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RESEARCH ARTICLE

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Performance, behaviour and meat quality of beef heifers fed concentrate and straw offered as total mixed ration or free-choice

Sergio P. Iraira[1], Ana Madruga[1], María Pérez-Juan[2], José L. Ruiz-de-la-Torre[1], María Rodriguez-Prado[1], Sergio Calsamiglia[1], Xavier Manteca[1] and Alfred Ferret[1]

[1] Universitat Autònoma de Barcelona, Animal Nutrition and Welfare Service, Department of Animal and Food Science. 08193 Bellaterra, Spain. [2] IRTA-Monells, Department of Product Quality, Finca Camps Armet, 17121 Monells, Spain

Abstract

Eighteen Simmental heifers were fed concentrate and barley straw offered as a total mixed ration (TMR) or separately as a free choice (FCH) to compare performance, behaviour, and meat quality. The heifers were assigned to treatments in a randomized complete block design. Animals were allotted to roofed pens with 3 animals per pen, and 3 pens per treatment. Intake of concentrate, average daily gain, and gain to feed ratio were not different between diets, being on average 7.6 kg/day, 1.38 kg/day and 0.18 kg/kg, respectively. Straw intake was greater in TMR than in FCH treatment (0.7 *vs* 0.3 kg/day, respectively; $p<0.001$). Crude protein intake, neutral detergent fibre intake and water consumption did not differ between treatments. Time spent eating was longer in FCH than in TMR ($p=0.001$), whereas time spent ruminating and total chewing time were longer ($p<0.01$) in TMR than in FCH. The number of displacements resulting from competition for feed in the main feeder in TMR treatment tended to be greater than in FCH treatment. There were no differences in the carcass characteristics and quality of meat of animals assigned to the different feeding methods, but the percentage of 18:2 n-6 was higher in FCH treatment. In summary, these results suggest that the use of TMR as a feeding method in beef cattle fed high concentrate diets did not affect performance and increased time spent ruminating with a potential decrease of ruminal acidosis incidence.

Additional key words: beef cattle; feeding method; high concentrate diets.

Abbreviations used: ADF (acid detergent fibre); ADG (average daily gain); BW (body weight); CLA (conjugated linoleic acid); CP (crude protein); DM (dry matter); FAME (fatty acid methyl esters); FCH (free choice diet); G:F (gain to feed ratio); LT (*Longissimus thoracis* muscle); MUFA (monounsaturated fatty acids); n-3 (omega 3 fatty acids); n-6 (omega 6 fatty acids); NDF (neutral detergent fibre); NFC (non-fibre carbohydrates); PUFA (polyunsaturated fatty acids); SFA (saturated fatty acids); TMR (total mixed ration); WBSF (Warner-Bratzler shear force).

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Correspondence should be addressed to Alfred Ferret: Alfred.Ferret@uab.es

Introduction

In feedlots, cattle are often fed high concentrate diets in which some forage source is offered together with concentrate. In these farming conditions, both components can be offered separately, as a free-choice, or mixed, as a total mixed ration (TMR). When animals are offered forage and concentrate in separate feedbunks, the forage intake is low, if forage quality is poor (*i.e.* cereal straw), because animals have a preference for concentrate. Devant *et al.* (2000) reported that the proportion of concentrate and barley straw consumed by crossbred heifers changed from 95% and 5% at 80 kg body weight (BW) to 92% and 8% at 230 kg BW. In other studies, when Friesian heifers were also offered concentrate and barley straw separately and on an *ad libitum* basis during the fattening period, the average proportion of concentrate and barley straw intake was 90% and 10%, respectively (Robles *et al.*, 2007; González *et al.*, 2008; Faleiro *et al.*, 2011). In these feeding conditions, rumination and chewing activity is more limited than when roughage is consumed in

greater amounts. A TMR promotes a greater intake of roughage component because when concentrate and barley straw are mixed, animals have been found to consume a bigger amount of roughage than when offered separately and spend a longer time ruminating (Iraira *et al.*, 2012). The promotion of rumination is, at the same time, a way to reduce the risk of ruminal acidosis when this feeding method is used.

Competition in a group of animals in an intensive production system is predominantly observed in the feeding area (DeVries *et al.*, 2004). Competition for feed can lead to more displacements while feeding, with subordinate animals being more likely to be displaced, which may lower feed intake. As competition increases, variation in animal performance increases and profitability decreases. Limiting feeding space in animals housed in groups increases the competition in the feedbunk and hence the concentrate eating rate, which in turn may result in lower ruminal pH (González *et al.*, 2008).

Our hypothesis was that offering concentrate and cereal straw in a TMR to heifers during the fattening period could increase the amount of roughage intake and the chewing activity without compromising performance and meat quality. We also hypothesized that feeding beef cattle with high concentrate total mixed diets, in a single feeder without increasing the feeding space availability, would increase the level of competition among animals for food resources. Thus, the objective of the present experiment was to compare the performance, behaviour, carcass characteristics and meat quality of heifers fed concentrate and barley straw offered as a total mixed ration, or separately as a free-choice diet.

