

Comparison of concentrates or concentrates plus forages in a total mixed ration or discrete ingredient format: effects on beef production parameters and on beef composition, colour, texture and fatty acid profile

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Diets consisting primarily of concentrates or of concentrates plus silage in a total mixed ration (TMR) or discrete ingredient format were compared for effects on beef production traits and on beef quality. Sixty continental cross heifers (377 kg, s.d. 31) were allocated to one of the following feeding regimens for 96 days pre-slaughter: (i) a control ration of grass silage, maize silage, a cereal-based concentrate and straw at proportionately, 0.23, 0.15, 0.59 and 0.03 of dietary dry matter, respectively; (ii) a total mixed ration (TMR) with the same dietary ingredients as the control ration; (iii) a high concentrate ration (HC) of a cereal-based diet and straw at proportionately 0.95 and 0.05 of dietary dry matter, respectively. Subcutaneous fat samples were taken from all animals at slaughter and the strip-loin was excised from 10 animals per group for colour, texture and fatty acid determination. The HC and TMR groups had higher ($P < 0.05$) daily live-weight gain, slaughter weight and carcass weight than the control group. Muscle protein was highest ($P < 0.01$) in the TMR group while muscle marbling was highest ($P < 0.01$) in the HC group. Subcutaneous fat from the HC group was less ($P < 0.001$) yellow than fat from the other groups. Fatty acid analysis of intramuscular fat showed that the HC group had higher $C_{18:1}$ and lower $C_{18:3}$ proportions than the control group ($P < 0.05$). The $n-6:n-3$ fatty acid ratio of intramuscular fat from the HC group was higher ($P < 0.05$) than that of the other groups. The results suggest that, at similar feed intakes, TMR feeding offers advantages for beef production

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over feeding ingredients separately, and yields muscle with a higher protein concentration, while high concentrate feeding yields whiter subcutaneous fat and intramuscular fat with a less nutritionally favourable *n-6:n-3* fatty acid ratio.

Keywords: Beef quality; fatty acids; production system; total mixed ration

Introduction

Beef finishing systems in Ireland have diversified in recent years from the conventional 'grass and silage plus concentrate' type to systems using alternative forages or 'complete concentrate' finishing. The development of these innovative finishing systems is principally the result of a need for improved animal performance and increased economic return from beef production. Previous research has shown that complete concentrate diets increase growth rate compared to forage-based feeding systems and reduce days to slaughter when animals are brought to a similar final weight (Oltjen, Rumsey and Putnam, 1971; Bidner *et al.*, 1986). In Ireland the use of a total mixed ration (TMR) in beef finishing systems is receiving considerable attention. The TMR system is one in which feed components, including forages, cereals and nutritional supplements, are pre-mixed prior to feeding, and animals are fed indoors for up to 3 months pre-slaughter.

To date, little research has been carried out to evaluate the effect of the TMR system on performance of beef animals. Furthermore, the effects of such diets on meat quality have not been evaluated even though it is clear from the literature that changing the production system has implications for meat quality. For example, previous research has shown that feeding animals on concentrate diets reduces the yellowness of subcutaneous fat (Davis *et al.*, 1981; Moloney *et al.*, 2000) and produces muscle with a brighter red colour

than that of animals finished on forage-based diets (McIntyre and Ryan, 1984; Muir *et al.*, 1992). These effects are of direct relevance for Irish beef produced for certain markets. Specifications for the Italian beef market, for example, include a requirement for carcasses to have "white" or "pale" subcutaneous fat and "pink" or "cherry pink" muscle (Anon, 1999).

There is evidence that complete concentrate diets can have beneficial effects on beef tenderness (Bowling *et al.*, 1977). Animals that grow faster in the pre-slaughter period have higher muscle protein turnover rates and elevated proteinase activity to support protein degradation *in vivo*; this can lead to an increased rate of post-slaughter meat tenderisation (Wood, Warriss and Enser, 1992). Furthermore, increasing pre-slaughter plane of nutrition results in increased levels of carcass fatness at slaughter (Smith *et al.*, 1977; Bidner *et al.*, 1981). Increased carcass fatness leads to better carcass insulation, which in turn decreases the rate of carcass cooling (May *et al.*, 1992) and may allow proteolytic enzymes to be more active in the immediate post-slaughter period. Increasing pre-slaughter plane of nutrition can also raise intramuscular fat concentration (French *et al.*, 2001). Elevated intramuscular fat may increase tenderness by permitting easier mastication of meat (Blumer, 1963).

The fatty acid composition of beef fat may be influenced by feeding regimen and changes in the fatty acid composition can affect the perceived healthiness of beef

(Wood and Enser, 1997). Beef fat has a high proportion of saturated fatty acids (SFA) and a low proportion of polyunsaturated fatty acids (PUFA) compared to the fat of other meat species. Increasing the PUFA:SFA and *n-3:n-6* fatty acid ratios is viewed as desirable from a human health perspective.

