). Thus, the determination of subcutaneous fat thickness and muscle depth by ultrasonography could show differences in the deposition of subcutaneous fat and muscle throughout the production cycle.

Muscle depth was different at the end of the steers' housing period, when Control bulls had greater muscle depth than G-supp and TMR steers (P<0.001; Table 3) but did not differ at the beginning of the steers' finishing period (12th July) and slaughter. The differences between concentrate-fed bulls and both groups of steers in muscle depth at the end of the steers' housing period were related to differences in LW, as both variables were highly correlated (r=0.72; P<0.001). Thereafter differences were not detectable as LW did not differ among management strategies.

Subcutaneous fat thickness differed between Control bulls and both groups of steers at the end of the steers' housing period (P<0.001) (Table 3) but did not differ thereafter. The greater subcutaneous fat thickness of Control bulls compared with TMR and G-supp steers was related to differences in LW as both variables were highly correlated (r=0.71, P<0.001). Moreover, concentrate feeding usually enhances fat deposition compared with forage feeding (Mandell *et al*., 1998; Steen *et al*., 2003). It would have been expected that TMR and G-supp steers had different subcutaneous fat thickness measured by ultrasonography because fatness differed in the commercial and 10th rib dissection. Nevertheless, ultrasonography was unable to detect differences in fat deposition between TMR and G-supp steers.

Carcass traits

The management strategy did not affect hot carcass weight and fatness score (Table 4), as reported in concentrate- or forage-fed cattle slaughtered at a similar weight (Blanco *et al*., 2010; Keane and Allen, 1998). It should be noted that the SEUROP classification of fat cover is unable to detect small differences in subcutaneous fat deposition, which can be evident in the dissection of the 10th rib, as already reported in Blanco *et al*. (2010). The steers finished on the TMR, however, had lower dressing percentage and worse conformed carcasses than Control bulls and G-supp steers (P<0.05), probably due to their heavier gut fill (Carstens *et al*., 1991), as slaughter weight did not differ among treatments. Supporting that, greater fill is usually detected with hay than with other roughages (Owens *et al*., 1995), particularly when compared to fresh pasture.

Data from the commercial dissection of carcasses indicated that Control bulls and G-supp steers had greater edible meat and lower fat percentages than TMR steers (P<0.01) (Table 4). Control bulls had greater percentage of edible meat in the thoracic limb and lower in the pelvic limb than both groups of steers (P<0.001), as observed by others (Mukhoty and Berg, 1973; Owens *et al*., 1995; Shahin *et al*., 1993). According to Brandstetter *et al*. (2000), the effect of testosterone on sexual dimorphism is evident by differential growth of forelimb and neck muscles in bulls and steers. Another possible explanation for the different percentage of edible meat in the

Table 3. Effects of the management strategy and measuring time on *Longissimus dorsi* muscle depth and subcutaneous fat thickness.

	Control	G-supp	TMR	SE	Pr>F		
					M	T	M×T
Longissimus dorsi depth, mm					0.06	0.001	0.001
End of the steers' housing period	67[a]	59[bx]	54[bx]	1.26			
Initial finishing period	-	60[x]	66[y]	1.07			
Slaughter	66	69[y]	65[y]	0.80			
Fat thickness, mm					0.37	0.001	0.001
End of the steers' housing period	6.5[a]	4.7[bx]	5.7[bx]	0.13			
Initial finishing period	-	7.2[y]	7.9[y]	0.11			
Slaughter	7.0	8.0[y]	8.5[y]	0.18			

Control, concentrate-fed bulls; G-supp, steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg dry matter (DM) corn/d; TMR, steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg DM corn/d and finished on a total mixed ration; M, management strategy; T, measuring time. [x,y]Within a parameter and column, means with different letter differ at P<0.05. [a,b]Within a parameter and row, means with different letter differ at P<0.05.

trunk and thoracic limb could be because of the different allometry of animals of the same breed but with different growth paths (Owens *et al.*, 1995). The percentage of edible meat in the thoracic limb did not differ between both groups of steers but TMR steers had greater percentage of edible meat in the trunk and lower in the pelvic limb than G-supp steers (P<0.01), which could be attributable to the greater development of this region to contain the greater digestive fill. It could also be due to the fact that muscle mass on the trunk can be affected by the energy of the diet. However, as in the abovementioned study, the relative commercial importance of this difference is questionable as the percentage of cuts of 1st, 2nd and 3rd quality did not differ between both groups of steers (unpublished data). The tissular composition of the 10th rib did not differ between TMR steers and Control bulls, except for a slightly different bone proportion (P<0.10) (Table 4), despite the differences in diet, gender and age at slaughter. The expected greater fat proportion of Control bulls because concentrate feeding usually enhances fat deposition when compared with forage feeding (Mandell *et al.*, 1998; Steen *et al.*, 2003) would be counterbalanced by the greater proportion of fat of steers compared to bulls (Mandell *et al.*, 1997; Steen and Kilpatrick, 1995). Bulls have higher energy expenditure and protein retention than steers, which contribute to a lower availability of nutrients for fat deposition (Hocquette, 2010). Control bulls had lower muscle (P<0.01), greater intermuscular fat (P<0.01) and slightly greater bone (P<0.10) and subcutaneous fat (P=0.05) percentages than G-supp steers. The steers finished on the TMR had lower muscle (P<0.001), greater intermuscular (P<0.01) and subcutaneous fat (P<0.001) proportions than G-supp steers probably related to the lower deposition of grazing cattle due to mobility on pasture. During the last 45 days of the finishing period, the steers finished on pasture had a low intake, which depressed growth rates (0.88 kg/d) and might have impaired the deposition of fat (Sainz *et al.*, 1995). Moreover, cattle finished on pasture have lower fatness because of a greater energy expenditure on exercise (Moloney *et al.*, 2004). Total fat in the carcass estimated with the commercial dissection was strongly correlated with subcutaneous fat in the 10th rib (r=0.71; P<0.001), with total fat in the 10th rib (r=0.64; P<0.001) and to a lower extent to intermuscular fat (r=0.58; P<0.01). Total edible meat in the carcass was correlated with muscle in the 10th rib (r=0.48; P<0.05) but total bone in the carcass and in the 10th rib were not correlated.