Material and methods

Animals, experimental design and housing

Animal procedures were approved by the Institutional Animal Care and Use Committee of the Universitat Autònoma de Barcelona (Spain). Eighteen Simmental heifers (initial BW of 247.3±4.4 kg) were blocked in three BW groups, and randomly assigned to each treatment. There were 3 pens per treatment, one for each block, with 3 heifers per pen. Heifers were purchased from a commercial farm where animals were housed in a well-ventilated barn in groups of 15 heifers per pen, placed in concrete pens bedded with straw and fed concentrate and barley straw offered separately on an *ad libitum* basis. In the experimental farm, heifers were housed in a well-ventilated barn, placed in concrete pens with wood shavings, in groups of three heifers per pen. Each roofed pen was 5 m long and 2.5 m wide (12.5 m^2/pen) and equipped with a feed bunk and water trough. The number of three animals per concentrate feeding place reflects the predominant practice in commercial feedlots in Spain. The adjacent pens were separated by a metal fence with a bar design that allowed contact between animals. An alley was located behind the pens, allowing for the movement of the cattle for weighing.

Performance and behaviour were studied in three 28-day experimental periods and sampling was carried out in the fourth week of each experimental period. Slaughter body weight was fixed at 400 kg, which was reached at the end of the experiment in the case of blocks with high BW, and 2 or 4 weeks after, for medium and low BW blocks, respectively. Heifers, in these two latter cases, were maintained in the same experimental treatment until slaughter weight was reached. Treatments were: (1) concentrate and barley straw fed as a free choice diet (FCH) and (2) concentrate and barley straw fed as a TMR. Feeds were offered *ad libitum* at 0900 h. Diet ingredients in the FCH treatment were offered in two separate feedbunks, while TMR treatment was offered in only one. Each feeder and water bowl had one opening to allow only one animal to feed at a time.

Animal behaviour was recorded using a digital video-recording device set up close to the pens (model VS-101P VioStor NVR, QNAP Systems Inc., Xizhi City, Taipei County, Taiwan). A digital colour camera (model VIVOTEK IP7142, VIVOTEK INC., Chung-HO, Taipei County, Taiwan) was set up in front of the feeding area of each pen at a height of 3 m, permitting a full view of the pen. An infrared light with photoelectric cells was set up at each end of the paddock to allow video-recording at night (λ = 830 nm and 500 W; Dennard 2020, Hants, UK).

Feed and data collection

Diets (Table 1) were offered *ad libitum* and formulated to be isocaloric on a metabolizable energy basis (3.0 Mcal/kg of ME, on dry matter basis), assuming the same proportion of barley straw in both diets, and to meet or exceed the NRC (2000) requirements of a beef heifer. All ingredients were ground with the exception of barley straw, which was offered whole in the FCH treatment or chopped and mixed with the remaining ingredients in the TMR treatment. Feeders were cleaned and orts collected at 08:30 h each morning, and feed was offered once daily at 09:00 h, at 15% above the previous day's intake. Feed offered

and refusal samples of each pen were collected daily for seven consecutive days in the sampling week for dry matter (DM) and chemical and particle size determinations. Feed intake per animal was measured by pen and calculated as the average of the three animals in each pen. To register water consumption, water bowls with direct reading flow meters were used (Model 620-C 15.115, Tashia SL, Artesa de Segre, Spain).

Particle size separation was performed using the 3-screen Penn State Particle Separator. This particle separation was used for diet typification (Table 1), to calculate the intake of each particle size and to ascertain the ability of animals to sort different particle sizes in the TMR diet. Sorting of particles was calculated as the actual intake of each fraction (Y_1 to Y_4) expressed as a percentage of the predicted intake, where predicted intake of Y_i equals the product of as-fed intake and as-fed fraction of Y_i in the diet (Leonardi & Armentano, 2003). Values <100% indicate selective refusals, >100% is preferential consumption and =100% is no sorting.