The objective of this study was to compare the feeding of diets consisting primarily of concentrates or of concentrates plus silage, in a TMR or discrete ingredient format, for effects on production traits and on meat quality.

Materials and Methods

Animals and diets

Sixty Charolais cross heifers were purchased at livestock marts in Ireland during the month of June and transported to Lyons Research Farm, University College Dublin (UCD), Newcastle, Co. Dublin. The animals were allowed an acclimatization period of at least 7 days at pasture followed by 10 days indoors during which they received grass silage and a coarse concentrate ration increasing from 1 to 3 kg per day over the 10-day indoor period. The average weight and age of the animals at housing were 377 (s.d. 31) kg and 440 (s.d. 42) days, respectively. The animals were then blocked in descending order of weight and allocated randomly from within block to one of three dietary treatments, namely control, TMR and high concentrate (HC) for 96 days prior to slaughter. The control group was fed grass silage, maize silage, cereal-based concentrate and straw at proportionally 0.23, 0.15, 0.59 and 0.03 of dietary dry matter (DM), respectively. The concentrate was a coarse concentrate mixture of rolled barley (0.33), rolled wheat (0.28), citrus pulp (0.16), soyabean meal (0.11), molasses (0.11) and a mineral/vitamin mix (0.01).

The TMR group was fed the same diet as the control group with the dietary ingredients mixed mechanically prior to feeding using a Keenan Klassik FP 100 diet feeder (Richard Keenan & Co. Ltd., Borris, Co. Carlow, Ireland). The HC group was offered a cereal-based concentrate diet and chopped straw at proportionally 0.95 and 0.05 of dietary DM, respectively. The concentrate consisted of a coarse mixture of rolled barley (0.42), rolled wheat (0.17), citrus pulp (0.17), distillers' grains (0.14), soyabean meal (0.03), molasses (0.06) and a mineral/vitamin mix (0.01).

Animal management

The animals were housed, by treatment, in groups of 20 in a peat bedded loose shed. On blocking, the control and HC groups were given 10- and 13-day lead-in periods, respectively, during which grass silage was gradually replaced with concentrate, to allow the animals to adjust to the increasing energy concentration in their diet (Cooke, 2002). All groups had feed available *ad libitum* and the amount fed from day to day depended on the amount left in the trough from the previous day. The aim was to feed to proportionately 0.1 in excess of intake. For the control group, the grass silage and maize silage were layered, grass silage first, then maize silage, in the group trough and the concentrate allowance was offered in equal measures in the morning and evening. The straw was given in a separate area of the trough. Animal live weights were recorded, without withholding food or water, on 3 consecutive days before housing and on 2 consecutive days immediately prior to slaughter. Intermediate live weights were taken at monthly intervals throughout the experiment on 2 consecutive days. Group feed intakes were recorded for 5-day periods on four occasions throughout the trial and expressed as kg DM/head per day.

Refused feed remaining in the troughs was discarded at 7-day intervals for the control and TMR groups, except during group feed intake measurements when feed refusals were weighed and discarded on a daily basis.

Animal slaughter

On the day of slaughter animals were transported 22 km to a commercial slaughter facility (Kepak, Clonee, Co. Meath) and slaughtered within 4 h of removal from the farm. After slaughter, cold carcass weight (hot carcass weight \times 0.98) and carcass conformation and fat scores were recorded. For the control and HC groups each carcass side was hung conventionally by the Achilles' tendon. For the TMR group the left side of each carcass was hung by the Achilles' tendon and the right side by the *obturator foramen* (hip-hung). All sides were chilled overnight at 4 °C.

Meat sampling

Subcutaneous fat samples (approximately 6 cm \times 6 cm) were taken from the mid-loin region of each carcass at 48 h post slaughter. Marbling scores, on the exposed loin muscle at the 5th rib, were assigned by an experienced factory assessor following splitting of the sides (pistola cut) into fore- and hind-quarters.

Ten carcasses from each group were randomly selected for meat sampling. A strip-loin "1 rib cut" (approximately 30 cm in length from the 12th/13th rib junction towards the posterior of the carcass) was dissected from the right side of each selected carcass. In the case of the TMR group both sides were sampled. The strip-loin samples were vacuum packaged and transported to the Meat Laboratory in the Department of Food Science at UCD where they were aged at 4 °C for 18 days prior to analysis. The subcutaneous fat

samples were loosely packed in individual bags and stored at 4 °C for 24 h prior to colour assessment.

Subcutaneous fat samples were removed from chill storage, allowed to equilibrate to ambient temperature (\sim 20 °C) and Hunter 'L' (lightness) and 'b' (yellowness) values were recorded using a Minolta CR-300 Chromameter (Minolta Co. Ltd., Osaka, Japan). Six colour measurements were made on each fat sample.