Economic analysis

Total costs during the winter feeding period (feeding costs and yardage expenses) were 11 to 16% lower in G-supp and TMR steers than in Control bulls (Table 5). However, G-supp and TMR steers had costs associated to grazing and finishing, thus had 46 and 78% higher total feed costs than Control bulls, respectively. Nevertheless, young bulls finished on concentrates for 58 or 138 days had greater costs than young bulls that grazed for 164 days slaughtered with similar age and weight (Blanco *et al.*, 2011). Finishing steers on the total mixed ration increased 18% total costs compared to G-supp steers because of the high dry matter intake during finishing and the price of the total mixed ration compared to grazing and the cost of producing the hay. Veterinary costs were lower in Control bulls than in both groups of steers because of costs associated to castration. Regarding income, Control bulls and G-supp steers had 6-8% greater income than TMR steers because they had better conformed

Table 4. Effect of the management strategy on carcass traits.

	Control	G-supp	TMR	SEM	Pr>F
Hot carcass weight, kg	291	293	280	19.6	0.70
Dressing percentage, %	58.7ᵃ	58.2ᵃ	56.0ᵇ	1.1	0.02
Conformation score (1 to 18)	10.6ᵃ	10.4ᵃ	8.2ᵇ	0.69	0.001
Fatness score (1 to 15)	5.0	4.1	5.0	0.64	0.18
Commercial dissection, g/kg					
Edible meat	749ᵃ	740ᵃ	716ᵇ	80.0	0.01
Thoracic limb	282ᵃ	256ᵇ	260ᵇ	4.6	0.001
Trunk	384ᵃᵇ	374ᵇ	390ᵃ	6.4	0.013
Pelvic limb	334ᶜ	370ᵃ	351ᵇ	5.9	0.001
Trim fat	53ᵇ	55ᵇ	72ᵃ	5.2	0.007
Bone	198	205	212	8.5	0.21
Edible meat:bone	3.8	3.7	3.4	0.2	0.09
Fat:bone	0.27ᵇ	0.27ᵇ	0.34ᵃ	0.024	0.002
10th rib tissular composition, g/kg					
Muscle	659ᵇ	716ᵃ	661ᵇ	16.9	0.001
Subcutaneous fat	24ᵃᵇ	17ᵇ	30ᵃ	4.1	0.004
Intermuscular fat	125ᵃ	94ᵇ	133ᵃ	13.0	0.004
Total fat	149ᵃ	112ᵇ	164ᵃ	15.8	0.003
Bone, vessels, tendons	192	173	175	10.2	0.06

Control, concentrate-fed bulls; G-supp, steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg dry matter (DM) corn/d; TMR, steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg DM corn/d and finished on a total mixed ration. [a,b]Within a row, means with different letters differ at P<0.05.

Table 5. Economic analyses (EUR/animal) of the management strategy.

	Control	G-supp	TMR
Veterinary costs	12	57	57
Winter housing period costs	273	246	235
Feeding	240	217	206
Yardage	34	29	29
Grazing period (18th Apr. to 12th July) costs		62	62
Feeding		62	62
Steers' finishing costs (12th July to slaughter)		51	152
Feeding			107
Hay harvesting			34
Yardage			12
Total costs	285	416	506
Income	1112	1137	1053
Carcasses	1112	1137	1002
Hay			51
Economic margin	826	720	547

Control, concentrate-fed bulls; G-supp, steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg dry matter (DM) corn/d.; TMR, steers fed a total mixed ration during the housing period followed by grazing supplemented with 1.8 kg DM corn/d and finished on a total mixed ration.

carcasses. Selling the hay produced in the meadow accounted for 51 EUR per head for TMR steers. Consequently, Control bulls had the greatest, G-supp intermediate and TMR steers the lowest economic margin. Finishing steers on pasture could be more economically interesting if meat could be sold under a quality label, such as organic farming. Just an increase of 9-10% in the price of the meat would render the same economic margin as Control bulls. Moreover, the price of concentrates in 2006 was low compared to other recent years (FAO, 2009), which reached 0.40 EUR/kg, compromising the viability of concentrate-based fattening systems. Finishing steers on the total mixed ration would not be advisable from an economic point of view.

Conclusions

Finishing steers on pasture with 1.8 kg DM corn/d after a winter housing period on high-forage diets is an alternative to fattening bulls on concentrates in dry mountain areas. However, carcass fatness of the steers finished on pasture was scarce which could reduce their acceptance. A greater supplementation on pasture to increase fat deposition could be studied. Similarly, finishing steers with a total mixed ration could also be an alternative to concentrate-feeding of bulls, however, it worsened carcass dressing percentage and conformation, which determines the income obtained per carcass. On the other hand, finishing steers with a total mixed ration when compared to finishing on pasture improved gains and carcass fatness but worsened carcass dressing percentage and conformation. Moreover, finishing cattle on the total mixed ration composed by alfalfa hay and concentrates would be not advisable, partly due to the high price of alfalfa hay and other forage sources should be tested. In order to choose the most appropriate fattening system, the availability of feedstuffs and their price should be taken into account and meat characteristics evaluated to ensure an acceptable quality.

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Performance and Carcass Quality of Forage-Fed Steers as an Alternative to Concentrate-Based Beef Production

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