Table 1. Ingredients and chemical composition of the diets

Item	FCH[1]		TMR
	Concentrate	Straw	
Ingredients (g/kg dry matter)			
Corn	450	–	414
Barley	200	–	184
Soybean meal, 440 g crude protein/kg	130	–	120
Soybean hull	49	–	45
Wheat middling	32	–	29
Bakery byproducts	100	–	92
Barley straw	–	*Ad–libitum*	80
Magnapac[2]	17	–	16
Salt	2	–	1.8
Bicalcium phosphate	2	–	1.8
Calcium carbonate	8	–	7.4
Sodium bicarbonate	3	–	2.8
Vitamin–mineral premix[3]	7.5	–	6.9
Composition (g/kg dry matter)			
Crude protein (CP)	130	36	132
Neutral detergent fibre (NDF)	164	722	194
Acid detergent fibre	71	–	95
Ether extract (EE)	35	–	42
Ash	63	–	76
Non–fibre carbohydrates[4]	609	–	556
Particle size[5] (%)			
> 19 mm	–	70.85	2.70
8-19 mm	–	11.73	7.13
1.18-8 mm	38.90	13.47	38.94
< 1.18 mm	61.10	3.95	51.23

[1] FCH = concentrate and barley straw fed separately; TMR = concentrate and barley straw fed as total mixed ration. [2] Palm fatty acids distilled calcium soap (NOREL, S.A., Madrid, Spain). [3] Vitamin and mineral premix (GEMAX Terneros 7.5 Unic, Talavera de la Reina, Spain) contained per kg: 1,333 kIU vitamin A, 266 kIU vitamin D_3, 506 mg vitamin E, 5,300 mg Fe, 100 mg I, 100 mg Co, 373 mg Cu, 3,920 mg Mn, 9,790 mg Zn, 17 mg Se, 2 mg organic Se (from *Saccharomyces cerevisiae*), 1.2×10^9 cfu of *Saccharomyces cerevisae*, 10,400 mg calcium propionate, 5,600 mg D,L-malic acid, 25,000 mg Sepiolite, 266 mg antioxidant extracted from *Vitis vinifera*, 13 mg natural extract (*Satureja* spp.). [4] Non-fibre carbohydrates calculated as 100 – (CP + ash + NDF + EE). [5] Particle size determined by Penn State Particle Separator.

Chemical analyses

DM content of offered feed and refusals was determined by drying samples for 24 h at 103ºC in a forced-air oven according to the AOAC (1990). Feed offered and refusal samples were dried prior to their analysis in a forced air oven at 60ºC for 48 h and then ground in a hammer mill through a 1-mm screen (P. PRAT SA, Sabadell, Spain). Nitrogen content was determined by the Kjeldahl procedure (AOAC, 1990; ID 976.05). Ether extract was performed according to AOAC (1990; ID 920.39). The neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents were determined sequentially by the procedure of Van Soest *et al.* (1991) using thermostable alpha-amylase and sodium sulphite. DM intake and daily nutrient intake were calculated as the difference between amounts offered and refused based on chemical analysis of the composited sample. Data were expressed per animal and per day.

Animal measurements and behaviour

Heifers were weighed before feeding on two consecutive days at the beginning and the end of the experiment (the day of slaughter and the day before slaughter), and every fourteen days during the experiment. Individual animal behaviour was video-recorded for 24-h on days 2, 4 and 6 of each sampling week. Data processing was carried out by scan sampling every 5 min for behaviour of each heifer and recorded activities were registered for each observation. Data for each activity is presented as the total time, expressed in minutes, in which the animal maintained this specific activity.

The behavioural categories used were divided into chewing and non-chewing behaviours. Chewing behaviour included eating and ruminating. An observation was defined as eating when the animal had its muzzle in the feed bunk or was chewing or swallowing feed with its head over it. Ruminating included the regurgitation, mastication and swallowing of the bolus.

Non-chewing behaviour categories were: drinking, self-grooming, social behaviour, oral behaviours, rummaging in wood shavings, rubbing and resting. An activity was recorded as drinking when the heifer had its muzzle in the water bowl or was swallowing the water. Self-grooming was defined as non stereotyped licking of the body or scratching with a hind limb. Social behaviour was registered when a heifer was licking or nosing a neighbouring heifer with the muzzle or butting. Oral behaviours included the act of licking or biting the fixtures, and tongue-rolling, both of which were considered stereotyped behaviours. Rummaging in wood shavings was considered an exploratory behaviour. Rubbing behaviour was registered when the heifer rubbed its body against a metal fence. Resting was recorded when no chewing behaviour and no apparent activity were being performed. A displacement occurred when one of the animals ("actor") displaced a pen mate ("reactor") that was eating or drinking and caused the reactor to remove its head from the container and quit the activity being performed. Only displacements with physical contact were considered.

Carcass and meat quality measurements

Heifers were slaughtered using standard procedures in an EU-licensed abattoir when the three animals in the pen achieved the target average weight of 400 kg. Immediately before transfer to the abattoir, the BW was registered. After slaughter, hot carcass weight was recorded, and carcass back fat and conformation were graded according to the EU classification system and classified into 1, 2, 3, 4 and 5 and into SEUROP categories (EC Regulation No 1234/2007 and No 1249/2008) (EC, 2007, 2008), respectively. Dressing percentage was calculated from hot carcass weight.