Starting at the anterior end of the aged strip-loins, five steaks were cut from each: two 2-cm steaks were used for colour measurement, one 3-cm steak was used for fatty acid analysis, one 6-cm steak was used for Warner Bratzler shear force measurement and one 4-cm steak was used for compositional analysis. Steaks for compositional analysis were retained at 4 °C for a further 2 days while all other samples, except the two steaks for colour analysis, were placed in bags, vacuum packaged and stored at -20 °C until required. The pH of the *longissimus dorsi* (LD) muscle on the remaining strip-loin portion was measured by making a knife incision and inserting a penetration combination electrode (Model EC2010-11, Amagross Electrodes Ltd., Castlebar, Ireland) attached to a portable pH meter (Model 210A, Orion Research, Boston, USA).

Proximate analysis

Dry matter and fat (ether extract) concentrations of all feed components, total nitrogen of grass and maize silage and crude protein of the concentrate rations and straw were determined according to the Association of Official Analytical Chemists (AOAC, 2002) procedures. For the meat samples, visible fat was removed from the steaks and the LD muscle was ground through a plate with 4.5 mm holes using a food mincer (OMAS Food

Machinery, 21040 Oggiona S., Stefano, Italy). The ground muscle was divided into three equal portions, one for measurement of ash and DM, one for fat determination and one for protein determination. Dry matter, ash, crude protein and crude fat were determined according to the procedures of the Association of Official Analytical Chemists (AOAC, 2002).

Muscle colour measurement

The freshly cut steaks were placed in plastic trays, covered with cling-film, placed in a chill (4 °C) and left to bloom for 3 h. Muscle (LD) colour measurement was carried out using a Minolta CR-300 Chromameter (Minolta Co. Ltd., Osaka, Japan) with the Hunter Lab colour scale from which the 'a' (redness) value and 'L' value were recorded. Three measurements were taken on each steak following blooming and at 2-day intervals for up to 8 days thereafter. The samples were recovered with cling-film after measurement.

Warner Bratzler shear force analysis

Warner Bratzler shear force (WBSF) analysis of beef samples (5 mm × 30 mm × 45 mm), cooked to 72 °C, was conducted using a computer controlled Instron 5544 Universal Testing Machine (Instron Corporation, Buckinghamshire, UK) equipped with a 500-N load cell and a Warner-Bratzler shearing attachment fitted with a 1-mm thick, flat blade, as described by Burke and Monahan (2003). WBSF values were calculated from peak force values and sample cross-sectional area (cm²) and expressed in N/cm².

Fatty acid analysis

Fat was extracted from the feed and muscle samples using the procedure outlined by Folch, Lees and Sloane Stanley (1957) and fatty acid methyl esters (FAME) were

prepared using the procedure described by Slover and Lanza (1979).

FAME were analysed on a Pye Unicam Series 204 gas chromatograph (Pye Unicam, Cambridge, UK) equipped with a flame ionisation detector and a fused silica column (30 m × 0.53 mm i.d.) (Quadrex, USA) coated internally with Carbowax 20M (film thickness, 1.0 µm). A Chromjet Integrator (Spectra Physics Analytical, California, USA) was used for the calculation of peak areas. Hydrogen was used as the carrier gas and was delivered at 4 ml/min. The column was temperature programmed from 120 °C to 220 °C at 6 °C/min and held at the final temperature for 20 min. Injector port and detector were set at 280 °C and 250 °C, respectively. The run time was set at 25 min.

Statistical analysis

Statistical analyses were carried out using the Statistical Analysis Systems Institute procedures (SAS, 1985). Data relating to animal performance were analysed by analysis of variance using a model that included treatment and block. Data relating to meat quality were analysed using a model that included treatment effects. The "estimate" statement of SAS was used to evaluate differences between treatment means. For the comparison of Achilles' tendon hanging *v.* hip hanging of TMR carcasses Student's *t*-test was used. The results are presented as treatment means with their standard errors.

Results

Proximate analysis and fatty acid composition of feedstuffs

Dry matter concentration of the main feed ingredients varied from approximately 200 g/kg for grass silage to 860 g/kg for the concentrate ration while fat concentration

varied from 13 g/kg for concentrate to 36 g/kg for grass silage and crude protein ranged from 92 g/kg for maize silage to 155 g/kg for the concentrate ration (Table 1). The DM concentration of the refused feed for the control and TMR groups was 249 (s.d. 17.8) and 363 (s.d. 16.3) g/kg, respectively.