After 24 h of carcass chilling under commercial conditions, a bone-in rib section at the sixth rib level was removed from each left and right carcass and transported for subsequent analysis. Once in the laboratory, the *Longissimus thoracis* (LT) muscle was excised from the sixth left rib and used for immediate measurements of pH and colour. After that, this sample and the sixth right rib were vacuum packaged and frozen at -20±2ºC for further analysis. The pH was measured using a Crisson portable pH-meter (model 507; Crisson Instruments SA, Alella, Spain) with a xerolyt electrode. Colour parameters (L*=lightness, a*=redness, b*=yellowness, C*=chroma and h=hue angle) were measured after 30 min blooming with a colorimeter HunterLab MiniScan EZ 45/0 LAV (Hunter Associates Laboratory, Inc, Reston, Virginia, USA), using illuminant D65 and observer 10º.

The same LT sample taken from the sixth left rib, once thawed, was used to determine intramuscular fat, protein and water content by near infrared transmission technique using a FoodScan™ analyzer (Type 78800, FOSS, Hilleroed, Denmark). Moreover, a subsample of 2 g from this left LT was used to determine the fatty acid profile. Fat from

LT was extracted as described by Folch *et al.* (1957); the 2-g subsample was homogenized in 100 mL of 2:1 (v:v) chloroform:methanol. After 24 h, the mixture was filtered and re-extracted twice in a separatory funnel. The filtrate was mixed at a ratio of 2.5:1 with 10% NaCl (v:v). After 24 h, the layer containing lipid in chloroform was decanted and dried in a rotary evaporator at 40ºC. Chloroform remaining was evaporated with a N_2 stream. Fatty acids were separated and quantified as fatty acid methyl esters (FAME) prepared by the AOAC (1990) method. The extracted fat was mixed with 1 mL of 1 M KOH and 1 mL of 14% (w:v) boron trifluoride in methanol. The sample was methylated by incubation at 100ºC for 60 min and, after cooling to room temperature, it was extracted with 5 mL of hexane. The FAME in the hexane layer were analyzed by GLC (5890 Series II GC, Hewlett Packard, S.A., Barcelona). All samples were methylated in duplicate, and 0.2 µL was introduced by split injection into a fused silica capillary column (30 m × ID 0.25 mm, BPX 70; 0.25-microm film thickness, Barcelona). Helium was the carrier gas at 30 cm/s. Column temperature was initially 150ºC for 1 min, increased by 4ºC/min to 200ºC, and then held at 200ºC for 10 min. Individual FAME were identified by retention time with reference to FAME standards (lipid standard: FAME mixture #189-19 L-9495; Sigma Chemical Co., St. Louis, MO, USA). The *cis*-9, *trans*-11-CLA and *trans*-10, *cis*-12-CLA isomers were identified with reference to methyl esters of CLA (O-5507, Sigma-Aldrich, St. Louis, MO). The fatty acids were expressed as g/100 g total fatty acids.

The sixth right rib was thawed for 24 h at 2±2ºC and lean, bone (including tendons and cartilage) and fat were separated and their respective weights were expressed as percentage of total rib weight. The right LT was transversally cut in two 2.5 cm thick steaks that were wrapped in aluminium foil and cooked in a convection oven (Spider 5, Novosir, Spain), preheated at 200°C, until reaching a core temperature of 71°C, monitored with a data logger and a thermocouple probe (Comark, Oregon, USA) inserted horizontally at the steak midpoint. Steaks were allowed to cool, at room temperature, before six 1.27-cm-diameter cores were removed from each steak parallel to the longitudinal orientation of the muscle fibres. All cores were sheared perpendicular to the long axis of the core using a Texture Analyser TA.HD plus (Stable Micro Systems Ltd., Surrey, UK) equipped with a Warner-Bratzler blade with crosshead speed set at 2 mm/s. The maximum peak force (N) was recorded and results were expressed as the average of all subsamples.

Statistical analyses

Daily means for intake of DM and nutrients were calculated as the average of seven days in each experimental period. Performance data were statistically analysed using the MIXED procedure of SAS (v. 9.2; SAS Institute Inc., Cary, NC, USA). The model contained the fixed effects of treatment and block, and random effects of pen and period. Behavioural activities were also analysed using the MIXED procedure of SAS (v. 9.2), but in this case the model contained the fixed effect of treatment and block, and random effect of period and heifer nested within pen. To adjust data to a normal distribution, logarithmic transformation was used. The variance components structure yielding the smallest Schwarz's Bayesian information criterion was chosen. For carcass data, meat quality and fatty acid profile, the heifers nested within pen were considered the experimental unit, data being analysed using the MIXED procedure of SAS (v. 9.2). The model contained the fixed effects of treatment and block, and random effect of heifer nested within pen. For fatness and conformation data, not normally distributed, rank transformation prior to the analysis was used. Analysis of rank-transformed data were analyzed by the Tukey adjust Multiple Comparisons test of the PROC GLM procedure of SAS (v. 9.2). Data from sorting of particle size were tested for a difference from 100 using the *t*-test. Stepwise regression was performed by means of the PROC REG procedure of SAS (v. 9.2) to ascertain the contribution of different dietary particle sizes to ruminating time across treatments (18 observations). Significance was declared at $p \leq 0.05$ and tendencies discussed at $p \leq 0.10$ unless otherwise noted.