The dominant fatty acid in grass silage was C_{18:3}, accounting for approximately 0.5 of the total fatty acids detected, while the dominant fatty acid in maize silage and concentrate was C_{18:2} (0.44 and 0.53 of total fatty acids, respectively) (Table 2). The proportion of C_{18:1} in the grass silage (0.058 of total fatty acids) was ~0.30 of

that present in the maize silage and concentrate. C_{16:0} was the dominant SFA in all feed components and was present in similar proportions (~0.2 of total fatty acids) in the silages and concentrate.

Animal performance and carcass characteristics

Both the HC and TMR groups had higher ($P < 0.05$) mean daily live-weight gains, slaughter weights and carcass weights than the control group (Table 3). Over the four periods when DM intake was measured the HC group had numerically higher DM intake values than the other groups. Mean DM intake values (kg DM/head per day)

Table 1: Compositional analysis of feeds (g/kg dry matter unless otherwise stated)

Component	Total mixed ration and control groups				High concentrate group
	Grass silage	Maize silage	Straw	Concentrate	Concentrate/straw mixture
Dry matter (g/kg fresh weight)	204	275	877	860	866
Crude protein	123	89	42	155	136
Ether extract	35.8	19.1	10.9	13.6	22.4
Ash	87.9	44.3	32.1	63.8	58.6
Acid detergent fibre	398	322	591	–	–
Starch	–	210	–	414	371

Table 2. Fatty acid profile (g/100 g FAME¹) of feeds used in the diets of the control, total mixed ration (TMR) and high concentrate (HC) groups

Fatty acid	TMR and control groups				HC group
	Grass silage	Maize silage	Straw	Concentrate	Concentrate/straw mixture
C 12	–	0.22	–	–	–
C 14	1.56	0.59	6.03	0.38	0.32
C 14:1	–	–	2.08	–	–
C 16	21.13	20.16	30.67	20.32	17.95
C 16:1	–	0.42	1.99	0.33	–
C 18	2.44	2.50	8.87	3.01	2.69
C 18:1	5.83	18.77	23.82	16.39	20.07
C 18:2	16.14	44.14	12.89	53.12	54.06
C 18:3	48.70	4.99	5.53	5.31	3.86
C 20	1.17	1.13	4.70	–	0.28
C 20:1	–	–	–	1.14	0.40
C 20:5	1.09	0.94	3.42	–	0.35
C 22:5	–	3.85	–	–	–

¹Fatty acids methyl esters.

Table 3. Effect of feeding regimen on mean values for growth and carcass characteristics

Trait	Treatment group			s.e.	Significance
	Control	Total mixed ration	High concentrate		
Initial weight (kg)	378	377	377	7.0	
Slaughter weight (kg)	502 ^a	520 ^b	533 ^b	5.2	***
Carcass weight (kg)	268.6 ^a	279.5 ^b	288.1 ^b	3.50	***
Live-weight gain (kg/day)	1.13 ^a	1.30 ^b	1.41 ^b	0.046	*
Kill-out proportion (g/kg)	0.534	0.538	0.543	0.005	
Carcass fat score ¹	4.20	4.11	4.00	0.147	
Carcass conformation score ¹	2.95	3.05	3.05	0.068	

¹Assessed according to the EU Beef Carcass Classification Scheme. Fat scores were assigned values of 3 for fat score 3, 4 for fat score 4L and 5 for fat score 4H. Conformation scores were assigned values of 4 for class U, 3 for class R and 2 for class O.

^{ab}Means, in rows, without a common superscript differ significantly ($P < 0.05$).

were 9.46, 9.84 and 10.80 for the control, TMR and HC groups, respectively. Kill-out proportion, calculated as the ratio of cold carcass weight to slaughter weight, and carcass fat and conformation scores were unaffected by feeding regimen.

Muscle traits

The protein concentration in muscle from the TMR group was higher ($P < 0.01$) than that of the control and HC groups (Table 4). The moisture, fat and ash concentrations of muscle were not significantly different between groups. The HC group had a higher ($P < 0.01$) marbling score than the TMR group but not the control group ($P = 0.079$). Muscle pH did not differ between the treatments.

WBSF values did not differ significantly between the treatments. When the TMR

carcasses were hip-hung, the mean WBSF value (52.1 N/cm^2 , $n = 9$) was significantly lower ($P = 0.02$) than that of the conventionally hung TMR carcasses (66.6 N/cm^2 , $n = 9$).

Fat and muscle colour

The HC group had lower ($P < 0.001$) carcass yellowness ('b' value) than the TMR and the control groups but there was no significant difference between the TMR and control groups (Table 5). Carcass fat lightness did not differ significantly between the three groups (mean 'L' value 63.8).

Muscle redness ('a' value) did not differ significantly between groups on any day of measurement. The 'a' value decreased over time in all groups. There was no significant difference in muscle 'L' value between the groups (mean 'L' value 36.0).

Table 4. Effect of feeding regimen on mean values for muscle composition, marbling score, shear force and pH

Trait	Treatment group			s.e.	Significance
	Control	Total mixed ration	High concentrate		
Moisture (g/kg)	744	734	739	2.6	
Protein (g/kg)	229 ^b	239 ^a	229 ^b	2.9	**
Fat (g/kg)	15.1	16.1	21.2	2.19	
Ash (g/kg)	12.1	11.1	11.4	0.38	
Marbling score ¹	2.05 ^{ab}	1.74 ^b	2.58 ^a	0.21	*
Shear force (N/cm^2)	63.4	67.2	58.9	4.46	
pH	5.56	5.55	5.59	0.029	

¹Marbling scores based on a scale of 1 to 4 where 1 = slight marbling; 4 = abundant marbling.

^{ab}Means, in rows, without a common superscript differ significantly ($P < 0.05$).

Table 5. Effect of feeding regimen on mean values for subcutaneous fat yellowness and on muscle redness of meat stored for up to 8 days at 4 °C

Colour	Treatment group			s.e.	Significance
	Control	Total mixed ration	High concentrate		
Fat yellowness ¹	12.6 ^b	13.1 ^b	9.7 ^a	0.336	***
Muscle redness ²					
Day 0	20.9	20.1	20.2	0.44	
Day 2	21.0	19.9	20.2	0.35	P = 0.073
Day 4	19.5	18.5	19.1	0.28	P = 0.068
Day 6	18.2	17.2	17.9	0.51	
Day 8	15.3	14.1	15.9	0.77	

¹Hunter Lab 'b' value.²Hunter Lab 'a' value.^{ab}Means, in rows, without a common superscript differ significantly (P < 0.05).

Fatty acid profile of intramuscular fat

Intramuscular fat from the HC animals had a higher proportion of C_{18:1} and a lower proportion of C_{18:3} compared to the control intramuscular fat (Table 6). The value for the TMR group was intermediate and not significantly different from the other two. The effect of feeding regimen on the conjugated linoleic acid (CLA) concentration in intramuscular fat approached significance (P = 0.08). The effect of feeding regimen on the total monounsaturated fatty acids (MUFA) concentration in intramuscular fat also approached significance (P = 0.08) and the MUFA proportion in intramuscular fat was in the order control < TMR < HC. The *n-6:n-3* ratio of fat from the HC animals was significantly higher (P < 0.05) than that of the TMR and control groups.

Discussion

Animal performance and carcass characteristics

Since the animals were group fed statistical analysis of the feed intake data was not possible. However, the numerically higher DM intake of the HC group is in agreement with previous work which showed that increasing the proportion of

concentrates in the diet of finishing animals leads to an increase in total DM intake (Pendlum, Boling and Bradley, 1977). The lower intake of forages has been attributed to the longer time required for their breakdown in the rumen (Blaxter and Wilson, 1962; Thornton and Minson, 1972). DM intake of the TMR group was numerically higher than that of the control group and while the results are not definitive in the absence of statistical analysis the trend towards higher intake in the TMR group concurs with other studies (Nocek, Steele and Braund, 1986; Atwood *et al.*, 2001). The higher DM content of the refused feed from the TMR group compared to the control group was as expected. Refusals from the TMR group contained all constituent feed components while those from the control group were predominantly grass and maize silage, since the concentrate component was offered twice daily and little remained in the refused feed. Thus, one would expect the DM intake of the control group to comprise a higher proportion of concentrate compared to the TMR group. However, refused feed accounted for only 2 to 3% of the total DM consumed over the entire study and thus any differences in the composition of the feed consumed are

Table 6. Effect of dietary regimen on the mean proportions (g/100 g FAME¹) of fatty acids in intramuscular fat

Fatty acid	Treatment group			s.e.	Significance
	Control	Total mixed ration	High concentrate		
C 10	0.15	0.10	0.05	0.053	
C 12	0.14	0.10	0.08	0.040	
C 14	2.25	2.16	2.46	0.167	
C 14:1	0.52	0.52	0.55	0.056	
C 15	0.28 ^a	0.26 ^a	0.36 ^b	0.021	**
C 16	26.53	26.72	25.08	0.589	
C 16:1	3.78	3.81	3.58	0.175	
C 17	0.75 ^b	0.60 ^a	1.02 ^c	0.048	***
C 17:1	0.84	0.81	0.86	0.058	
C 18	13.84	13.51	13.69	0.375	
C 18:1	39.06 ^a	40.41 ^{ab}	42.26 ^b	0.888	*
C 18:2 (<i>n</i> -6)	5.88	5.34	5.67	0.691	
C 18:3 (<i>n</i> -3)	1.13 ^b	0.98 ^{ab}	0.74 ^a	0.108	
Conjugated linoleic acid	0.35	0.25	0.36	0.036	P = 0.085
C 20:1	0.38	0.34	0.38	0.035	
C 20:3 (<i>n</i> -6)	0.50	0.63	0.61	0.093	
C 20:4 (<i>n</i> -6)	1.96	1.78	1.44	0.304	
C 20:5 (<i>n</i> -3)	0.77	0.81	0.57	0.131	
C 22.5 (<i>n</i> -3)	1.22	1.36	0.79	0.194	
Saturated fatty acids (SFA)	43.79	43.26	42.65	0.883	
MUFA ²	44.49	45.89	47.58	0.932	P = 0.081
PUFA ³	11.72	10.85	9.77	1.409	
<i>n</i> -6 fatty acids	8.29	7.70	7.66	1.045	
<i>n</i> -3 fatty acids	3.12	3.20	2.13	0.411	
<i>n</i> -6: <i>n</i> -3 ratio	2.72 ^a	2.66 ^a	3.83 ^b	0.231	**
PUFA:SFA	0.28	0.26	0.23	0.036	