Results

Intake and growth performance

Concentrate intake, on a DM basis, was not affected by treatment (Table 2). In contrast, barley straw intake, also on a DM basis, was greater in TMR than in FCH diet ($p<0.001$). Thus, the percentages of barley straw consumed were 4 and 8% for FCH and TMR, respectively. In this latter case, we assumed that the concentrate to barley straw ratio was the same as that formulated because sorting values recorded were equal to 100, so no sorting of particles was detected. Crude protein (CP) and NDF intake did not differ between treatments. Average daily gain (ADG) and gain to feed ratio (G:F) were not affected by treatment, being on average 1.38 kg/day and 0.18 kg/kg, respectively (Table 2). Water consumption, expressed as L/day, was not affected by treatment.

Behaviour

Time spent eating was longer in FCH than in TMR (Table 3; p=0.001), whereas time spent ruminating and total chewing was longer in TMR than in FCH (p=0.001 and p=0.003, respectively). Drinking time tended to be longer in TMR (p=0.091). Social behaviour, oral behaviour and rubbing activity did not differ between treatments. In the TMR treatment, rummaging in wood shaving and resting behaviour were shorter than in FCH (p=0.017 and p=0.049, respectively).

The number of displacements among animals, which were competing to eat concentrate in the FCH treatment, and complete ration in the TMR treatment, tended (Table 4, p=0.10) to be greater in TMR than in FCH. The number of displacements was affected by period, whereas Treatment × Period interaction was not significant. The competition in the containers decreased from the first to the third period (Fig. 1), the p values being p<0.05 for the main feeder and total containers, and p=0.002 for the water bowl.

Table 2. Intake and performance of heifers fed concentrate and barley straw offered as a free choice diet (FCH) or as a total mixed ration (TMR)

Item	Treatments		SEM	*p*-value
	FCH	TMR		
Concentrate intake (kg DM/day)	7.4	7.7	0.31	0.153
Barley straw intake (kg DM/day)	0.3	0.7	0.02	<0.001
Crude protein intake (kg DM/day)	1.0	1.1	0.07	0.142
NDF intake (kg DM/day)	1.5	1.6	0.11	0.126
ADG (kg/day)	1.36	1.39	0.098	0.835
Gain to feed ratio (kg/kg)	0.18	0.18	0.010	0.312
Water consumption (L/day)	22	21	3.0	0.762

Table 3. Behavioural activities of heifers fed concentrate and barley straw offered as a free choice diet (FCH) or as a total mixed ration (TMR)

Item (min/day)	Treatments		SEM	*p*-value
	FCH	TMR		
Eating	104.5	86.2	2.77	0.001
Ruminating	239.9	309.0	11.08	0.001
Total chewing	342.0	395.3	10.13	0.003
Drinking	19.1	23.1	1.47	0.091
Social behaviour	54.9	54.6	3.31	0.822
Self-grooming	67.4	91.4	3.61	0.001
Oral behaviours	55.9	65.5	5.01	0.286
Rummaging in wood shavings	8.0	4.1	0.92	0.017
Rubbing	20.9	18.3	2.67	0.737
Resting	869.4	787.7	17.42	0.049

Table 4. Number of displacements per hour in the feeders and water bowls of heifers fed concentrate and barley straw offered as a free choice diet (FCH) or as a total mixed ration (TMR)

Item	Treatments (T)		SEM	*p*-value		
	FCH	TMR		T	Period[1]	T × Period
Main feeder[2]	1.3	2.6	0.37	0.100	0.020	0.995
Total containers[3]	1.8	2.6	0.39	0.267	0.028	0.684
Water bow[1]	0.24	0.25	0.067	0.862	0.002	0.889

[1] Period effects are shown in Figure 1. [2] Main feeder refers to the concentrate feeder for the FCH diet, and the feeder where total mixed ration was offered in the case of TMR diet. [3] Total containers for the FCH diet refers to the two feeders used, one for concentrate and another for barley straw. For the TMR diet there was only one container.

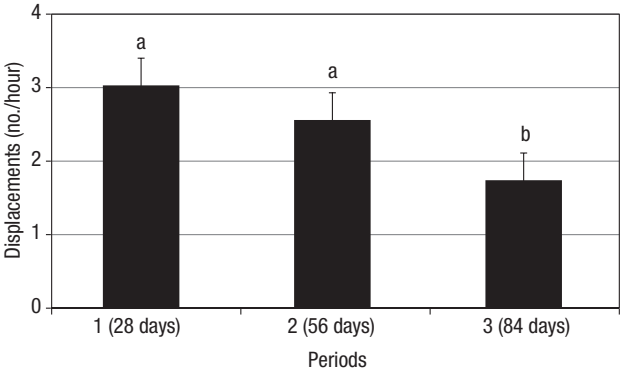

Figure 1. Changes over time (period) in the total number of displacements (no./h) among heifers across treatments.

Carcass characteristics and meat quality

Average slaughter weight (406.7 kg) and hot carcass weight (218.6 kg) were not different between treatments (Table 5). Dressing percentage tended to be higher in FCH than in TMR (p=0.094). All carcasses of heifers fed FCH and 8 of 9 of heifers fed TMR were classified as "R" (good conformation), the remaining ones being classified as "O" (fair conformation). In the case of the fatness score, 8 of 9 carcasses were classified as "3" (average fatness) in FCH, the remaining ones being classified as "2" (slight fatness), and all carcasses of heifers fed TMR were classified as 3. The percentages of fat, lean and bone after dissection of the sixth rib were not affected by treatment, being on average 21.4%, 58.5% and 20.2%, respectively (Table 5). The pH of LT muscle was not different (pH=5.56) for all heifers, independently of treatment. There were no differences in the meat colour of both treatments. Shear force values and muscle composition did not differ between treatments. Shear force and the percentages of intramuscular fat, protein and water were on average 41.8 N and 4.7%, 21.8% and 72.6%, respectively.

The fatty acid profile of the LT muscle is presented in Table 6. The percentage of 18:2 n-6 was higher in heifers fed FCH (p=0.03). In the TMR treatment the percentages of 18:0 and 18:1 n-7 tended to be higher and lower, respectively. The treatment did not affect the remaining fatty acids, but there was a tendency (p<0.10) for the sum of PUFA, n-6 and the PUFA:SFA ratio.

Table 5. Carcass and meat quality of *Longissimus thoracis* (LT) muscle of heifers fed concentrate and barley straw offered as a free choice diet (FCH) or as a total mixed ration (TMR)

Item	Treatments		SEM	*p*-value
	FCH	TMR		
Carcass				
Final BW (kg)	408.3	403.0	11.87	0.769
Hot weight (kg)	222.2	215.0	6.03	0.448
Dressing (%)	54.5	53.2	0.42	0.094
6th rib dissection				
Fat (%)	21.0	21.7	1.48	0.747
Lean (%)	59.0	58.0	1.31	0.598
Bone (%)	20.0	20.3	0.79	0.782
LT muscle				
pH	5.56	5.55	0.029	0.950
Colour[1]				
L*	39.4	39.1	0.75	0.778
a*	17.0	16.7	0.34	0.503
b*	14.5	13.9	0.24	0.124
C*	22.4	21.8	0.32	0.195
h*	40.4	39.8	0.69	0.573
WBSF[2] (N)	41.0	42.6	4.22	0.794
Composition (%)				
Intramuscular fat	4.6	4.7	0.65	0.853
Protein	21.9	21.6	0.25	0.412
Water	72.6	72.6	0.58	0.989

[1] Colour: L *= lightness, a* = redness, b* = yellowness, C* = chroma, h* = hue angle. [2] Warner–Bratzler shear force.

Table 6. Fatty acid profile (g/100 g of total fatty acids) of the *Longissimus thoracis* muscle of heifers fed concentrate and barley straw offered as a free choice diet (FCH) or as a total mixed ration (TMR)

Fatty acid	Treatments		SEM	*p*-value
	FCH	TMR		
14:0	2.42	2.44	0.131	0.907
15:0	0.83	0.93	0.091	0.445
16:0	24.78	24.97	0.626	0.833
16:1 n-9	0.51	0.50	0.053	0.916
16:1 n-7	3.20	3.27	0.133	0.738
17:0	1.16	1.16	0.076	0.965
17:1	0.77	0.76	0.037	0.917
18:0	13.86	15.37	0.550	0.071
Sum of 18:1 trans	4.26	2.78	0.646	0.126
18:1 n-9	31.05	33.37	1.053	0.140
18:1 n-7	2.05	1.63	0.156	0.076
18:2 n-6	9.72	7.95	0.523	0.030
18:3 n-6	0.20	0.11	0.057	0.289
18:3 n-3	0.42	0.33	0.040	0.151
CLA cis 9, trans 11	0.22	0.19	0.024	0.330
CLA trans 10, cis 12	0.08	0.08	0.049	0.584
20:1 n-9	0.21	0.20	0.016	0.481
20:2 n-6	0.15	0.10	0.019	0.104
20:3 n-6	0.93	0.89	0.074	0.723
20:4 n-6	3.01	2.79	0.303	0.628
20:5 n-3	0.14	0.11	0.021	0.458
22:6 n-3	0.05	0.04	0.009	0.611
SFA[1]	43.05	44.88	0.980	0.207
MUFA[2]	42.06	42.51	0.629	0.619
PUFA[3]	14.90	12.61	0.906	0.095
SFA:UFA	0.76	0.82	0.031	0.212
PUFA:SFA	0.35	0.28	0.027	0.099
n-3[4]	0.60	0.49	0.065	0.255
n-6[5]	14.00	11.85	0.848	0.093
n-6:n-3	25.05	24.22	1.336	0.668