¹Fatty acids methyl esters.

²Total monounsaturated fatty acids.

³Total polyunsaturated fatty acids.

^{abc}Means, in rows, without a common superscript differ significantly (P < 0.05).

unlikely to invalidate the comparison between the control and TMR groups.

Live-weight gain, slaughter weight and carcass weight were significantly affected by feeding regimen. Other authors (Ferrell *et al.*, 1978; Calderon-Cortes and Zinn, 1996) have shown that increasing the level of concentrates fed to animals increases live-weight gain and slaughter weight if animals are slaughtered after a fixed time. The results of the present study support these findings with animals finished on the HC diet having higher live-weight gain and slaughter weight than the control group. Keane and Drennan (1980) showed that animals finished on concen-

trates and straw (ratio 3:1) had similar growth rate and final weight to animals finished on grass silage and barley (ratio 2:1 DM basis) when energy concentration and DM intake were similar for the two diets. The difference in growth rate shown in the present study may be attributed to both the higher intake of the HC group and the higher energy concentration of the HC diet compared to the control diet, which contained (proportionally) 0.95 and 0.59 concentrate, respectively. Metabolisable energy values estimated from published values for the various feed ingredients (O'Mara, 1996) were 11.6 MJ/kg DM for the control and TMR

groups, and 12.5 MJ/kg DM for the HC group.

The TMR group had a significantly higher live-weight gain, slaughter weight and carcass weight than the control group. Previous comparisons of combined and discrete feeding of silage and concentrates have revealed no significant difference in growth rate although the combined feeding tended to have higher DM intake, higher growth rate and higher feed conversion efficiency (Petchev and Broadbent, 1980). Drennan (1978) showed that combined feeding of silage and concentrates increased total weight gain and carcass gain (9 kg difference) compared to feeding concentrates once daily over a 114-day feeding period. In the present study carcass weight was approximately 11 kg higher for the TMR group compared with the control. Possible explanations for the difference in growth rate between the TMR and control groups are that the TMR diet produced a more stable rumen fermentation pattern and that there was better synchronisation between energy and protein supply with the TMR diet. Synchronising the availability of energy and protein in the rumen is seen as offering potential to enhance the efficiency of microbial growth in the rumen (Newbold, 1994). This is particularly the case when diets contain large quantities of readily digestible carbohydrate (Kim, Choung and Chamberlain, 1999) as was the situation with the present diets.

Increasing the level of concentrate in the diet of finishing animals has previously been reported to increase kill-out percentage (Bond *et al.*, 1972; Keane and Drennan, 1994) and differences in kill-out percentage have been attributed to differences in gut-fill contents (Keane and Drennan, 1980). However, not all authors have reported similar findings and, in agreement with the present study, some

authors have found that varying the concentrate level in the diet of beef animals does not affect kill-out percentage (Prior *et al.*, 1977; Kreikemeier *et al.*, 1990). In the present study the grass silage is the component most likely to affect gut fill but it represented only 0.25 of the diet in the control and TMR groups and this, together with the fact that 0.59 of these diets was composed of concentrate, may have made the differences in indigestible DM in the diet insufficient to elicit a significant difference in gut contents between animals on these diets and those on the HC diet.

Muscle composition and pH

Previous studies involving comparisons of forage and concentrate feeding of beef animals showed that concentrate feeding produced meat with higher intramuscular fat (Bowling *et al.*, 1978; Miller, Masor and Riley, 1981; French *et al.*, 2001) and marbling score (Davis *et al.*, 1981) with the elevated values being attributed to deposition of fat following consumption of a more energy-dense diet (Clemens *et al.*, 1973). In agreement, meat from the HC group had a higher marbling score than meat from the other groups, although only the HC and TMR groups differed significantly and intramuscular fat, while not significantly different between treatments, was numerically higher for the HC group. In several studies in which the effects of forage and grain feeding on meat quality were assessed, the forage diets were entirely forage. For example in the studies of Miller *et al.* (1981) and Davis *et al.* (1981) forage-fed animals consumed a diet of grazed grass with no concentrate supplementation and meat from these animals was compared with that from animals fed a complete concentrate diet. In the present study forages accounted for only ~0.40 of dietary DM for the TMR and control groups and consequently the

effects of forage *v.* concentrate feeding would be expected to be less pronounced.