[1] SFA=∑ 14:0, 15:0, 16:0, 17:0, 18:0. [2] MUFA=∑ 16:1 n-9, 16:1 n-7, 17:1, 18:1 trans, 18:1 n-9, 18:1 n-7, 20:1. [3] PUFA=∑ 18:2 n-6, 18:3 n-6, 18:3 n-3, CLA cis 9, trans 11, CLA trans 10, cis 12, 20:2 n-6, 20:3 n-6, 20:4 n-6, 20:5 n-3, 22:6 n-3. [4] n-3=∑ 18:3 n-3, 20:5 n-3, 22:6 n-3. [5] n-6=∑ 18:2 n-6, 18:3 n-6, 20:2 n-6, 20:3 n-6; 20:4 n-6.

Discussion

Feeding method did not affect ADG and G:F ratio of beef heifers when concentrate and barley straw were offered separately as a free-choice or as a TMR. These results agree with those reported by other authors (Atwood *et al*., 2001; Moya *et al*., 2011). Atwood *et al.* (2001) compared the performance of fattening calves given *ad libitum* access to either a mixed ration of rolled barley (31.3%), rolled corn (31.3%), corn silage (15.5%) and alfalfa hay (18.9%), or the same feeds offered individually as a free choice diet. Calves offered the TMR did not gain at a faster rate, in spite of the fact that they tended to eat more than calves offered a choice, and the G:F ratio was similar for both groups. Moya *et al*. (2011) found no differences in DM intake and animal performance, ADG and G:F ratio, when crossbred heifers were fed a TMR with a proportion of

10 and 90% of corn silage and concentrate respectively, than when heifers received both feeds separately. In the present experiment, no differences exist in the concentrate DM intake, whereas the barley straw DM intake of heifers fed TMR was twice that of heifers fed FCH.

While heifers fed FCH spent more time eating than those fed TMR, time spent ruminating and total chewing time was longer in heifers fed TMR. The longer eating time in heifers fed FCH could be explained by the fact that heifers needed to visit two different feedbunks to access the feed, whereas the longer ruminating time and total chewing time in heifers fed TMR was due to the greater amount of barley straw eaten by these heifers. The low roughage intake registered in heifers fed FCH is in agreement with data reported by Iraira *et al.* (2012), who recorded an average proportion of 96% and 4% of concentrate and barley straw respectively, when they used this feeding method in Simmental heifers fed a concentrate diet from 115 to 185 kg of BW. This contrasts, however, with data obtained by other authors (Mach *et al*., 2006; Robles *et al*., 2007; González *et al*., 2008) who also worked in the finishing period and fed animals with concentrate and barley straw, both offered separately and *ad libitum*. These latter studies reported proportions of concentrate in the diet ranging from 86 to 88%, and proportions of barley straw ranging from 14 to 12%. However, whereas the breed used in these experiments was Holstein, bulls in Mach *et al*. (2006), and heifers in Robles *et al*. (2007) and González *et al*. (2008), Simmental heifers were used in the present experiment.

In the experiment by Iraira *et al*. (2012), the authors concluded that TMR could be a good way of promoting greater intake of roughage and more time spent ruminating, because animals consume a larger amount of barley straw than when offered separately. They also concluded that the promotion of rumination due to the TMR feeding method would be a way to reduce the risk of ruminal acidosis in intensive beef production systems. These results are in agreement with those registered in the present experiment with regard to time spent ruminating, linked to a greater intake of barley straw in heifers fed TMR. Moreover, the longer time spent ruminating in heifers fed TMR would explain the shorter time in resting activity in these animals, because resting was recorded when no chewing behaviour and no apparent activity were being performed. In contrast, the shorter time spent ruminating in heifers fed FCH would suggest that the longer time spent rummaging in wood shavings was a way to redirect behaviour to another stimulus.

Intake of dietary particle size of between 8 and 19 mm explained 46% of the variability of time spent ruminating. The resulting equation was: rumination time (min) = 233.9 + 132.4x (p=0.002; root mean squared error=38.57), where x is the intake of particle size of between 8 and 19 mm (kg). When stepwise regression included the particle sizes of between 1.18 and 8 mm and more than 19 mm, the percentage increased to 55%. Thus, the stepwise regression analysis only excluded the smallest particle size of less than 1.18 mm. This moderated correlation between feed particle size and ruminating time is in accordance with the results reported by Beauchemin *et al.* (2003) in lactating dairy cows fed diets consisting of 60% concentrate and 40% forage.

Cattle are social animals and readily form dominance hierarchies, especially at the feed bunk (Friend & Polan, 1974). Competition in a group of animals under intensive conditions is predominantly observed in the feeding area (DeVries *et al.*, 2004) where a great amount of aggression among mates is recorded (Miller & Wood-Gush, 1991). In the present experiment the number of displacements in the main feeder tended to be affected by treatment, being greater in heifers fed TMR than FCH. This competition disappeared when the barley straw container was included in the FCH treatment or when competition was studied in water bowls. In the first treatment, heifers must compete for feed offered in a single feed bunk, whereas heifers fed FCH distributed the competition between two different feeders, one for concentrate and another for barley straw. González *et al*. (2008), studying the social competition of Friesian heifers housed in pens with 2, 4, and 8 individuals per concentrate feeding place, found that the number of displacements among pen mates from the feeders increased linearly with an increasing number of animals per feeding place. Nevertheless, in spite of the increased number of displacements in heifers fed TMR, animal performance did not differ between treatments. In contrast, social behaviour registered as non-aggressive activity, like licking or nosing a neighbouring heifer with the muzzle in the non-feeding area, was unaffected by diet. In any case, it might be advisable to increase the number of feeding places if the feeding method chosen in a feedlot was TMR.

A decrease in the number of displacements in the feed container from the first to third period was recorded. This fact coincides with the usual increase in the DM intake, in correspondence with the growing process. The effect of time on the number of displacements can be accounted for by the fact that social hierarchy becomes firmly established after the animals have been kept for some time (Kondo & Hurnik, 1990). A second possibility is that the animals modify their feeding behaviour to reduce competition by either increasing their eating rate or shifting their feeding behaviour to periods of time when feeders are less visited.

Carcass characteristics and meat quality of heifers fed concentrate and barley straw, offered either as a free choice or as a TMR, did not differ and the values reported can be considered within normality when beef cattle are fed concentrate diets. Carcasses classified according to the EU classification system were close to values recorded by FEDNA (2008) for Simmental heifers. The final pH (5.6 on average) was in the interval considered to be normal (between 5.4 to 5.8) for beef (Mach *et al*., 2006). These values suggest that there was no increased stress before slaughter, because the acidification of the muscle occurred as expected. Similar values of lightness, chroma and hue angle were reported by Albertí *et al.* (2014) in young bulls of the Pirenaica breed fed a concentrate diet, and the chemical composition of LT muscle was close to the values reported by Moloney *et al*. (2008) when Charolais × Friesian steers were fed a 60:40 concentrate to forage diet. The WBSF values recorded in LT muscle in both treatments (41.8 N, on average) were below the threshold of 58.9 N proposed by Shackelford *et al*. (1997) to differentiate between tender and tough meat. The tendency detected in the dressing percentage could be related to the different straw intake recorded between treatments, influencing gut fill.

The most abundant fatty acids in LM muscle were 18:1 n-9 (32.2%, on average), 16:0 (24.9%, on average), and 18:0 (14.6%, on average), as was previously reported by Enser *et al.* (1996) in beef. Although there was a tendency for a higher 18:0 proportion in FCH than in TMR, SFA were similar in both treatments (44% on average) and close to the value recorded by Mach *et al.* (2006) in Holstein bulls fed a high concentrate diet. The most important difference in the fatty acid profile between diets was detected in the proportion of 18:2 n-6, which was greater in heifers fed FCH than in TMR. The extensive but incomplete rumen biohydrogenation of dietary linoleic acid (Doreau & Farley, 1994; Beam *et al.*, 2000; Bauman *et al.*, 2003) is reduced when high concentrate diets are fed. This effect can be attributed to inhibition of lipolysis at the low pH that is typically observed in these diets (Van Nevel & Demeyer, 1996; Bauman *et al.*, 2003). The higher proportion of 18:2 n-6 in FCH diet would explain the tendency observed for the higher proportion of n-6, PUFA and PUFA:SFA ratio. However, feeding method did not affect the content of n-3, resulting in a similar n-6 to n-3 ratio in both treatments, and therefore no differences in the health quality of intramuscular fat.

In conclusion, performance and meat quality of Simmental heifers fed concentrate and barley straw offered as a total mixed ration or as a free-choice diet did not differ, but fatty acid profile was affected by treatment because 18:2 n-6 content was greater in intramuscular fat of heifers fed FCH. Nevertheless, the main treatment effect was related to the behaviour of the animals, because heifers fed TMR spent a longer time ruminating and chewing. This effect, in correspondence with a greater roughage intake, could reduce the risk of ruminal acidosis when this feeding method is used in high concentrate diets fed to beef cattle.

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