McCaughey and Cliplef (1996) showed that diet can influence the protein concentration of muscle although a decrease in protein concentration in that study was related to an increase in fat and no change in moisture concentrations. In the present study, however, the 10 g/kg difference in protein concentration of muscle from the TMR group compared to muscle from the control and HC groups could not be directly attributed to decreases in moisture or fat levels.

Carcass fat and muscle colour

Several authors have shown that carcass fat from animals fed concentrate diets is whiter than that from animals fed forage diets (Davis *et al.*, 1981; McIntyre and Ryan, 1984; French *et al.*, 2000a) but not all studies have demonstrated the effect (Muir *et al.*, 1998). In the present study the data show that inclusion of forages at ~0.40 of total dietary DM in the TMR and control groups, with the balance composed of a concentrate, was sufficient to bring about a difference in yellowness of carcass fat between these groups and the HC group. The difference may be attributed to the carotenoid content of the diets containing forage. Based on data reported by Roche (1982) and Loughery (2001) the carotenoid content was estimated at 30 mg/kg DM for the TMR and control diets and at 2 mg/kg DM for the HC diet.

With regard to muscle colour, a confounding factor in comparisons of grain and forage-fed animals in previous studies (Bidner *et al.*, 1986; Morris, Purchas and Burnham, 1997; Muir *et al.*, 1998) was the exposure of animals to different levels of exercise in addition to different feed components. Thus, the lack of an effect of diet on muscle colour in the present study may not be surprising since all animals were

housed indoors for the duration of the study.

Warner Bratzler shear force

Previous authors have shown that beef from grain-fed animals had higher tenderness score and lower shear force relative to beef from animals finished on forages (Oltjen *et al.*, 1971; Bowling *et al.*, 1977; Davis *et al.*, 1981). The differences in muscle tenderness attributed to diet, when animals are fed forage or concentrate-based diets, can be confounded by differences in the rate of gain of animals in the pre-slaughter period and differences in the level of finish of the animals at slaughter. When animals were slaughtered at similar carcass weight or level of finish there was no difference in muscle tenderness regardless of diet (Young and Kauffman, 1978; Bidner *et al.*, 1981; Mandell, Buchanan-Smith and Campbell, 1998; French *et al.*, 2000a). In the present study differences in carcass weight at slaughter although significant were small compared with previous studies. This suggests that there was not a large difference in level of finish in the present study and may explain the lack of an effect of diet on muscle tenderness.

In agreement with the original work of Hostetler *et al.* (1970) hanging carcasses by the hip-bone resulted in muscle which had a significantly lower WBSF value than muscle from carcasses hung in the conventional manner (Achilles' tendon). The results of the present study suggest that hip-hanging is likely to have a more dramatic effect on the tenderness of beef striploin than the pre-slaughter manipulation of forage and concentrate intake followed by conventional hanging of carcasses.

Fatty acid composition

The fatty acid composition of grass silage was similar to that reported in a recent

Irish study by French *et al.* (2000b). In contrast to the results of the present study, French *et al.* (2000b) reported higher levels of $C_{16:0}$ and $C_{18:0}$ and lower levels of $C_{18:2}$ in their concentrate. This difference can be explained by the presence of tallow, which has a high proportion of $C_{16:0}$ and $C_{18:0}$, in the concentrate used by French *et al.* (2000b).

Proportions of individual fatty acids in intramuscular fat reported in this study are generally in agreement with those reported by French *et al.* (2000b) although SFA, particularly C_{14} , C_{17} and C_{18} , tended to be lower and PUFA, particularly $C_{18:2}$, $C_{20:4}$ and $C_{20:5}$, tended to be higher in the present study. The difference may be attributed to the higher fat concentration of muscle in the study of French *et al.* (2000b) compared with the present study (~ 37 g/kg *v.* ~ 17 g/kg). Since the phospholipid level is likely to remain relatively constant in the *longissimus dorsi* muscle (Dugan, 1987), the higher intramuscular fat concentration in the study of French *et al.* (2000b) may be attributed to a higher concentration of triacylglycerides, which are more saturated than the phospholipids.

The higher $C_{18:1}$ concentration of the intramuscular fat from the HC animals may be attributed to differences in dietary $C_{18:1}$ intake. Based on the fat concentration and fatty acid profile of the various feed components (Table 4), and the feed intake data (Table 1), dietary intake of $C_{18:1}$ was estimated at 23, 24 and 48 g/day for the control, TMR and HC groups, respectively. Other authors have also reported increased $C_{18:1}$ in intramuscular fat of concentrate- or grain-fed animals compared to forage-fed animals (Rumsey *et al.*, 1972; Mitchell, Reed and Rogers, 1991; Mandell *et al.*, 1998). However, in studies comparing the effect of feeding concentrate and forage diets over a pre-

determined time period, concentrate-fed animals tended to be heavier and fatter at slaughter. Leat (1978) postulated that as animals become fatter the proportion of fat deposited as MUFA increases. Thus, differences in the fatty acid profile of intramuscular fat, as a result of differences in diet, could be confounded with differences in fatness. This hypothesis is supported by studies comparing the effect of forage and grain feeding in which animals were slaughtered at similar weights, or levels of finish, where grain feeding had no effect on the level of $C_{18:1}$ or MUFA (Mandell *et al.*, 1998; French *et al.*, 2000b).

The lower $C_{18:3}$ concentration of intramuscular fat from the HC animals compared to the control group may be attributed to differences in the $C_{18:3}$ concentration of the feed constituents. Average daily intakes of $C_{18:3}$ in the present study were estimated at ~ 43 g/day for the TMR and control groups and ~ 9 g/day for the HC animals. In comparisons of concentrate and forage feeding, various authors (Mitchell *et al.*, 1991; Enser *et al.*, 1998; Mandell *et al.*, 1998; French *et al.*, 2000b) have shown that muscle from animals fed concentrates had a lower concentration of $C_{18:3}$ when compared to muscle from animals finished on forages.

While differences in the proportions of $C_{18:1}$ and $C_{18:3}$ in intramuscular fat between the control and TMR groups, or the TMR and HC groups, were not significant, proportions of $C_{18:1}$ and $C_{18:3}$ were in the order control < TMR < HC and control > TMR > HC, respectively. As the composition of the control and TMR diets was identical, these trends may arise as a result of differences in the growth rate of animals (control < TMR < HC) and differences in intramuscular fat concentration as intramuscular fat increased with increasing growth rate. In addition, an effect on rumen metabolism of mixing

ingredients (TMR group), as opposed to feeding the various ingredients separately (control group), may explain why muscle proportions of C_{18:1} and C_{18:3} in the TMR group fell between, and were not significantly different from, those of the control and HC groups.

While individual CLA isomers were not identified it is assumed that the chromatographic peak due to CLA could be attributed to the c9, t11 isomer which is the most common natural form of CLA in beef (Chin *et al.*, 1992). Tissue levels of CLA are believed to be influenced by rumen conditions affecting bacterial biohydrogenation of fatty acids (French *et al.*, 2000b) and by the dietary intake of fatty acids, particularly C_{18:2} (Ivan *et al.*, 2001). In the present study C_{18:2} intake was estimated at ~66 g/day for the TMR and control groups and ~136 g/day for the HC group but the difference in C_{18:2} intake failed to elicit a significant response in muscle CLA. French *et al.* (2000b) showed that animals fed grass silage and concentrates individually (similar to the control group in the present study) had similar levels of CLA when compared to animals finished on a predominantly concentrate diet.

Health recommendations for PUFA:SFA and *n-6:n-3* ratios of fat-containing foods are 0.45 and <4.0, respectively (Department of Health, 1994). The PUFA:SFA ratios reported in the present study (0.23 to 0.28) are considerably higher than the values reported by French *et al.* (2000b) (0.09 to 0.13) and Enser *et al.* (1996) (0.11). The difference may be attributed to the higher intramuscular fat concentration (34 to 45 g/kg), and associated saturated fatty acids of triacylglyceride origin, of beef used in the studies of French *et al.* (2000b) and Enser *et al.* (1996) compared to the present study (15 to 21 g/kg). Concentrate finishing of

animals has been shown previously to increase the *n-6:n-3* ratio of intramuscular fat when compared to forage feeding (Marmer, Maxwell and Williams, 1984; Enser *et al.*, 1998; French *et al.*, 2000b). The value for *n-6:n-3* reported in the present study (3.83) is close to that reported by French *et al.* (2000b) (4.15) for muscle from animals finished on concentrates. However, muscle from animals finished on the forage-based diets tended to have a lower *n-6:n-3* ratio in the present study (2.72) compared to that of French *et al.* (2000b) (3.61), a difference which may be explained by the higher proportion of long-chain *n-3* fatty acids in the present study. Enser *et al.* (1996) reported an average value for beef muscle of 2.11 for *n-6:n-3* ratio.

Acknowledgements

The financial support of Richard Keenan and Co. Ltd. is gratefully acknowledged. The authors are also grateful to Dr Aidan Moloney (Teagasc, Grange Research Centre, Dunsany, Co. Meath) for his assistance with confirmation of the CLA peak.

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Received 8 August 2003

